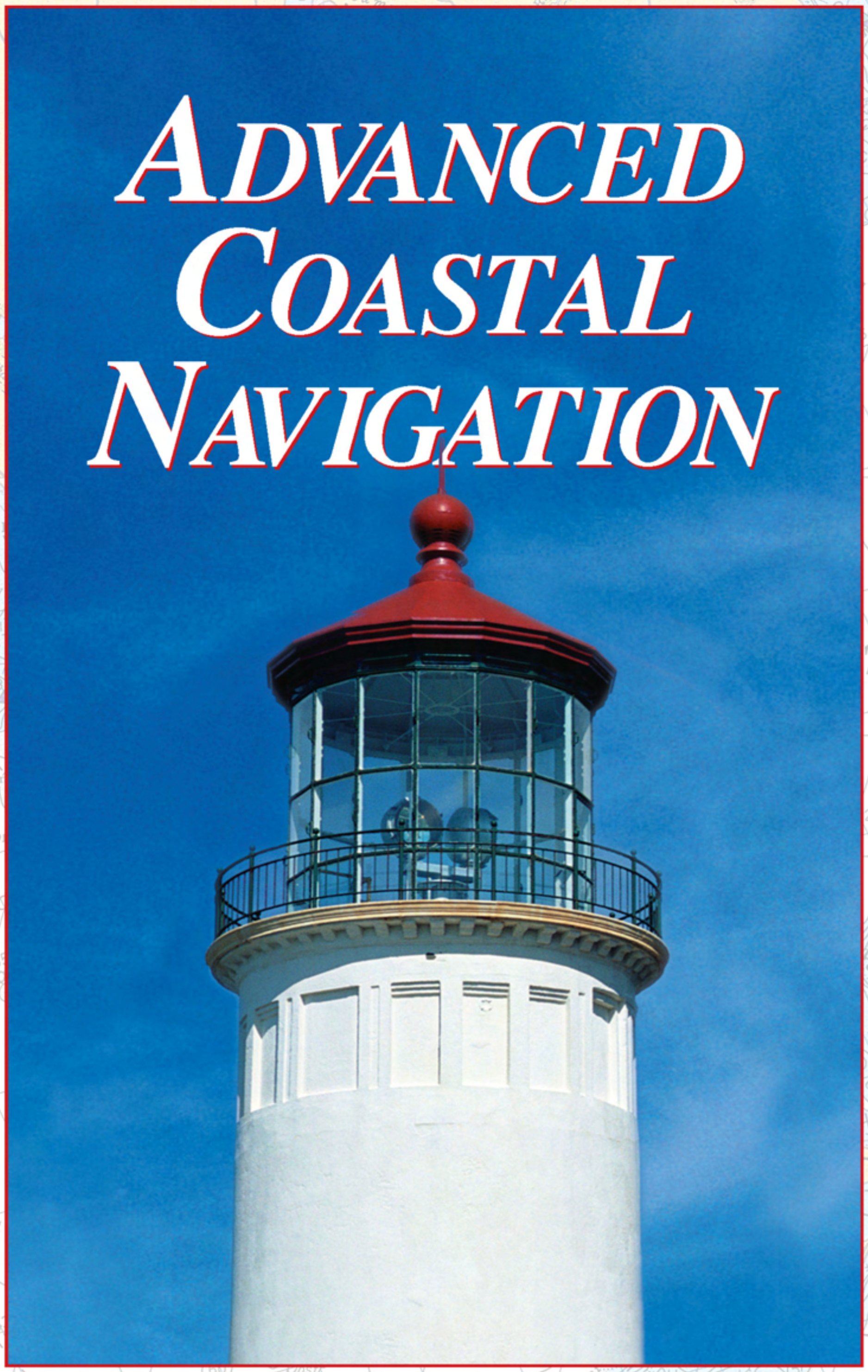
United States Coast Guard Auxiliary

America's Volunteer Lifesavers℠

FOURTH EDITION

ADVANCED COASTAL NAVIGATION



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THE COMMANDANT OF THE UNITED STATES COAST GUARD
WASHINGTON, D.C. 20593-0001

FOREWORD

As the National Recreational Boating Safety Coordinator, I rely on the Coast Guard Auxiliary to promote recreational boating safety by means of public education classes, free courtesy marine examinations, and on-the-water operations. In addition, I am proud to introduce this excellent coastal navigation book as another of the Auxiliary's important education outreaches.

This fourth edition of the *Advanced Coastal Navigation* book is an excellent text on the most current and valuable information available concerning the art of navigation. The accompanying course to this book has the most up-to-date methods and tools used in modern coastal navigation, including detailed information on the Global Positioning System. Also, this latest revision presents additional material on radar navigation and plotting. I am sure you will find this book's layout and illustrations attractive, easy to understand, and educational.

I commend the Coast Guard Auxiliary for developing this text, which I heartily endorse for everyone who uses our nation's waters for recreational boating.

Sincerely,

JM Loy

James M. Loy
Admiral, U. S. Coast Guard

THE COMMODORE
OF THE UNITED STATES COAST GUARD AUXILIARY

Viggo C. Bertelsen, Jr.
23825 SE 46th Place, Issaquah, WA 98029-7571
H: 425-391-6757 Fax: 425-391-1548
e-mail: vcbertelsenjr@worldnet.att.net

1 May 2002

Dear Coastal Navigation Student,

The Coast Guard Auxiliary Association, Inc. (CGAuxA) has produced this Fourth Edition of *Advanced Coastal Navigation* (*ACN*), the textbook, at no cost to the government, as the text for the U. S. Coast Guard Auxiliary's navigation specialty course, Auxiliary Advanced Coastal Navigation (AUXACN), an advanced course now also offered to the public.

The Auxiliary uses the text, *ACN*, and supporting materials in both its public education and member training classes to teach both Basic Coastal Navigation (BCN) and AUXACN (formerly the course called Advanced Coastal Navigation). AUXACN is one course of seven used by Auxiliary members to train and qualify for the specialty AUXOP designation. The Fourth Edition of *ACN*, the text, has been updated and revised to provide you with a comprehensive learning exposure to the latest techniques in coastal navigation as required by the Coast Guard for its Auxiliary operations specialists. These revisions reflect many useful comments from instructors and students as well as advances in technology (e.g. Night-vision devices, GPS). We hope the informality and clarity of earlier editions has been retained.

Although the talents of many Auxiliary/CGAuxA members contributed to the development of the *ACN* text and related courses, BCN and AUXACN, the combined expertise, hard work, and devotion to this project of L. Daniel Maxim (the text author) assisted by the editing skills of Derrick Young, Ralph Neal and Dean and Nanci Terencio plus the proof reading skills of Jane Keener have resulted in an excellent course for all students of navigation. We think you will agree.

We hope you find this text and the AUXACN and BCN courses stimulating, enlightening, and that they will help you to become proficient and confident in your navigation skills as you explore the coasts and inland waters of this great country. Also, since by completing the AUXACN course you would be well on the way to qualification as an operational Auxiliarist, let me invite you to become one of us, a member of the U. S. Coast Guard Auxiliary, "*America's Volunteer Lifesavers* sm" by joining the 34,000 plus members of our organization dedicated to recreational boating safety and support of the United States Coast Guard.

Sincerely,

Viggo C. Bertelsen, Jr.
National Commodore
United States Coast Guard Auxiliary

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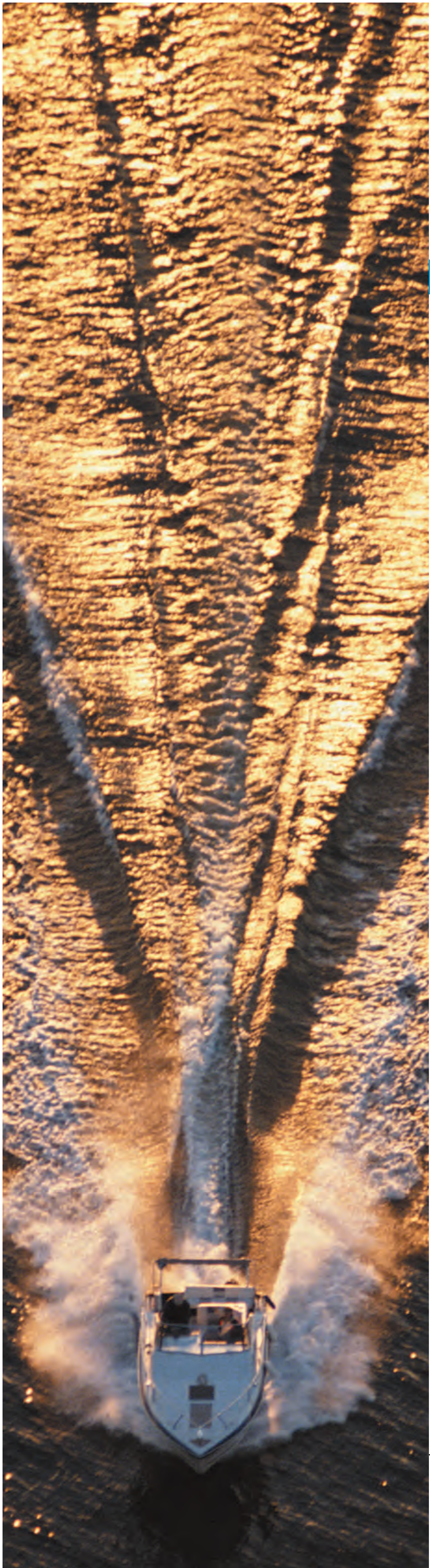

INTRODUCTION

WELCOME ABOARD!

Welcome to the exciting world of marine navigation! This is the fourth edition of the text *Advanced Coastal Navigation* (ACN), designed to be used in concert with the 1210-Tr chart in the Public Education (PE) course of the same name taught by the United States Coast Guard Auxiliary (USCGAUX). Portions of this text are also used for the *Basic Coastal Navigation* (BCN) PE course. ACN is now used internally by USCGAUX as the navigation text in their member training classes. PE students who successfully complete the ACN course (including necessary examinations) and who elect to join are credited with completion of the USCGAUX course.

This fourth edition builds upon the first three editions of this same text but has been updated to reflect the helpful advice of numerous dedicated USCGAUX instructors, student feedback, and recent technical developments in the field—particularly in the area of electronic navigation. Graphics and layout have been substantially improved from earlier editions.

The ACN and BCN courses are not intrinsically difficult, nor do they have advanced educational requirements. Students from many walks of life and of widely varying educational backgrounds have successfully completed the course. But it does require a professional attitude, careful attention to classroom presentations, and diligence in working out sample problems.

The ACN course has been designed to utilize the 1210-Tr nautical chart. It is suggested that this chart be readily at hand so that you can follow along as you read the text. We recognize that students from all areas of the United States enroll in the course and that a better geographic "balance" to the examples might be attractive. Where necessary as, for example, in the discussion of polyconic charts of the Great Lakes in Chapter 3, illustrations from other areas of the country are included. But the 1210-Tr chart contains a wide variety of features of interest to the navigator and, moreover, contains a useful summary of chart symbols printed on the reverse side for ready reference. In short, this is an ideal training chart.

The ACN text has been designed, for the most part, to teach you the "classical" methods of coastal navigation applicable to small vessels. Shortcuts, such as might be taken for routine cruises in very familiar waters, are mentioned only briefly. Experience, sometimes called the "seaman's eye", teaches the navigator which shortcuts can safely be taken and under what circumstances. But the basis for shortcuts should rest on a firm foundation/ mastery of "the textbook solution," and not simply arise from laziness, lack of knowledge, or being out of practice.

Over the past few years there have been revolutionary developments in the field of marine electronics. Modern Global Positioning System (GPS) or Loran-C receivers, the fluxgate compass, radar, fuel flow meters and computers, electronic charts, and autopilots serve as examples. These devices, tied together with onboard navigational computers, have revolutionized both the art and science of marine navigation. Today it is literally true that, by merely pressing a few buttons, you can program an entire voyage and simply sit back, watch for traffic and be prepared to dock the vessel at the conclusion of the voyage. Alarms warn of the approach of vessels within a predefined exclusion zone, passage into shallow water, and arrival at waypoints or the final destination. Once, such an "electronic voyage" would have come from the dreams of Jules Verne, or been impossibly out of reach for most boaters. But recent advances in the state of the art of marine electronics have brought science fiction into the realm of the possible and affordable.

These modern miracles have led some students to question the role of classical methods of coastal navigation, such as the use of visual fixes, dead reckoning plots, and the like. Why, after all, learn the tedious procedures required to calculate tide height or tidal current, for example, when an hour-by-hour calculation requires only seconds on a laptop computer? The answer is very simple. First, not all vessels are equipped with the latest in marine electronics; students come to the ACN/BCN course owning everything from runabouts equipped with little more than a compass to large yachts equipped with virtually the entire contents of one of the numerous catalogs of purveyors of marine electronics. The ACN/BCN course is designed for skippers of both of these types of vessels. Second, and perhaps more important, even if a vessel is equipped with the latest in navigation systems, the reliability of seaborne electronics is still far from perfect. The classical methods of navigation are required to monitor the performance of even the best-equipped vessel. And, should these systems fail, classical methods can be used to bring you home safe and sound.

ACN does include material on more sophisticated marine electronics, such as GPS, Loran-C, and radar. The coverage is not designed to teach you how to operate any particular make or model but, rather, to acquaint you with the general principles and techniques so that you can make better use of whatever equipment you own or elect to purchase.

ACN also contains a novel chapter on fuel planning, a subject usually given short shrift, or omitted entirely, in the typical text on navigation. Unfortunately, fuel starvation and/or fuel exhaustion cause all too many preventable Search and Rescue (SAR) cases.

Several sections of this text are identified as "more technical." This material is included for those readers who have a technical background and are interested in a more complete and detailed exposition. Students who lack the necessary background or interest can omit these sections without loss of continuity. Material so identified is not included in the final examination for the PE course, but may appear on the USCGAUX navigation course examination. Additionally, a list of references is appended to chapters for those who wish to learn more about particular topics. Sidebars are used to set off summaries, provide highlights, and add items of historical interest that would otherwise disturb the flow of the narrative.

Perhaps surprisingly, several aspects of navigation (generally those relating to the "art" of navigation) are controversial. For example, there are those who advocate that all plotting should be done with respect to magnetic, rather than true north. Although this text takes a position on many of these points of controversy, books or articles that espouse a contrary point of view are included among the references. Therefore, the student should not assume that either the United States Coast Guard (USCG) or the USCGAUX specifically endorse any work listed in the references. These are included to add balance, perspective, and interest. Likewise, any mention or inclusion of pictures of particular makes or models of equipment does not imply that these are recommended or endorsed by USCGAUX or USCG.

Thanks to the many firms that supplied pictures and/or illustrations for use in this text. Acknowledgments are included in the caption for each illustration.

Although theory is not slighted, the emphasis in the text is on practical, time-tested approaches to navigation. The text contains numerous discussions of practical methods and numerical examples to provide a firm foundation in the art and science of coastal navigation.

In recent years, the amount of useful material posted on the Internet has increased substantially. Web Site addresses are included as references at various points in the text. These addresses were valid at the time that this edition went to press. Addresses change, as does the material posted. We opted to include this information, despite possible changes, because the supplementary material is so valuable, and we apologize in advance if the information referenced is not available.

This text contains a glossary of terms, given in Appendix A. Readers encountering an unfamiliar term or abbreviation may wish to consult this appendix for a brief explanation.

Each page of the logbook of Christopher Columbus was headed with the title *Como Dios Manda* (As God Ordains), which was testimony both to his religious faith and to the primitive state-of-the-art of navigation at the time. This book is dedicated to the notion that you should also have a hand in the outcome of a voyage.

Remember that you have the choice of being the operator of your vessel or merely an occupant. Knowledge, skill, and experience are required to transform occupants into competent operators. Remember, also, that each voyage should be a learning experience. In this sense, all of us should be perpetual students.

May you always have fair skies, calm seas, fair currents, and following winds. But, more important, may you learn how to navigate safely and efficiently regardless of sea or wind conditions.

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

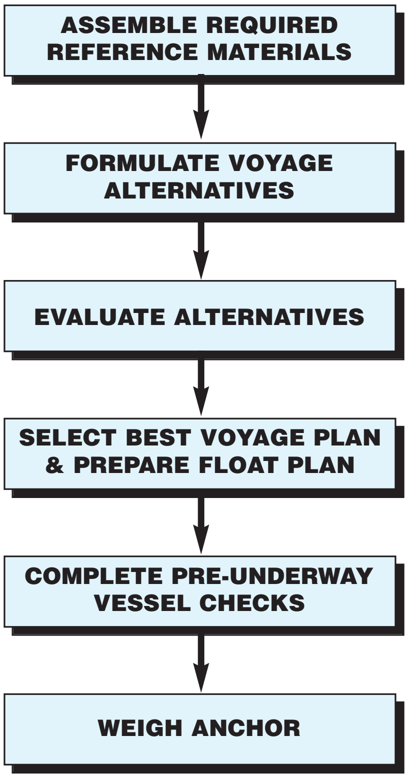

FIG. 1-1–Steps in Voyage Planning

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.

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*

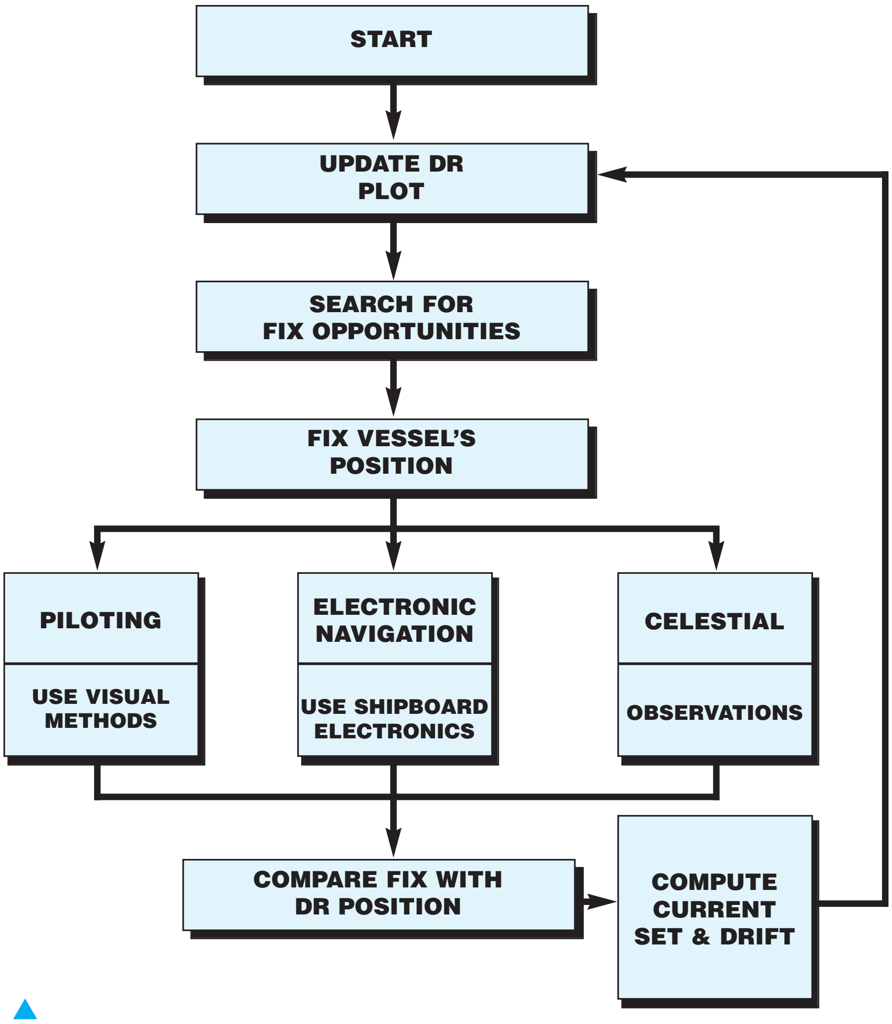

FIG. 1-2–Steps in Underway Navigation

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

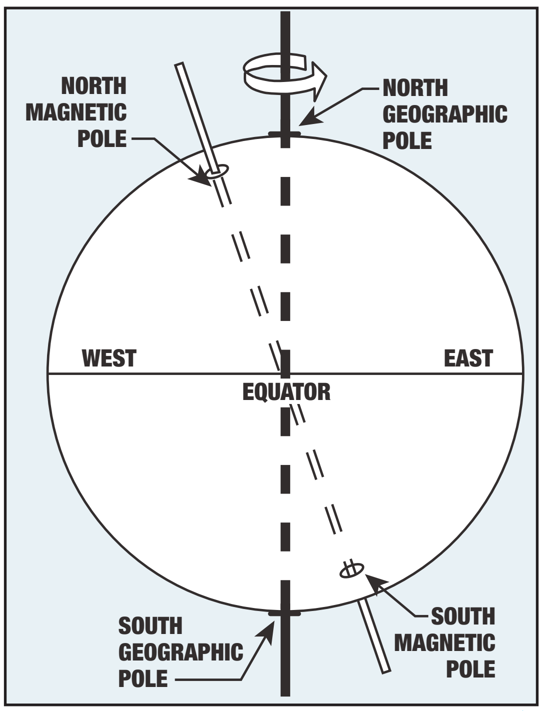

FIG. 1-3–The Earth and Its Poles

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.)

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

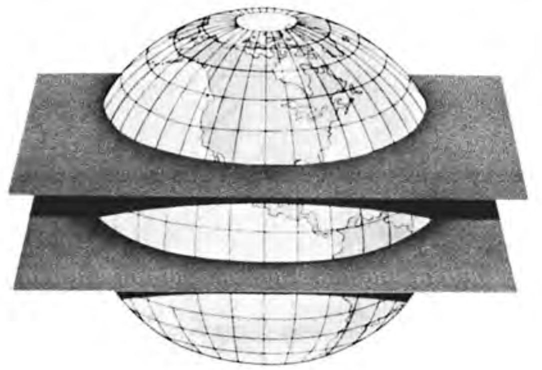

FIG. 1-5–A Parallel of Latitude

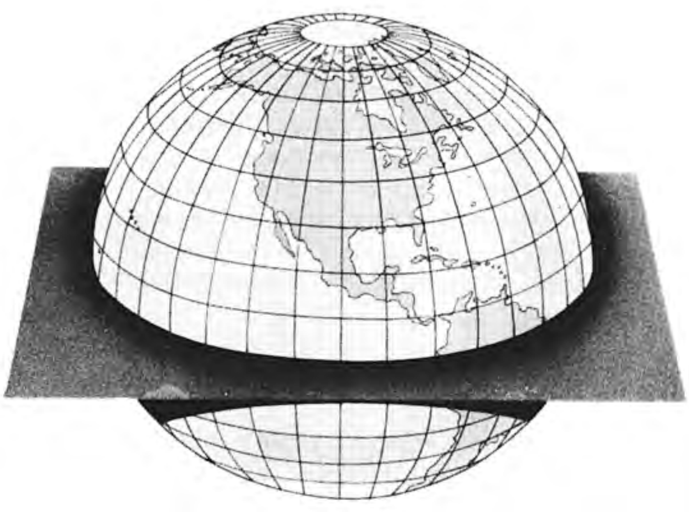

FIG. 1-4–The Equator

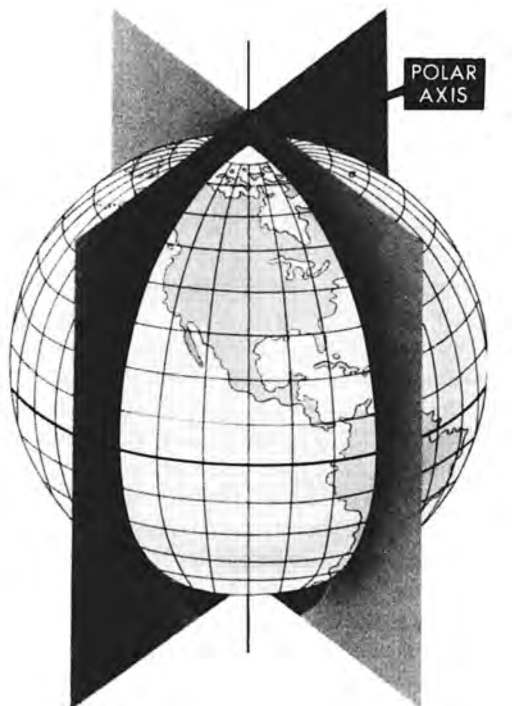

FIG. 1-6–The Planes of the Meridians (Longitude) Meet at the Polar Axis

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.

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

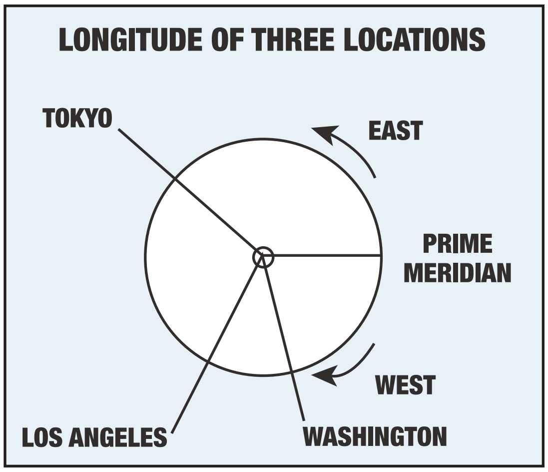

FIG. 1-7–Longitude for Three Locations on the Earth's Surface

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).

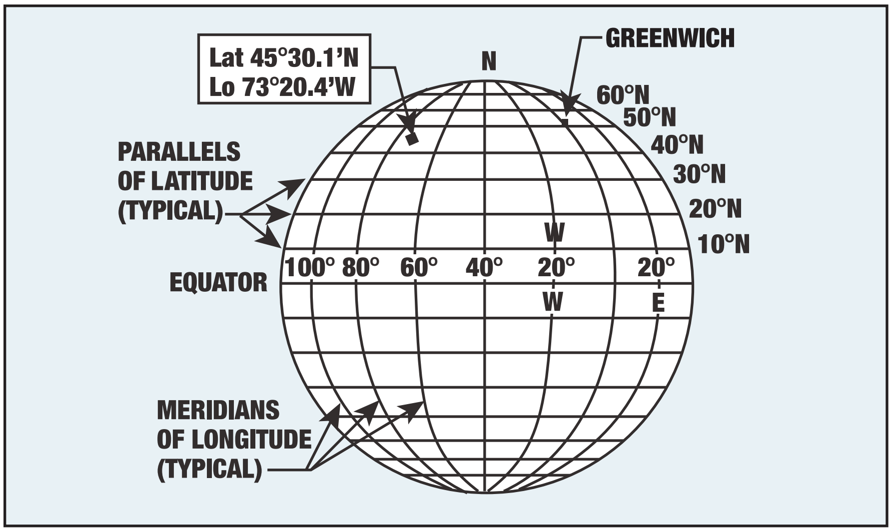

FIG. 1-8–Grid System of Latitude and Longitude

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-

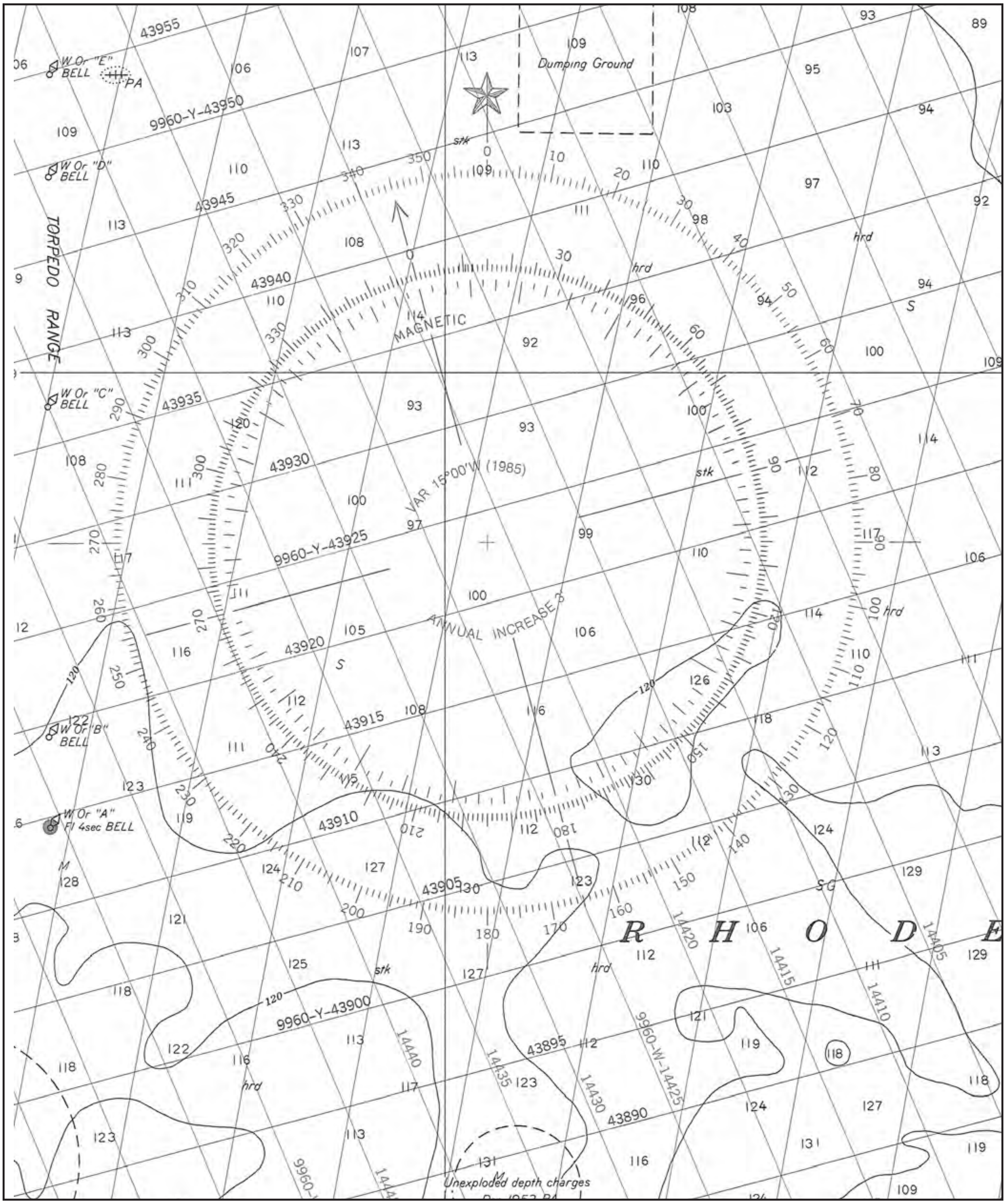

FIG. 1-9–True and Compass Rose as Presented on the 1210-Tr Chart

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.

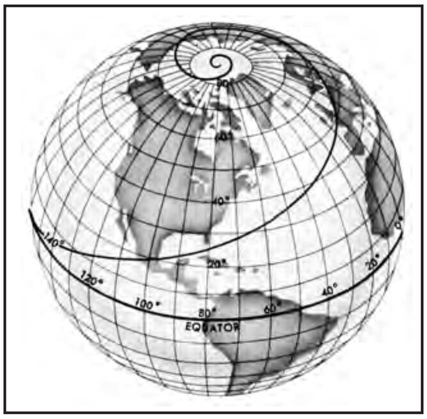

FIG. 1-10–A Rhumb Line or Loxodrome as Given in Bowditch

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 1-12 or

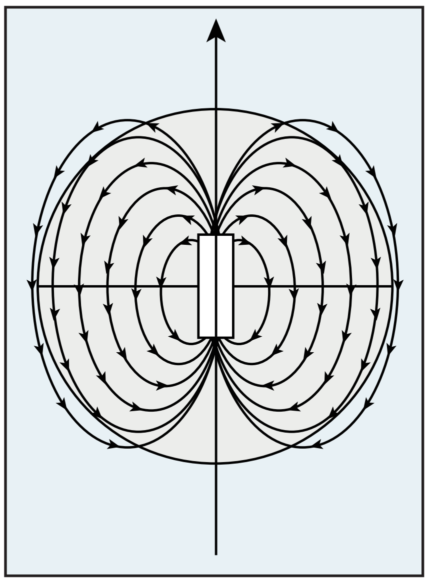

FIG. 1-11–The Earth is a Magnet

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

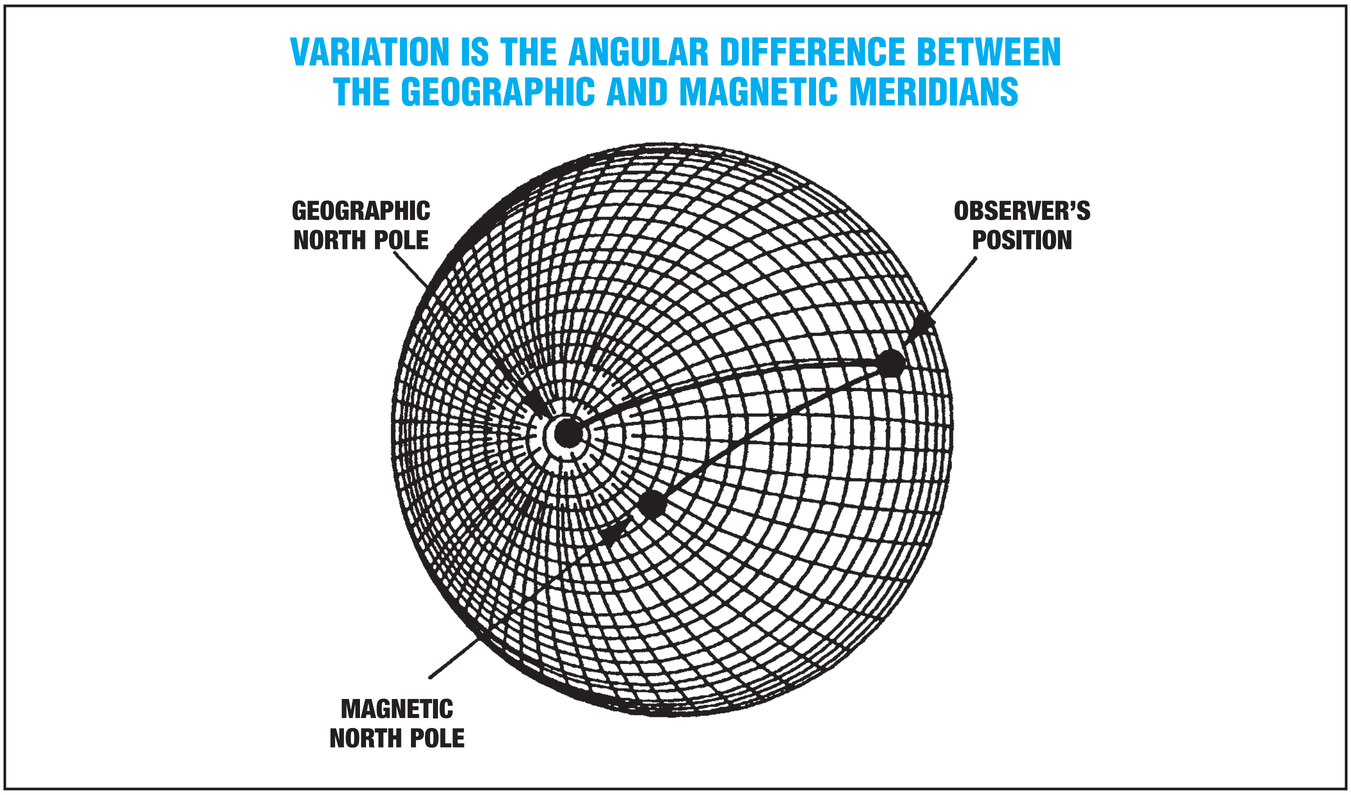

FIG. 1-12–Variation: The Approximate Difference Between the Directions to the North Geographic Pole and the Magnetic Meridian

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

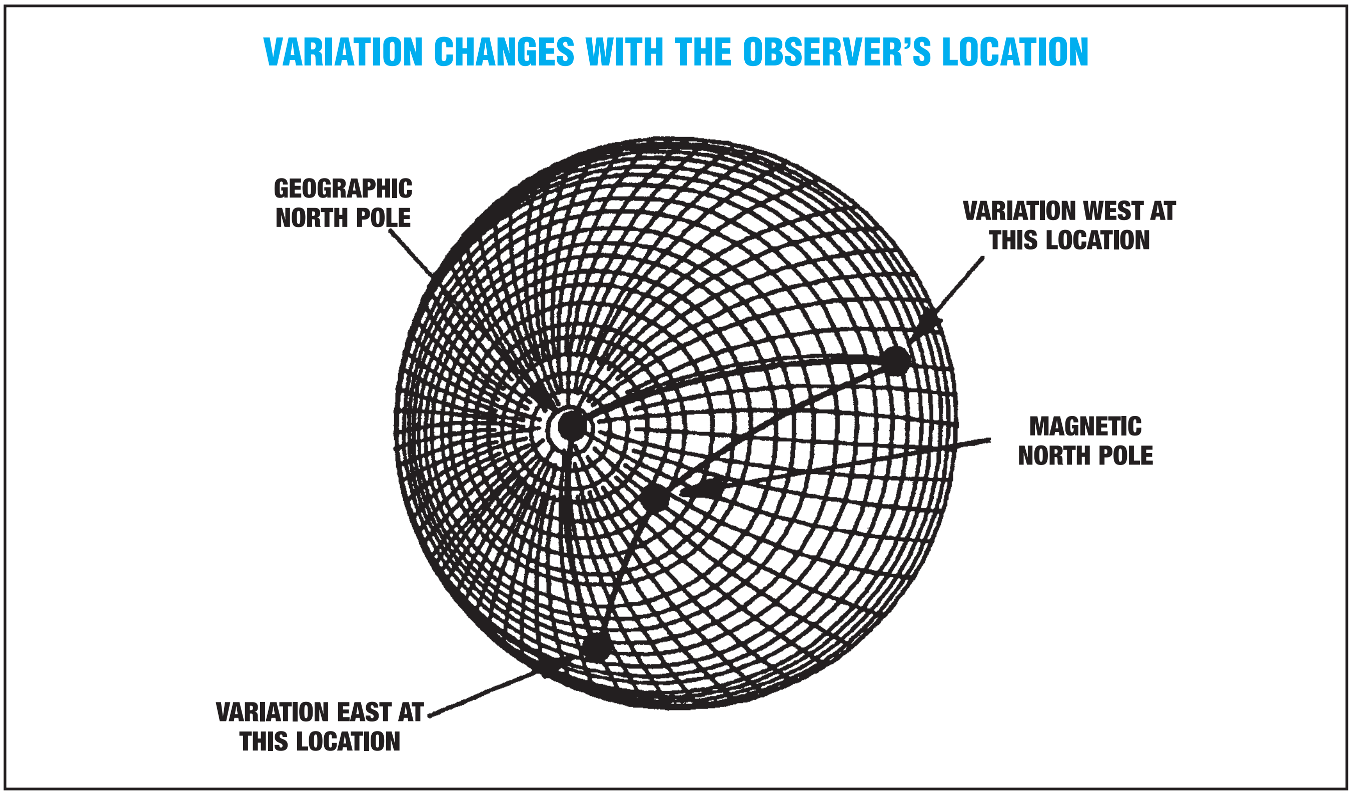

FIG. 1-13–Variation is the Angular Difference between the Geographic (True) Meridian and the Magnetic Meridian. Variation Changes with Locality.

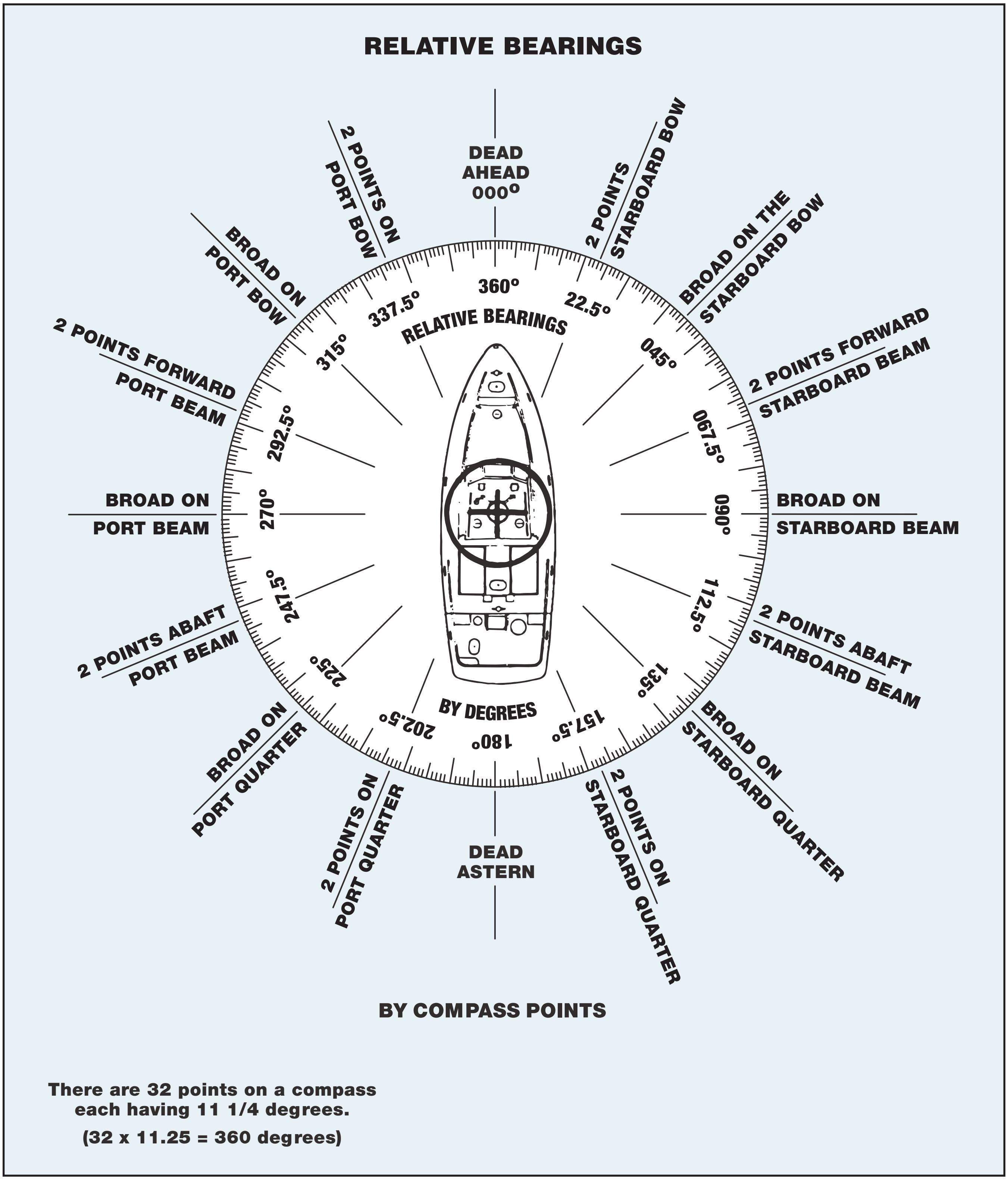

FIG. 1-14–Relative Bearings by Degrees and Points

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.

SELECTED REFERENCES

Bowditch, N., (1995). *American Practical Navigator; An Epitome of Navigation,* Pub No. 9, Defense Mapping Agency, Bethesda, MD.

Brogdon, B., (1995). *Boat Navigation for the Rest of Us: Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Budlong, J. P., (1977). *Shoreline and Sextant, Practical Coastal Navigation,* Van Nostrand Reinhold Co., New York, NY.

Cline, D.A., (1990). *Navigation in the Age of Discovery,* Montfleury, Inc., Rogers, AR.

Departments of the Air Force and the Navy, (1983). *Air Navigation,* AFM 51-40, NAVAIR49, 00—80V—49, U. S. Government Printing Office, Washington, DC.

Eyges, L., (1989). *The Practical Pilot: Coastal Navigation by Eye, Intuition, and Common Sense,* International Marine, Camden, ME.

Kals, W.S., (1972) *Practical Navigation,* Doubleday & Company, Inc., Garden City, NY.

Kielhorn, W. V., (1988). *A Piloting Primer,* privately printed, Naples, FL.

Maloney, E. S., (1985). *Dutton's Navigation and Piloting,* 14th edition, Naval Institute Press, Annapolis, MD.

Markell, J., (1984) *Coastal Navigation for the Small Boat Sailor,* Tab Books Inc., Blue Ridge Summit, PA.

Ministry of Defense (Navy), (1987). *Admiralty Manual of Navigation,* BR 45 (1), Volume l, Her Majesty's Stationary Office, London, UK.

Moody, A. B., (1980). *Navigation Afloat, A Manual for the Seaman,* Van Nostrand Reinhold Co., New York, NY.

Naval Training Command, (1972). *A Navigation Compendium,* NAVTRA 10494-A, U. S. Government Printing Office, Washington, DC.

Norville, W., (1975). *Coastal Navigation. Step by Step,* International Marine Publishing Co., Camden, ME.

O'Malley, M., (1990). *Keeping Watch, a History of American Time,* Viking Penguin, New York, NY.

Queeney, T. E., (1986). "The Wandering Magnetic Pole," *Ocean Navigator,* No. 9, pp. 3 et seq.

Saunders, A. E., (1987). *Small Craft Piloting and Coastal Navigation,* Alzarc Enterprises, Scarborough, Ontario, Canada.

Schofield, Admiral B.B., (1977). *Navigation and Direction, The Story of HMS Dryad,* Kenneth Mason, Homewell, UK.

Schufeldt, H. H., Dunlop, G.D., and A. Bauer, (1991). *Piloting and Dead Reckoning,* 3rd edition, Naval Institute Press, Annapolis, MD.

Sobel, D., (1995) *Longitude the True Story of a Lone Genius who Solved the Greatest Scientific Problem of His Time*. Walker and Company, NY.

Tver, D. F., (1987). *The Norton Encyclopedia Dictionary of Navigation,* W.W. Norton & Company, New York, NY.

U.S. Coast Guard Auxiliary, (1983). *Coastal Piloting,* U.S. Coast Guard Auxiliary National Board, Inc., Washington, DC.

Wright, F.W., (1980). *Coastwise Navigation,* Jason Aronson Inc., New York, NY.

CHAPTER 2

THE MARINE MAGNETIC COMPASS

"Truth lies within a little and certain compass,
but error is immense."

–Henry St. John, Viscount Bolingbroke,
Reflections upon Exile (1716)

INTRODUCTION

This second chapter of the *Advanced Coastal Navigation* (ACN) Course explores the marine compass and its use. The compass is one of the simplest and most useful navigation instruments to be carried aboard a vessel. Arguably, a competent navigator, well-found vessel, up-to-date charts, timepiece, and a good compass are the only real requirements for a safe and efficient voyage. Columbus was able to do this even without good charts or timepieces!

This chapter provides a brief history of the compass, a discussion of the types and parts of the modern compass, an exposition of the principle of operation of the compass, and finally, a discussion of possible compass errors and their measurement so that the mariner can compensate for these errors and steer correct courses. In particular, this chapter reviews so-called TVMDC computations, named for the sequence *True-Variation-Magnetic-Deviation-Compass* that is used to determine compass courses from true courses.

Compass adjustment refers to the process of adjusting small magnets contained in the compass to remove as much error as possible. Many modern textbooks devote considerable space to compass adjustment, and the reader may wonder why this topic is covered only briefly here. The reason is simple. Although compass adjustment is not impossibly complex, it is not trivial and needs to be done right! Professional compass adjusters are available at reasonable cost to perform this service and, unless the mariner is willing to devote a substantial amount of time and intellectual effort, this is a job best left to experts. In addition to adjusting the compass, a professional can provide good advice on the placement of the compass, shipboard electronics, and other gear that may affect the compass. For those who disagree with this assessment and have the time and inclination to master the intricacies of compass adjustment, a brief description is included. Moreover, the references included at the end of this chapter provide a useful starting point for home study.

The material in this chapter is not difficult. But teaching experience indicates that considerable practice is required in order to rapidly and reliably solve the problems discussed in this chapter.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ***The "anatomy" of a compass***
- ***Compass types***
- ***Compass deviation and its measurement***
- ***TVMDC calculations***
- ***Compass errors***

BRIEF HISTORY

The exact origin of the compass is lost in antiquity. Although some accounts claim that the compass was invented well before the birth of Christ (Hewson, 1983), documentary evidence of its use in Europe and China dates back only to approximately 1100 AD (Aczel, 2001; Bowditch, 1995; Collinder, 1955; Jerchow, 1987). (Incidentally, by convention the early Chinese compasses were said to point south, as this was considered a more noble aspect.) The modern compass card (as opposed to needles used on the earliest compasses) apparently originated with Flavio Gioia of Amalfi in southern Italy sometime around 1300 AD (Collinder, 1955), although this is questioned by some (Aczel, 2001).

By the time of Columbus, the compass was well developed and there is evidence (from the diaries of Columbus) that the phenomenon of magnetic variation was at least partially understood. By the early 1700s, charts showing the locations of lines of equal variation *(isogonic lines)* were available. Likewise, compass deviation, an important subject discussed below, was understood in qualitative terms at about this same time, although practical means for compensating for deviation were not developed until 1801 by Captain Matthew Flinders (from which the Flinders bar used in compass adjustment takes its name).

The modern liquid-filled compass, similar to those used on yachts today, dates back to the period 1850 to 1860 when it was developed and patented by E. S. Ritchie of Boston, Massachusetts. (The company founded by Ritchie is still in business today.) Since that time, there have been evolutionary rather than revolutionary developments in the magnetic (mechanical) compass. For example, new lightweight materials are used for compass cards, improved magnets are available, and many other incremental improvements have been made to increase the accuracy, stability, and utility of the magnetic compass.

Elmer Sperry, an American, and Anschutz-Kampfe, a German, during the early part of the 20th century developed the modern gyrocompass, an instrument capable of indicating true rather than magnetic north. Gyroscopes were widely used in naval and merchant ships since the end of World War I. Heretofore, gyroscopes have been electromechanical devices, but laser gyros are now in development that may revolutionize this field. (Gyroscopes are not discussed in this text, as these are not presently available at reasonable cost to the typical boater.)

During the mid-1920s, an electronic compass—termed a fluxgate compass—was developed for aircraft to provide better directional information in turns and during maneuvers. In recent years, this technology has become available at a reasonable cost to the mariner, and for this reason is given passing mention.

The "electronics revolution," a phrase used frequently in this text, also includes directional systems. Outputs from a fluxgate compass can be "processed" by a wide variety of computer systems and used for automated steering (autopilots), and navigational computers (e.g., to compute current set and drift, as discussed in Chapter 7). Yet more sophisticated developments are likely in the near future.

For all these newer developments, the traditional magnetic compass remains one of the most important navigational instruments, as evidenced by the fact that even the most sophisticated ship or aircraft in service today still has at least one magnetic compass aboard. Its relative simplicity, reliability, and lack of dependence on electrical power sources will probably ensure its survival well into the future.

PARTS OF THE COMPASS

Over the years, the marine magnetic compass has evolved into a functional, easy-to-read, convenient, and relatively inexpensive navigational instrument. The damping system of a modern, spherical,

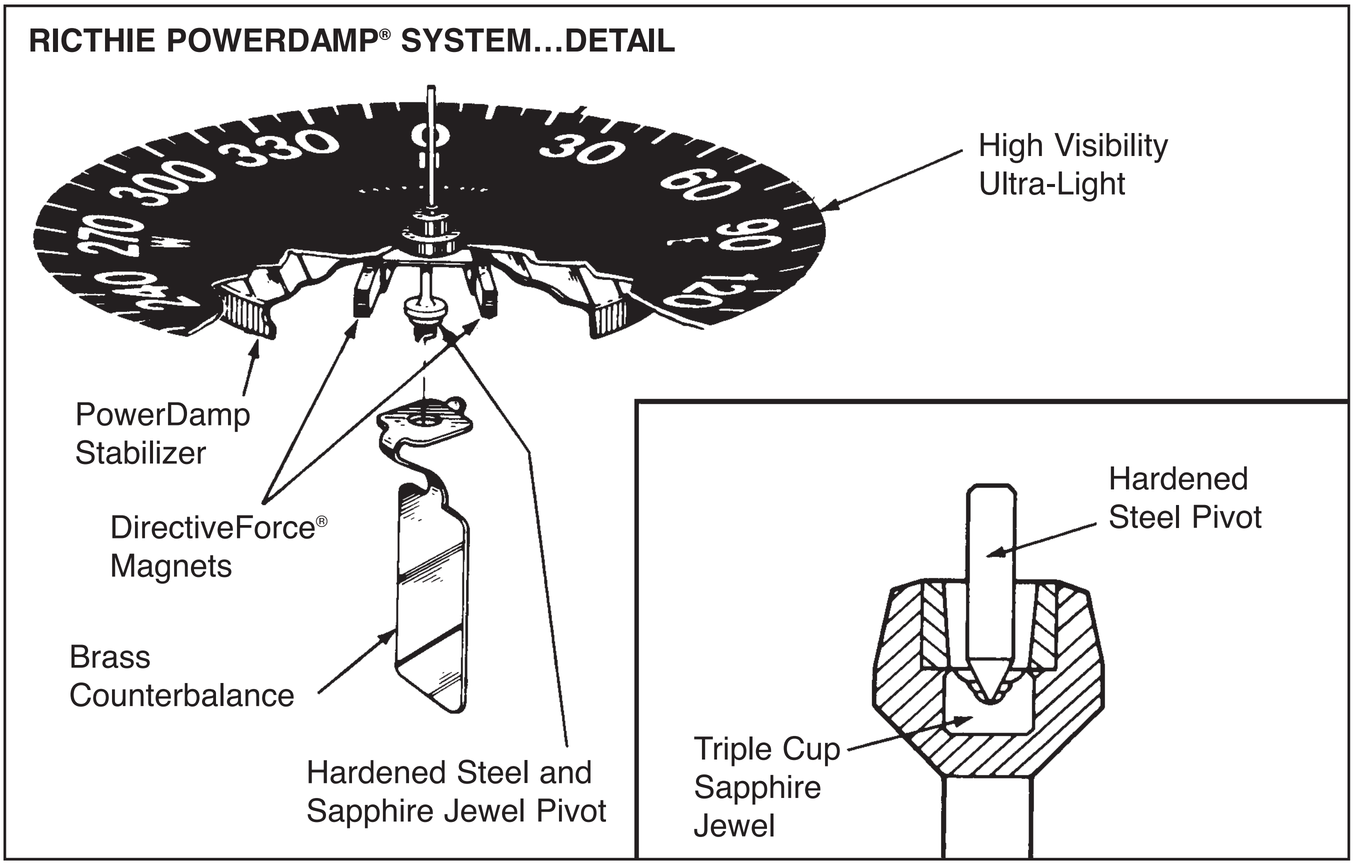

FIG. 2-1–Damping System of Modern Compass

liquid-filled marine magnetic compass is shown in Figure 2-1. In this compass, a lightweight dial or *compass rose* is graduated in degrees increasing in a clockwise direction from 000 degrees to 359 degrees to indicate the compass heading. The increments shown on the compass dial can be 1 degree, 2 degrees, or, more typically for compasses used on small vessels, 5 degrees. (Studies conducted just prior to World War II indicated that graduations every 5 degrees were significantly easier to read than finer graduations and, in practical terms, nearly as accurate.) Numbers are typically spaced every 30 degrees, and the cardinal points (north, south, east, and west, or abbreviated N, S, E, and W) are also indicated on the dial. Arrows or other marks are sometimes used to designate the intercardinal points (e.g., NE, SE, SW, and NW). Older compasses were traditionally graduated in the mariner's "point" system, mentioned in Chapter 1, in which the circle was divided into 32 compass points, each of 11.25 degrees. These are named, in clockwise order from north: north, north by east, north-northeast, northeast by north, northeast, northeast by east, east-northeast, east by north, east, etc. Naming these points, termed "boxing the compass," was an unpleasant and confusing task used historically in hazing rituals for midshipmen and other would-be mariners. Fortunately, mariners have rediscovered the joy of numbers and the older point system is now only of historical interest. (If you have such a compass, mount it in your den, not on your boat!)

Attached to the dial are the "north-seeking" compass magnets. The dial is supported on a jeweled bearing, which turns on a pivot. In turn, the pivot is mounted in a gimbal system, designed to keep the dial level with the horizon if the vessel pitches or rolls. Fastened to the gimbal is one (or more) *lubber's line*(s). The lubber's line (also termed lubber line [Moody, 1980]) is the index mark against which the dial graduations are read to determine the direction of the vessel rel-

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FIG. 2-2–Combination Front and Top Reading Compass

ative to that of the card. The lubber's line (or principal lubber's line if there are more than one) should be aligned with the fore-and-aft axis of the vessel.

The gimbals, card, and magnets are enclosed in a bowl with a clear, transparent, hemispherical glass (or plastic) top, within which the card and gimbals are free to rotate independently of the attitude of the container. The top (dome) may be impregnated with inhibitors to reduce any discoloration of the card or fluid from ultraviolet radiation and may also magnify the readings, so that the apparent card size is larger. The bowl is filled with a nonfreezing liquid to damp (slow down) the motion of the dial for increased stability and to support much of the weight of the card and the magnets, so as to reduce wear on the pivot. The ultra-lightweight dials in use can be damped with fluids that are not viscous (thick), a combination that provides stability and accuracy without a tendency to "overshoot" and oscillate as the vessel is turned to a new heading. The compass also contains an expansion diaphragm to allow for the expansion and contraction of the damping fluid with temperature or pressure changes. A fill plug is used to replace or "top off" the damping fluid. (It is important that there are no air bubbles in the compass fluid.)

The bowl is supported by a case or holder, generally called a binnacle. Somewhere near the bowl are found the compensating magnets, used to adjust the compass to compensate for the vessel's magnetic environment.

Most compasses are lighted for night use. A low intensity red lamp is preferred to avoid or minimize adverse effects on the night vision of the helmsman or crew. (Incidentally, the wires to the compass light should be twisted to minimize magnetic effects.)

Many compasses come with a hood (adjustable on some models) to reduce glare and improve readability. Removable protective covers are also recommended if the compass is installed in a location where it is exposed to the elements.

COMPASS DIAL DESIGN

There are two principal designs for the compass rose or dial. These are discussed briefly below.

❑ The first design is termed a *top-reading compass* (also a *flat card compass* by some manufacturers). With this design, the mariner reads the heading or bearing "across the card." The lubber's line is located behind the card. The numbers that indicate heading or bearing increase in a clockwise direction—a correct geometric representation. A heading of 030 degrees is to the

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FIG. 2-3–Fluxgate Compass with Digital Readout right of a heading of 000 degrees, for example, and the compass provides the same representation. If the helmsman is asked to turn to 030 degrees from a heading of north, it is clear that this must be a turn to the right. It is also relatively easy to read compass bearings over this compass dial. The compass dial itself is unobstructed through 360 degrees, although its placement aboard the vessel usually limits this range. A top-reading compass is installed forward of the steering mechanism and beneath the helmsman's eye level.

- The second design is termed a *front-reading compass* (also called a *direct reading compass* by some manufacturers). This compass dial design is typical of most aircraft compasses and is also used for marine compasses. With this design, the lubber's line is in front of the dial and indicates the direction toward which the vessel is heading. However, the dial is graduated in a counterclockwise direction. Thus, for example, the 30-degree graduation on the front-reading dial is located to the left of 000. This apparent reversal in direction is made necessary because the lubber's line is located in front of the dial. The mounting of a front reading compass usually precludes its use for obtaining bearings. This is not a real detriment, since a hand-bearing compass, discussed in Chapter 4, is a ready substitute.

Either design correctly shows the vessel's actual heading, but the front-reading compass design is slightly more confusing and requires a bit more practice before familiarity is assured. An inexperienced helmsman, asked to come to a heading of 030 degrees from north, could glance at the front-reading dial and see that this heading is to the left, and, therefore, begin a turn in the wrong direction before discovering the error. From the perspective of ease of interpretation, the top-reading compass dial is greatly to be preferred. But, it is also important to consider how the compass will be viewed once installed. In the typical powerboat installation (and in sailboats where the compass binnacle is integrated with the wheel), the compass is located on a panel immediately in front of the helmsman, and so a top-reading compass is easy to see. However, in a typical light aircraft the compass is installed at the top of the cockpit (where it is least likely to be affected by magnetic interference from radios or other electronics), at or above the eye level of the pilot, necessitating a front-reading design. Similarly, in certain sailboats the compass is mounted on the outer cabin bulkhead—nearly at eye level for the helmsman seated several feet away—and a front-reading compass is necessary.

Some compass designs, such as that shown in Figure 2-2, combine both types of compass displays in one unit. The model shown in Figure 2-2 shows a front reading dial graduated in 5-degree increments and a top-reading dial that omits a numerical display of degrees. Some compasses also include *inclinometers,* to measure the angle of roll of the vessel.

Yet other compass displays, typically those used with fluxgate compasses, feature a direct digital readout of the heading. Figure 2-3 shows the display unit of a fluxgate compass with digital readouts. Digital readouts are generally shown to the nearest degree, rather than 5 degrees as is common on conventional compasses. Although many prefer digital displays, these also have limitations or disadvantages. (For example, it is impossible to take a bearing on any object that is not aligned with the vessel's heading.) Moreover, the digital display provides less "situational awareness" for the helmsman than does

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FIG. 2-4–Fluxgate Compass with Digital Readout and Conventional Displays the top-reading compass. This disadvantage can be overcome if the fluxgate compass also incorporates a conventional dial, as is shown in Figure 2-4, which provides precise heading information and situational awareness. The display shown in Figure 2-4 cannot be used to take bearings, however.

Finally, some compasses—called *telltale compasses*—should be mounted in an upside down (overhead mount) position. The telltale compass is usually installed in the ceiling of the navigator's berth, so that the navigator can read the vessel's heading when not on duty. Overhead-mount compasses are a favorite of "single handlers," and can double as a backup compass. (Incidentally, the practice of "single-handing" (voyaging for long distances with only one person aboard) is unsafe, a violation of the navigation rules (a proper lookout cannot be maintained by a sleeping helmsman), and is strongly discouraged.)

Whatever display is chosen, it is important that the numerals on the dial be large and easy to read. Ornate displays, such as were found on older marine compasses, are less readable than the simple, clean designs of today.

BRIEF ADVICE ON COMPASS SELECTION

The best advice on compass selection is not to be miserly. With compasses, as with other items of equipment, you generally get what you pay for. Because the compass is such an important navigational instrument, it is essential that it be of high quality. Incidentally, this comment also applies to small vessels. On average, small vessels are significantly more "lively" than larger vessels. Larger and more expensive compasses have better gimbals and have larger and easier to read dials. The saying "bigger is better" almost always applies to the selection of a compass. Finally, it is recommended that a vessel be equipped with at least two compasses as a precaution against compass failure. A handheld compass (discussed in Chapter 4) can serve as a backup.

> **PRACTICAL TIP**
>
> ***Carry at least one spare compass aboard—if only a hand-bearing compass. This is cheap insurance. According to Morrison (1942), early mariners carried plenty of spare "needles" (compass needles) aboard. Ferdinand Magellan reportedly had thirty-five spare needles on his ship!***

COMPASS MOUNTING

Ideally, the compass should be mounted where it can easily be read, is protected from the elements, and is free of any magnetic influences aboard the vessel (see below). The lubber's line should be precisely aligned with the fore-and-aft axis of the vessel. On larger vessels, these requirements are easy to meet, but this is sometimes more of a problem in smaller craft. Consult a compass adjuster and read the owner's manual (or product literature) for advice on this important topic.

There are several types of compass mounts, each with advantages and disadvantages. Compass mounts include the bracket mount (fast and versatile installation—particularly for angled surfaces), flush mount, deck or binnacle mount, and bulkhead/dash mount.

PRINCIPLE OF OPERATION: DEVIATION

The modem magnetic compass is highly sensitive and is able to align itself with weak magnetic fields, such as the earth's magnetic field. The magnets underneath the compass card will align with the magnetic field and indicate direction relative to this field. But, the magnetic field aboard a ship is actually a combination (resultant) of multiple magnetic fields—that of the earth and those of the vessel and its equipment.

Were the earth's magnetic field acting alone, the compass would indicate direction in the magnetic direction system—that is, the compass would point in the direction of magnetic north. (Please refer again to Chapter 1.) Determination of the direction with respect to true north would involve nothing more than adding or subtracting the local magnetic variation from the indicated compass direction (more below).

However, the magnetic field aboard a vessel is not solely due to the earth's magnetic field. Shipboard electronics, windshield wiper motors, compressed-gas horns,

WARNING

DO NOT PLACE METAL OBJECTS NEAR COMPASS

Do not use the area near the compass as a resting place for metal objects, such as flashlights, cameras, kitchen utensils, certain plotting instruments, and even metal sunglasses. These can affect the accuracy of the compass readings and cause serious course errors!

tachometers, electrical motors, television sets, and other equipment also generate magnetic fields. Indeed, flashlights, camera light meters, tools, and even some kitchen utensils can also affect the compass. (For skeptics, a simple experiment proves this and is highly instructive. For example, note the compass reading, then place a flashlight near the compass and observe how the reading changes.) The vessel itself—particularly steel vessels—may have magnetic fields oriented in a variety of ways. The vessel's magnetic field may even depend upon the direction the vessel was facing when it was constructed or last laid up for the winter (Kielhorn and Klimm, 1978). These additional fields also affect the compass, with the result that the compass heading of the vessel may differ from its magnetic heading. The difference between these is termed deviation. There are actually three "norths" that the mariner need be concerned with: *true north, magnetic north, and compass north. Simply put, deviation is the difference between the direction that the compass actually points and the direction that it would point if there were no local magnetic fields aboard the vessel.* Although statistics on the deviation of uncompensated compasses aboard recreational boats are not available, these deviations could be quite large, say 10 degrees to 15 degrees, and possibly even more.

It is precisely because of the deviation caused by the vessel's magnetic field that correcting magnets are found in all good compasses. A skilled compass adjuster can move the adjusting magnets so as to remove most of the deviation normally caused by the vessel's magnetic field. (A good compass adjuster can also serve as a consultant on compass placement and can advise the mariner how to stow other gear to minimize deviation in the first place.)

Compass Adjustment—A Brief Digression

As noted above, the use of a professional compass adjuster is recommended. This material is added for those interested in a do-it-yourself project. The material in this section is adapted loosely from the former AUXNAV specialty course (COMDTPUB P16798.16A) documentation:

USEFUL TIP

It is important to emphasize that deviation varies with the vessel's heading. When converting a relative bearing to a true or magnetic bearing, novices often make the mistake of applying the deviation appropriate to the relative bearing rather than the vessel's heading. Be careful not to make this error!

❑ First, carefully read the directions that come with the vessel's compass and ensure that the compass is mounted in such a way to minimize possible sources of deviation.

❑ Second, follow the directions given below to determine the compass deviations on various headings. If these deviations are "acceptable" (a judgement call), then use the "For/Steer" table (see below) directly and do not undertake compass adjustment. If not, then either call a professional compass adjuster or use the following procedure. Read the directions for compass adjustment (contained in the owner's information supplied with the compass) again to ensure that you are thoroughly familiar with the procedure and the location of the two adjusting screws.

❑ Third, make the following working tool. Take a sturdy cardboard and a dowel (a pencil will do). Make a hole for the dowel in the center of the cardboard and draw a straight line across the cardboard through the center. Select a calm, sunny day (with minimal traffic to avoid) for this evolution, in mid-morning or afternoon when the sun will cast a shadow on the dowel. Take the boat out and maintain a constant heading of north as indicated by the compass. Place the dowel in the hole and rotate the board until the shadow of the dowel falls on the line. Now turn the boat in the opposite direction until the shadow falls on the other side of the line. You will have turned 180° (turn and steady on the reciprocal course promptly because the sun moves about 1° in 4 minutes). Read the compass on this heading. Most probably, it will not read *exactly* 180°. Now, use a stainless steel or brass screwdriver on the athwartships (N-S adjustment) adjusting screw; remove half of the difference between the compass reading and 180°. For example, if the compass were to read 170°, use the adjusting screw to set the compass to 175°. Turn back on the original course until the shadow falls on the other side and take out half of the difference between the compass reading and 000°.

❑ Fourth, repeat the process until you can't remove any more error.

❑ Fifth, do the same thing on east-west headings. Head 090° by compass, align the shadow with the line, turn 180°, read the compass, and take out half the error with the other (E-W) adjusting screw. When no further improvements can be made, make another compass deviation card as described below.

For other perspectives, read through appropriate sections of Brogden (1995), Eyges (1989), Denne (1979), and Kaufman (1978) included in the references at the end of this chapter.

It is seldom the case that all the effects of this magnetic field can be compensated for by the adjusting magnets, and usually a small residual deviation (say 2 degrees to 4 degrees, but sometimes more) remains after adjustment. The mariner has two options for dealing with residual deviation. The first is simply to ignore any residual error and effectively compensate for its presence by fixing the vessel's position more often. As a rough rule of thumb, an unrecognized error of 1° means that a vessel would be approximately 1 mile off course (termed *cross-track error*) if it traveled a distance of 60 miles. Table 2-1 shows the cross track error as a function of the distance traveled and the angular error or residual deviation. For short distances, small angular errors are practically insignificant and can sometimes be ignored. However, for longer distances or in conditions of poor visibility (which would prevent detection and identification of landmarks, fixed *aids to navigation* (ATONs), or buoys), simply ignoring deviation cannot be recommended.

The second, and generally preferable, option is to measure the compass deviation, and use this measured value to correct the observed compass heading to a magnetic heading in the same manner as variation is used to "correct" the magnetic heading to a true heading. However, unlike variation, which depends solely on the vessel's *position*, deviation varies with the vessel's *heading*. Therefore, it is necessary to use the deviation appropriate to the vessel's compass heading before it can be used to convert to the correct magnetic heading. Although, theoretically, this deviation could be different for each possible heading, in practice the deviation is determined for each 15-degree or 30-degree heading increment; then these values are interpolated to estimate the deviation on intermediate headings. This process of determining the deviation on various headings is termed *swinging ship* or *swinging the compass* and is discussed below.

SWINGING SHIP

Normally, professional compass adjusters will swing ship as part of their services to compensate the compass and provide a table of deviations to the mariner. In such cases, the mariner will probably wish to spot-check this table periodically to verify its continuing accuracy. However, the procedures (discussed below) are the same whether the entire deviation table is being prepared or individual values are being spot-checked.

In brief, the procedure for swinging ship is to steady on a known compass course and then take bearings on a distant object or range. The vessel is positioned so that the magnetic bearing to the object to be observed is known. The compass bearing is read directly, or converted from a relative bearing obtained using a *pelorus* and compared with the object's known mag-

DISTANCE TRAVELED MILES	ANGULAR ERROR (DEGREES) 1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00
1.00	0.02	0.03	0.03	0.04	0.05	0.07	0.09	0.13	0.18
2.00	0.03	0.05	0.07	0.09	0.10	0.14	0.17	0.26	0.35
3.00	0.05	0.08	0.10	0.13	0.16	0.21	0.26	0.39	0.53
4.00	0.07	0.10	0.14	0.17	0.21	0.28	0.35	0.53	0.71
5.00	0.09	0.13	0.17	0.22	0.26	0.35	0.44	0.66	0.88
6.00	0.10	0.16	0.21	0.26	0.31	0.42	0.52	0.79	1.06
7.00	0.12	0.18	0.24	0.31	0.37	0.49	0.61	0.92	1.23
8.00	0.14	0.21	0.28	0.35	0.42	0.56	0.70	1.05	1.41
9.00	0.16	0.24	0.31	0.39	0.47	0.63	0.79	1.18	1.59
10.00	0.17	0.26	0.35	0.44	0.52	0.70	0.87	1.32	1.76
12.50	0.22	0.33	0.44	0.55	0.66	0.87	1.09	1.65	2.20
15.00	0.26	0.39	0.52	0.65	0.79	1.05	1.31	1.97	2.64
17.50	0.31	0.46	0.61	0.76	0.92	1.22	1.53	2.30	3.09
20.00	0.35	0.52	0.70	0.87	1.05	1.40	1.75	2.63	3.53
22.50	0.39	0.59	0.79	0.98	1.18	1.57	1.97	2.96	3.97
25.00	0.44	0.65	0.87	1.09	1.31	1.75	2.19	3.29	4.41
27.50	0.48	0.72	0.96	1.20	1.44	1.92	2.41	3.62	4.85
30.00	0.52	0.79	1.05	1.31	1.57	2.10	2.62	3.95	5.29
35.00	0.61	0.92	1.22	1.53	1.83	2.45	3.06	4.61	6.17
40.00	0.70	1.05	1.40	1.75	2.10	2.80	3.50	5.27	7.05
45.00	0.79	1.18	1.57	1.96	2.36	3.15	3.94	5.92	7.93
50.00	0.87	1.31	1.75	2.18	2.62	3.50	4.37	6.58	8.82
60.00	1.05	1.57	2.10	2.62	3.14	4.20	5.25	7.90	10.58
70.00	1.22	1.83	2.44	3.06	3.67	4.89	6.12	9.22	12.34
80.00	1.40	2.09	2.79	3.49	4.19	5.59	7.00	10.53	14.11
90.00	1.57	2.36	3.14	3.93	4.72	6.29	7.87	11.85	15.87
100.00	1.75	2.62	3.49	4.37	5.24	6.99	8.75	13.17	17.63

TABLE 2-1–Cross-track error as a function of distance traveled and residual deviation or other angular helm error.

netic bearing, and the deviation is calculated. Professional compass adjusters often use the sun for observation, but most mariners are unfamiliar with celestial navigation and elect to use something simpler, such as a prominent object or range. The object(s) selected for observation should be a good distance away (e.g., 6 miles) to minimize parallax error in the calibration. It is important that swinging ship is done when conditions are nearly ideal, in calm waters and in good visibility. The need for good visibility is obvious. The reason why calm waters are preferred is to simplify steadying the vessel on a compass heading

FIG. 2-5–The range formed by the spire in New Bedford and the Butler Flats light bears approximately 310 degrees.

and reading the compass. Experience shows it can take several hours to swing ship, so the exercise should be planned with sufficient time allowance to be completed within the daylight hours.

The procedure for swinging ship depends upon the compass to be examined and the ability to take bearings on objects not directly aligned with the fore-and-aft axis of the vessel. If the compass is graduated to the nearest degree, and designed and located so that an unobstructed view is possible throughout all 360 degrees, then only a compass is necessary. (This is likely to be the case for relatively few boats.) If, as is more common, the compass is graduated only in 5-degree increments or bearings are not easily read throughout 360 degrees, then it is necessary to use a pelorus as well (discussed below).

DIRECT OBSERVATION USING A RANGE

The easiest method for swinging ship, if circumstances permit, is to use a range and read the compass directly. A range consists of two charted objects that can be viewed and aligned from a distance. For example, consider the spire in New Bedford and the Butler Flats Light located south and east of New Bedford shown in the 1210-Tr chart and in Figure 2-5. Both of these objects are likely to be prominent and relatively easy to identify. Approaching from the south, these two objects are exactly in line (one behind the other or in range) on a bearing of 310 degrees true from the vessel to the objects. The bearing can be read from the chart as discussed in Chapter 3, but take the answer as given for the present. The variation in this area, read from the nearest compass rose, is approximately 015 degrees west; so the magnetic bearing of this range would be 310 + 015 = 325 magnetic. (See below for a handy rule to remember whether to add or subtract variation.)

Suppose that the vessel were steadied on a compass course of 000 degrees (compass north) while the vessel was somewhere south of the line drawn on the chart. (This

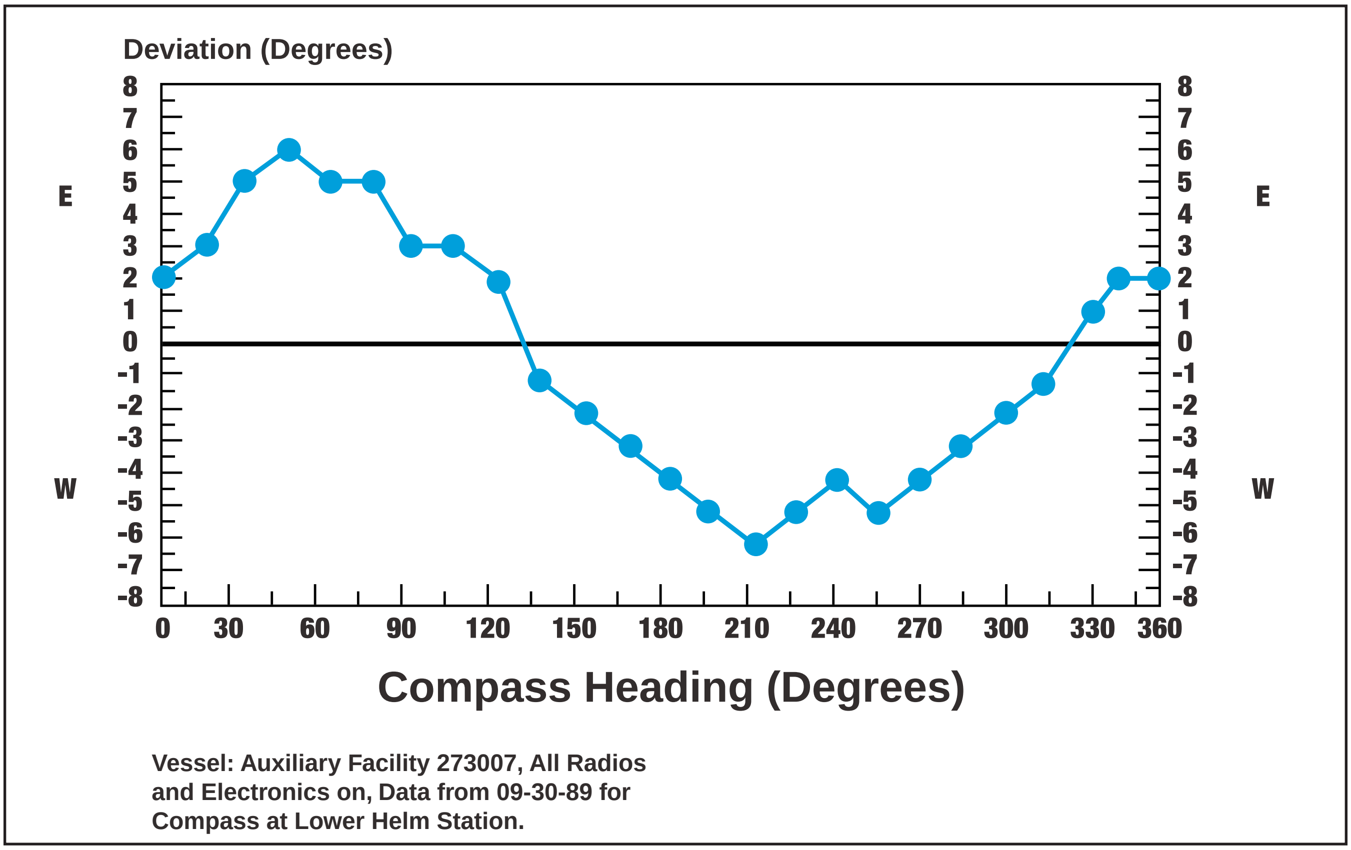

FIG. 2-6–A Plot of Compass Deviations

would, of course, be evident from the vessel because the Butler Flats Light would be to the right of the spire. At the precise instant that the light and the spire appeared to be in line, the magnetic bearing of the range would be 325 degrees from the vessel. At this same instant, suppose that the compass bearing of the range (read over the compass) was 323 degrees (while the compass heading was 000 degrees). The deviation on this heading is the difference between the magnetic bearing, 325 degrees, and the bearing read from the compass, 323 degrees, or 2 degrees. But, is it 2 degrees east, or 2 degrees west? It can, of course, be worked out from first principles (refer to Chapter 1), but it is easy to remember the simple phrase, "compass least, error east." That is, if the compass bearing is less than the magnetic bearing (as it is in this case, 323 degrees is less than 325 degrees), then the deviation is "east." (If not, then the error would, of course, be "west.") Thus, in this example, the estimated compass deviation on a heading of 000 degrees is 002 degrees east. To confirm this result, the process might be repeated and the average deviation noted.

It is convenient to use a worksheet, such as is shown in Table 2-2 to record the observations. This worksheet contains directions as well, which makes it handy to use. The process is now repeated on a compass heading of 015 degrees, 030 degrees, etc., until all observations are recorded.

PLOTTING THE RESULTS

The results should be plotted on a sheet of graph paper to see if there are any "anomalous" results that do not fit the pattern. Overall, the line drawn through the measured deviations should appear as a smooth curve (actually a mixture of trigonometric functions for those technically inclined) free of "bumps" or observations that appear discrepant. Such a curve is drawn in Figure 2-6 and appears generally to confirm the adequacy of the measurements, although the deviations on some headings, such as 240 degrees, should be rechecked. (In Figure 2-6 easterly deviations are shown with a plus sign, and westerly with a minus sign.) Additionally, the deviations on some headings are relatively large (5 or 6 degrees), so the compensation is far from perfect. (A more technical analysis, omitted here, suggests that improved compensation is possible. However, the example is continued for illustrative purposes.)

USE OF A PELORUS

As noted, most marine compass installations do not permit direct reading of compass bearings through a full 360 degrees. Additionally, many compasses are graduated only to 2 degrees or 5 degrees, rather than in 1-degree increments. If either of the statements is true, it is necessary to modify the procedure given above for swinging ship. The most convenient solution is to use a *pelorus,* sometimes called a *dumb compass*.

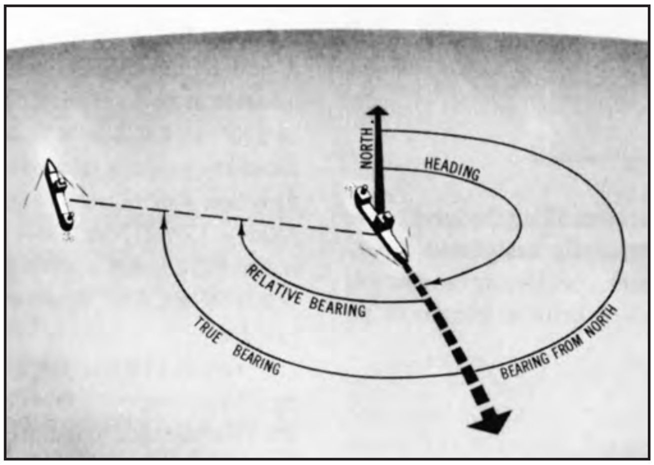

FIG. 2-7–Relative Bearing

A pelorus consists of a graduated compass-like dial (l-degree increments) and sighting vanes that can be rotated around the dial to take bearings. Unlike the "north-seeking" compass dial, however, the position of the dial on the pelorus does not change with the vessel's heading. The pelorus is mounted and the dial fixed so that the 000-degree mark on the dial is pointed so as to be parallel to the vessel's bow, precisely aligned with the fore-and-aft axis of the vessel. (Consult the directions supplied with the pelorus for mounting instructions and pay particular attention to the alignment procedure.) The pelorus should be mounted so that the navigator can easily view objects throughout a full 360 degrees.

The bearings read from the pelorus are relative bearings (refer to Chapter 1), rather than compass bearings. For this reason it is necessary to calculate the compass bearing from the simple equation: Ship's heading + Object's relative bearing = Object's compass bearing. Figure 2-7 illustrates this equation.

DATE: *10-15-99* **NAVIGATOR:** *LDM* **VESSEL:** *Altair*
RANGE: *Spire in New Bedford and Butler Flats Light*
NOTES: *Loran, Radar, and VHF Radio ON*

TRUE BEARING OF RANGE: *310* Determined from Nautical Chart or Other Source
VARIATION: *015 West* Determined from Nearby Compass Rose
MAGNETIC BEARING OF RANGE: *325 Magnetic* True +/- Variation, +West, -East

Entry	Vessel's Head Per Compass	Magnetic Direction of Range	Direction of Range Per Compass	Estimated Deviation on This Heading	Notes
1 Where Obtained	2 Read From Lubber's Line Directly	3 Taken From Above Calculation	4 Bearing of Range as Read Over Compass	5 Difference Between Columns 3 and 4 If Column 4< Column 3, Deviation is "East," Otherwise Deviation "West"	This worksheet is designed to be used for determination of deviation where a range is available and can be sighted over the compass. The true bearing of the range can be determined from a nautical chart, *Light List*, or other source. Compass deviation should be determined every 15 degrees of heading, generally starting at 000 degrees. The "notes" section should identify the electronics on board, and operating at the time of the calibration. It is suggested that two tables be prepared, one with all electronics on, and the other with electronics off.
	000	*325*	*323*	*2E*	
	015	*325*	*322*	*3E*	
	030	*325*	*320*	*5E*	
	045	*325*	*319*	*6E*	
	060	*325*	*320*	*5E*	
	075	*325*	*320*	*5E*	

TABLE 2-2–Portion of Worksheet for Determination of Deviations from Range

This extra step requires a slight modification to the worksheet given in Table 2-2 to prepare a compass deviation table. This modified worksheet is shown in Table 2-3. To clarify by example, suppose that a compass deviation table is being prepared using the same range as given in Table 2-2. While on a compass heading of 015 degrees, the navigator sights over the vanes of the pelorus as the range is perfectly aligned. The navigator calls "mark-mark-mark" to allow the helmsman to make slight heading changes to bring the vessel back to the assigned 015-degree heading, and notes the relative bearing, say 307 degrees. Alternatively, the helmsman sings out the vessel's heading on hearing "mark-mark-mark," and the navigator notes this heading. The compass bearing to the range is, therefore, 015 + 307 = 322 degrees (360 degrees will have to be subtracted from this total if the total exceeds 360). The deviation on a compass heading of 015 degrees is, therefore, 3 degrees east as in the earlier example (remember, compass least, error east).

SPOT CHECKS

To spot-check a previously prepared deviation table, all that is necessary is to take advantage of ranges that may appear near the vessel's course. In this case, the helm is put over briefly to align the vessel with the range, the compass heading noted, and the deviation on this heading calculated as discussed above. At a minimum, compass headings should be recorded in a log (see sidebar) for later analysis when the vessel is anchored or docked.

PRACTICAL TIP: USE OF A COMPASS IN REPEATABLE MODE

Get in the habit of entering compass headings in a log on your trips—particularly when in good weather. If the same trip is repeated in conditions of reduced visibility, these same compass headings can be used—even if the compass has not been checked for deviation and errors exist. This use of a navigation instrument is termed its use in repeatable mode. If you return to the same readings of the compass (or other navigation instrument), you compensate for its error. For an interesting discussion of this principle, refer to Brogden (1995).

During a typical voyage there are many opportunities for such spot checks, and these should be used to advantage. Throughout the navies of the world, it is common practice to check the compass at least once daily and to report the results to the captain. For the average boater, it is not necessary to make such frequent or formal checks, but it is appropriate to check deviation at least a few times during the boating season, and whenever a major voyage is planned. Deviation can change whenever new electronic gear is brought aboard (or moved), the vessel is laid up for the winter, or someone inadvertently leaves a flashlight or camera near the compass.

Lightning strikes near the vessel can also affect deviation, and the compass should be checked after electrical storms have passed through the area.

DEVIATION ON INTERMEDIATE HEADINGS

The deviation table consists of entries spaced every 15 degrees or every 30 degrees. Values for intermediate headings are obtained by interpolation. For example, if the deviation were 3 degrees east on a compass heading of 000 degrees and 0 degrees on a heading of 015 degrees, it would be approximately 2 degrees on a heading of 005 degrees. Fancy formulas are not warranted here; simply prorate the deviation directly and round the calculation to the nearest degree.

USE OF THE DEVIATION TABLE

The deviation table is used for two important purposes. First, it is used to calculate the vessel's actual magnetic heading when steering a known compass heading. Second, it is used to calculate the correct compass heading to steer to make good a desired magnetic heading.

The deviation table solves the first objective directly. Refer to Table 2-4, for example, based upon the measurements discussed above.

DATE: *10-15-99* **NAVIGATOR:** *LDM* **VESSEL:** *Altair*
RANGE: *Spire in New Bedford and Butler Flats Light*
NOTES: *Loran, Radar, and VHF Radio ON*

TRUE BEARING OF RANGE: *310* Determined from Nautical Chart or Other Source
VARIATION: *015 West* Determined from Nearby Compass Rose
MAGNETIC BEARING OF RANGE: *325 Magnetic* True +/- Variation (+West, -East)

Entry	**Vessel's Head Per Compass**	**Relative Bearing of Range**	**Direction of Range Per Compass**	**Magnetic Direction of Range**	**Estimated Deviation on This Heading**
1 Where Obtained	2 Read From Lubber's Line Directly	3 Read From Pelorus	4 Vessel's Head (2) Plus Relative Bearing (3) (360° may have to be substracted)	5 Taken From Above Calculation	6 Difference Between Columns 4 and 5 If Column 4< Column 5, Deviation is "East," Otherwise Deviation "West"
	015	*307*	*322*	*325*	*3E*

TABLE 2-3–Portion of Worksheet for Determination of Deviations Using Relative Bearings

COMPASS TO MAGNETIC		MAGNETIC TO COMPASS	
(A) Compass Heading	(B) Deviation	(C) Magnetic Heading	(D) Deviation
000	2E	000	2E
015	3E	015	3E
030	5E	030	4E
045	6E	045	6E
060	5E	060	5E
075	5E	075	5E
090	3E	090	3E
105	3E	105	3E
120	2E	120	1E
135	1W	135	1W
150	2W	150	2W
165	3W	165	2W
180	4W	180	4W
195	5W	195	5W
210	6W	210	6W
225	5W	225	5W
240	4W	240	4W
255	5W	255	5W
270	4W	270	4W
285	3W	285	3W
300	2W	300	2W
315	1W	315	1W
330	1E	330	1E
345	2E	345	2E
360	2E	360	2E

TABLE 2-4–Sample Deviation Table [All Values in Degrees(°)]

Suppose that the vessel's compass heading were 045 degrees. From the first two columns of this table (headed by the phrase "compass to magnetic"), the deviation corresponding to a compass heading of 045 degrees is 6 degrees east. The magnetic heading is the compass heading plus or minus the deviation. Converting from a compass heading to a magnetic heading is often termed "correcting," because this process removes (corrects for) the deviation error. A simple rule to remember is "correcting add east," meaning that in converting from a compass heading to a magnetic heading, easterly deviation is added (westerly deviation is, therefore, subtracted). Using this rule, the corrected or magnetic heading corresponding to a compass heading of 045 would be 045 + 006 = 051 degrees magnetic. Similarly, a compass heading of 030 degrees corresponds to a magnetic heading (refer to Table 2-4) of 035 degrees.

Frequently, however, it is necessary to reverse the process. That is, to find the appropriate compass course to steer to make good a particular magnetic heading. For this task it is necessary to reverse the logic discussed above. For example, suppose that the mariner wants to make good a course of 045 magnetic. What compass course should be steered? From the above discussion, note that on a magnetic heading of 035 degrees the deviation is 5 degrees east, whereas on a magnetic heading of 051 degrees, the deviation is 6 degrees east. A simple interpolation (rounded to the nearest degree) indicates that the deviation on a 045 degree heading is approximately 6 degrees (5 + 10(6-5)/16 = 5.625, rounded to 6). Therefore, the approximate deviation on a magnetic heading of 045 degrees is 6 degrees east, as shown in Table 2-4. When making interpolations, remember that deviations are only measured to the nearest degree. A calculation is only as accurate as the least accurate number, so round all interpolated numbers to the nearest degree.

Continuing the process leads to the results shown in Table 2-4, which completes the deviation table. Use the left half of the table when correcting from compass to magnetic, and the right half when "uncorrecting" from magnetic to compass. (Unless the deviations are quite large, the two halves of the table are virtually identical and, in practice, these differences are often neglected.) Incidentally, the data presented in the *right hand side* (RHS) of Table 2-4 are often used to make a simple "For/Steer" correction card. Entries for this table can be computed as follows. Sup-

NAME	BRIEF DESCRIPTION	REMARKS
Northerly Turning Error	Applies principally when vessel is on northerly or southerly headings and the compass card is tilted with respect to the horizon. Effect is for compass to lag the turn, or momentarily show a turn in the opposite direction when turning from north. In turns from south, the compass leads the turn, i.e., shows the vessel turning more rapidly than it actually is. The effect is greatest in a rapid, steeply banked turn.	Of principal concern to aircraft, but of relevance to all fast boats. Arises from magnetic dip. Phenomenon described for northern hemisphere only.
Acceleration Error	Also due to dip, this error is greatest on headings of east or west and zero on north or south. If the vessel is accelerated on either of these headings, the compass will indicate an apparent turn to the north. When decelerating, the compass indicates a turn to the south. A memory aid to remember the word "ANDS," for Acceleration – North, Deceleration – South.	Effect greatest with vessels capable of large accelerations, e.g., speed boats. Also seen with aircraft. Often observed when boat butts into head sea, or planes down a swell while on an east or west heading.
Oscillation Error	Though listed as a separate error in some texts, this is actually a combination of the above errors. Results from erratic movements of the compass card caused by rough seas or abrupt helm changes. Helmsman has to "average" out oscillations mentally for precise steering.	
Heeling Error	Of particular relevance to sailing vessels, this error arises from change in the horizontal component of the induced or permanent magnetic fields at the compass due to rolling or pitching of the ship. To a lesser extent heeling errors may be affected by the angle of plane of a powerboat.	Adjusted for by heeling magnets on some compasses.Adjustment is partially a function of the magnetic latitude of the vessel.

NOTE: See article by Kielhorn for details on some of these errors.

TABLE 2-5–Additional Compass Errors Which Arise if Vessel is not Straight and Level, and at Constant Speed pose that the mariner wishes to follow a magnetic heading of 000. Reference to Table 2-4 shows that on a magnetic heading of 000 the deviation is 2° east. Therefore, the compass heading in this case would be 358. So, for a course of 000 magnetic, the mariner should steer 358. Under the heading "For" is placed the magnetic course 000 and under the heading "Steer" is placed 358. The table is completed to create a For/Steer card that is normally posted next to the compass.

COMPASS CALCULATIONS

Navigators need to become familiar with the calculations necessary for converting from true courses to compass courses, and vice versa. Although these calculations are quite simple, practice is necessary to ensure familiarity. For this reason, the following text and examples are given.

> **VARIATION AND DEVIATION**
>
> ***Variation is the angular difference between true and magnetic north—see Chapter 1. Variation is a function of the vessel's location on the earth. It can be found on the nautical chart. Deviation is the difference between magnetic north and compass north. It is particular to each vessel and is a function of the heading of the vessel. Although related, these are distinct concepts.***
>
> ***DO NOT CONFUSE THESE TWO TERMS.***

It is often necessary to convert from true to compass headings or bearings. As discussed in later chapters, courses are laid out on nautical charts and, typically, measured with respect to true north. But to undertake the voyage, the navigator needs to determine how to convert this true course to a compass course to steer. The overall sequence for this conversion is to start with the true course, add or subtract variation to calculate a magnetic course, and then again add or subtract deviation to calculate a compass course: True, Variation, Magnetic, Deviation, Compass, or as it is sometimes said, TVMDC. In addition to learning the sequence of calculations, it is useful to have a handy rule to remember whether to add or subtract variation and deviation.

Throughout history there have been a series of "salty" mnemonics used to help remember the TVMDC sequence. The current politically correct mnemonic is TeleVision Makes Dull Children; Avoid Watching. Decoded, it reveals the sequence of calculations TVMDC and the reminder (AW) to add west when converting from true to compass. For example, what is the compass heading to steer if the true course is 060, variation is 015 west, and the deviation table is as given in Table 2-4? The answer is calculated as follows:

- ❑ First, start at the true course, 060, and convert it to the magnetic course. Since the variation is west, it is added to the true course. The magnetic course is, therefore, 060 + 015 = 075.
- ❑ Second, from Table 2-4, the deviation corresponding to a magnetic heading of 075 degrees is 5 degrees east. From the simple rule to add west in this sequence, it follows that a 5-degree easterly deviation would be subtracted.
- ❑ Third, from the above steps, the required compass course is 075 - 005 = 070 degrees.

The important points to remember are the sequence of calculations and whether to add or subtract variation and deviation. If all else fails, reference to the nearest compass rose on the nautical chart will enable you to figure out whether to add or subtract variation (or deviation).

Sometimes it is necessary to reverse the process, and convert from compass to true. For example, a bearing on a distant object may be taken from the vessel's compass, and it is necessary to convert this bearing to true, before plotting on a nautical chart. The sequence of calculations is just the opposite of that discussed above, i.e., CDMVT. As well, the sign to apply to east or west variation or deviation is also reversed. That is, east is added, and west is subtracted. Although this is simple enough to remember, some prefer to use the additional memory aid: Can Dead Men Vote Twice? At Elections! The first letters are the memory aid to the sequence: Compass, Deviation, Magnetic, Variation, True, and Add East. (Some aircraft pilots were taught the phrase: Can Ducks Make Vertical Turns?)

To illustrate, suppose that the compass heading of the vessel is 065 degrees and an object is sighted bearing directly ahead per the vessel's compass in an area where the variation is 015 degrees west. What is the true bearing? Assuming that the deviation table is as given in Table 2-4, the deviation on a compass heading of 065 degrees is 5 degrees east and, therefore, the magnetic heading of the vessel is 065 + 005 = 070 degrees (add east). In turn, the true heading is the magnetic heading plus or minus variation. If east is to be added, then west should be subtracted for this calculation, so the true heading is 070 – 015 = 055 true. That's all there is to it. Practice until you are proficient.

PHOTO COURTESY OF KVH INDUSTRIES, INC.

FIG. 2-8–Fluxgate Digital Compass. Both the fluxgate sensor and the *Liquid Crystal Display* (LCD) are enclosed in one watertight unit.

LOCAL MAGNETIC DISTURBANCE

Notes indicating magnetic disturbance are printed in magenta on U. S. charts. Where space permits, these notes are printed in the specific area of local magnetic disturbance. Here are some examples of how these are shown:

> **LOCAL MAGNETIC DISTURBANCE**
> ***Differences from normal variation of as much as 5° have been observed in Gastineau Channel in the vicinity of Lat. 58° 15'.***

> **LOCAL MAGNETIC DISTURBANCE**
> ***Differences of 12° or more from normal variation may be expected in X Channel in the vicinity of Z Point.***

Where limited by space, the full note is placed elsewhere on the chart and the following reference note shown (in magenta) in the area of the disturbance:

> **LOCAL MAGNETIC DISTURBANCE**
> **(See Note)**
> ***Mariners should exercise particular vigilance when operating in these areas.***

ADDITIONAL POINTERS ON THE COMPASS

It is important to remember that compass readings are most accurate only when the vessel is level (as opposed to heeling), traveling at a constant speed, and maintaining a constant course. Otherwise, a series of additional compass errors is introduced, as shown in Table 2-5. It is not a good idea to use compass readings obtained while the vessel is heeling, turning, or accelerating/decelerating. The effects of these errors are to make the compass difficult to read and/or to give erroneous indications. These errors are largest for vessels capable of substantial acceleration (e.g., speedboats), and substantial angles of heel or bank. (Consult the references at the end of this chapter for more details.) Directional gyros or gyrocompasses are less prone to these errors and sometimes favored by mariners for this reason (among others).

LOCAL MAGNETIC DISTURBANCES

In some areas of the world, the measured values of magnetic variation differ from the expected (charted) values by several degrees. The sources of these discrepancies are termed *local magnetic disturbances, local attractions, or magnetic anomalies*. Magnetic disturbance notes identify such areas on U. S. nautical charts where errors are greater than or equal to 2° (3° in Alaska). The note will indicate the location and magnitude of the disturbance. The indicated magnitude should not be considered as the largest possible value that may be encountered. Large disturbances are more frequently encountered in the shallow water areas near landmasses (particularly mountains) than on the ocean. Fortunately, the effect of a local magnetic disturbance typically diminishes rapidly with distance. However, in some locations there are multiple sources of disturbances and the effects may be distributed for many miles. Read the nautical chart carefully to determine if there are areas of local magnetic disturbance located along your proposed route. Exercise extra vigilance when transiting these areas. Do not rely entirely on the compass; steer by reference to landmarks and/or ATONs, if possible, and fix your position frequently. Obviously, you should not attempt to calibrate a compass in an area of known local magnetic disturbance. (Local magnetic disturbances are not a compass error, *per se*. Nonetheless, this magnetic phenomenon does affect the compass and should be noted.)

THE FLUXGATE COMPASS

Finally, any modern discussion of compasses would be incomplete without, at least, a passing mention of the fluxgate compass. The fluxgate compass senses the earth's magnetic field electronically, rather than with magnets. (Readers wishing a more complete discussion should refer to the bibliography.) The fluxgate compass consists of a sensor and a display unit. (The sensor and the display unit may be in the same, or different, units.) If separate from the display unit, the sensor can be located remotely, in an area of the vessel where magnetic disturbances are at a minimum. The display unit is small and can be mounted for optimum visibility. Most modern fluxgate systems are integrated with microprocessors, which can perform many useful functions. The model, pictured in Figure 2-8, automatically compensates for deviation (to within +/- 1 degree, in most cases) by simply making a 360 degree turn with the vessel! Other models can also display headings in either true or magnetic (variation data are stored in the microchip) and can furnish electronic inputs to other navigation systems such as the Global Positioning System (GPS), Loran-C, or radar.

An electronic compass is very convenient. However, it does not eliminate the need for a magnetic compass, because electronics are dependent upon a reliable power supply and are easily damaged in the marine environment.

SELECTED REFERENCES

Aczel A. D., (2001). *The Riddle of the Compass, The Invention That Changed the World,* Harcourt, Inc., New York, NY.

Anon., (1988). *The Magnetic Compass, Principles, Selection, Navigation,* E. S. Ritchie & Sons, Inc., Pembroke, MA.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA) Marine Navigation Department web site (http://www.nima.mil/).

Brogden, B., (1995). *Boat Navigation for the Rest of Us, Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Cohan, L. S., (1988). Compass Deviation Affected by Lightning, *Ocean Navigator,* No. 17, January/February.

Collinder, P. A., (1955). *History of Marine Navigation,* St. Martin's Press, Inc., New York, NY.

Dahl, N., (1983). *The Yacht Navigator's Handbook,* Hearst Books, New York, NY.

Defense Mapping Agency, Hydrographic/Topographic Center, (1980). *Handbook of Magnetic Compass Adjustment,* Fourth Edition, Pub. No. 226, Washington, DC.

Denne, W., revised by Cockcroft, A. N., (1979). *Magnetic Compass Deviation and Correction, A Manual of the Theory of the Deviations and Mechanical Correction of Magnetic Compasses in Ships,* Brown, Son & Ferguson, Ltd., Glasgow, Scotland.

Department of Transportation, Federal Aviation Administration, (1987). *Instrument Flying Handbook,* AC61-27C, Washington, DC.

Eyges, L., (1989). *The Practical Pilot, Coastal Navigation by Eye, Intuition and Common Sense,* International Marine Publishing Co., Camden, ME.

Fuson, R. H. (Translator), (1987). *The Log of Christopher Columbus,* International Marine Publishing Company, Camden, ME.

Ganssle, J. G., (1989). Anatomy of a Fluxgate, *Ocean Navigator,* September/October.

Hempstead, R. L., (1987). Magnetic Compasses in the Small Boat Environment, *Ocean Navigator,* No. 12, March/April, pp. 21 et seq.

Hewson, J. B., (1983). *A History of the Practice of Navigation,* Second Edition, Brown, Son & Ferguson, Ltd. Publishers, Glasgow, Scotland, UK.

Jerchow, E., (1987). *From Sextant to Satellite Navigation, 1837-1987, 150 Years,* C. Plath, Hamburg, Germany.

Kaufman, S., (1978). *Compass Adjusting for Small Craft,* Surfside Harbor Associates, Surfside, FL.

Kielhorn, W. V., (1988). *A Piloting Primer,* privately printed at Naples, FL.

Kielhorn, W. V., (1957). The Northerly Turning Error, *The Rudder,* Vol. 73, No. 2, pp. 40-42.

Kielhorn, W. V., and H. W. Klimm, (1978). A Preliminary Study of the Changes of Magnetic Structure in a New Steel Trawler, *Navigation, Journal of the Institute of Navigation,* Vol. 6, No. 6, pp. 365 et seq.

Moody, A. B., (1980). *Navigation Afloat: A Manual for the Seaman,* Van Nostrand Reinhold, New York, NY.

Morrison, S. E., (1942). *Admiral of the Ocean Sea, A Life of Christopher Columbus,* Little, Brown and Company, Boston, MA.

Queeney, T. E., (1985). Beyond the Lodestone, *Ocean Navigator,* No. 3, September/October, pp. 33 et seq.

Queeney, T. E., (1987). Future Heading Systems, Are Lasers The Next Step, *Ocean Navigator,* No. 12, March/April, pp. 35 et seq.

SELECTED REFERENCES

Rousmaniere, J., (1989). *The Annapolis Book of Seamanship,* Simon and Schuster, New York, NY.

Saunders, A. E., (1987). *Small Craft Piloting and Coastal Navigation,* Alzarc Enterprises, carborough, Ontario, Canada.

Van Heyningen, M. A. K., (1987). The Evolution of the Modern Electronic Compass, *NMEA News,* January/February.

CHAPTER 3

THE NAUTICAL CHART

"It would appear that on some [of the Marshall Islands]…***these charts were considered so precious that they might not be taken to sea.*** This was partly because they might be damaged in the canoes and partly, perhaps, because the people might never come back, in which case the tribe's precious property would be lost forever". [Emphasis added]

–Per Collinder, *A History of Marine Navigation*

INTRODUCTION

This chapter provides an introduction to the nautical chart, how it is constructed, how to determine position, course, and distance on the chart, how to read the chart, and, finally, some practical ideas about chart interpretation and use. The material in this chapter is not difficult, but there is a lot to learn.

Read this chapter with a nautical chart, preferably the 1210-Tr, close at hand. Refer to the chart often. Don't despair, it takes a great deal of experience to become fully familiar with the wealth of relevant information depicted on the nautical chart! This chapter provides an introduction to the nautical chart. As you work the homework problems throughout the course, you will gradually become more familiar with the nautical charts and how they are used.

DIFFERENCES BETWEEN CHARTS AND MAPS

At the outset, get in the habit of calling this *a chart—not a map*. A map depicts information relevant to terrestrial travel and provides the answers to such questions as:

- ❏ What are the route numbers?
- ❏ Where do the roads lead?
- ❏ What are the distances between cities and towns?
- ❏ Which roads are improved and which are limited access roads?
- ❏ Where can you find services such as fuel, food, and lodging?
- ❏ Where are the entrances to national parks?

It is useful to know the answers to these questions if you plan to take a family camping vacation or a business trip by automobile. The map generally emphasizes land-

PHOTO COURTESY OF UNITED STATES COAST GUARD

forms (sometimes including the representation of relief) and highways with the shoreline represented as an approximate delineation, usually at mean sea level. Maps do not usually present detail on water areas. Maps depict roads but, typically, do not provide information on the condition of any road, although this can sometimes be inferred by collateral information (e.g., whether or not a road is part of the interstate system).

Although maps provide a great deal of information, much is omitted—the height of a tower, for example, or the precise locations of church spires, water towers, monuments, and conspicuous dwellings, would normally not be shown on a map because this information is of limited utility to the map user.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❑ *Chart projections*
- ❑ *How to establish a position on a nautical chart*
- ❑ *How to measure direction and distance on a nautical chart*
- ❑ *Chart scales and their significance*
- ❑ *Types of nautical charts*
- ❑ *How soundings and bottom characteristics are depicted*
- ❑ *How heights are depicted*
- ❑ *How to read the General Information Block on a chart*
- ❑ *Practical pointers on finding your position on a chart*
- ❑ *ATONs and dangers to navigation*
- ❑ *Chart storage*

The practice of marine navigation has unique information requirements. Water depths, *aids to navigation* (ATONs) and their relevant attributes (radio frequencies, light colors, sectors, and characteristics), landmarks, unmarked hazards to navigation, land outlines, bridge clearances, distance, and direction, are all pertinent to marine navigation. The nautical chart is a graphic portrayal of the marine environment. Together with supplemental navigational aids, it is used to define courses, fix a vessel's position, ensure the vessel does not stray into dangerous waters, and navigate vessels by a safe and efficient route.

A chart is normally a working document. Courses, *lines of position* (LOPs), fixes, waypoints, and other relevant data and information are plotted on the chart. In use, a nautical chart normally has numerous marks, courses, LOPs, fixes, and annotations made by the mariner. And, unlike the practice of early mariners in the Marshall Islands (see introductory quotation), charts are intended to be carried on board! In contrast, a map is generally a static document, used as a reference guide.

Marine navigation, being both an ancient art and science, has evolved its own prejudices and jargon. To a mariner, a chart is a veritable treasure—something to be used, but also treated with reverence and care. To this group, a map is something that can be purchased at a gasoline station vending machine, located next to advertisements for recaps, a cooler full of hot soda, and a dog with an infected ear. If you haven't guessed already, mariners are snobs. (For that matter, so are aircraft pilots, who refer to their maps as "aeronautical charts.") So, don't risk being branded a "landlubber"; refer to a chart by its proper name.

A SOURCE OF VITAL INFORMATION

As noted above, a marine chart depicts information of use for marine navigation. This includes a host of data on navigable (and not-so-navigable) water and the contiguous land. As you read through the material in this chapter, think about why cartographers chose to include this information on the chart and how you could use it to advantage. In very broad terms, information depicted on charts can be used to:

- ❑ **Orient the mariner and help to establish (fix) the position of the vessel:** Landmarks (e.g., spires, buildings, water towers, and tanks), geographic features (e.g., mountains, elevation contours), and ATONs (e.g., buoys, range markers) are depicted, inter alia (among other things), to help fix the vessel's position and mark the location of various channels. Parallels of latitude, meridians of longitude, and compass roses are included to enable the user to determine geographic coordinates and to measure courses and distances.

- **Highlight and locate possible hazards to navigation:** Water depths and the location of obstructions, shoals, rocks, sunken wrecks, and fish trap areas are included to warn mariners of both marked and unmarked hazards to navigation. Some of these data may have multiple uses. For example, water depths can be used in voyage planning to identify possible "shortcuts" for the trip. Wrecks may be of intrinsic interest to divers and anglers. Nautical charts are annotated with a series of "caution" notes (see sidebar) that warn the mariner about various hazards to navigation.
- **Facilitate voyage planning:** Much information is provided that facilitates voyage planning and/or the practice of good seamanship. For example, symbols that identify the nature of the bottom (sand, mud, rocks, grass) provide information regarding the suitability of a possible anchorage area and/or the type of anchor necessary to optimize holding power.
- **Identify and locate areas of regulatory significance:** Restricted areas, prohibited areas, and other related information is provided to alert the mariner to areas that are subject to certain restrictions.
- **Identify areas/objects of specific interest to particular user groups:** The location of designated anchorage areas, pilot operating areas, piers, and oil platforms are of interest to specialized user groups.

The above list is by no means complete. It provides instructive examples to stimulate your thinking. The amount, complexity, and diversity of material presented on the typical nautical chart is astounding! Nautical cartography is a highly developed art and science. Presenting the required information in easy-to-understand and compact format requires integrating the efforts of those in numerous disciplines to select the "right" method of chart projection, appropriate choice of scale, chart symbols, abbreviations, lettering styles, colors, paper, and printing techniques to produce today's high-quality nautical chart.

REPRESENTATION OF A SPHERICAL SURFACE UPON A PLANE OR FLAT SURFACE

It is impossible to represent a spherical surface upon a flat surface without introducing some distortion—in distance, direction, shape, and/or area. Even the school reference globe made out of paper or plastic printed on flat or rotary presses is made up of *gores* of essentially flat surfaces cut to bend and fit upon a spherical surface. If the globe were disassembled and its separate pieces laid out, one would have a flat surface where areas would be "correct," but there would be huge gaps between the gores; and direction, shape, and distances would have no meaning in the spaces between, nor continuity from one gore to another, except at the equator where all gores are joined.

CHART PROJECTIONS

Throughout the history of navi-

CAUTION NOTES

Caution notes are included on nautical charts to alert the mariner to certain hazards. Examples of caution notes taken from several charts include:

- ***Extremely heavy tide rips and strong currents may be encountered in the vicinity of the islands shown on this chart.***
- ***Improved channels shown by broken lines are subject to shoaling, particularly at the edges.***
- ***Mariners are warned that numerous uncharted duck blinds and fishing structures, some submerged, may exist in the fish trap area. Such structures are not charted unless known to be permanent.***
- ***Mariners are warned to stay clear of the protective riprap surrounding navigational light structures.***
- ***St. Lucie Inlet: The channel is subject to continual change. Entrance buoys and lights are not shown because they are frequently shifted in position.***

Where space permits, caution notes are shown near to the hazard noted. However, space constraints may make this impossible. Read the chart carefully to find all applicable caution notes.

gation, there have been numerous attempts to depict a round surface with a flat one. Some have been remarkably successful under certain conditions, but all such projections suffer some limitations. The goal of the various projections, a sampling of which is given in Figure 3-1, is to balance and minimize the distortions to produce a representation that preserves (to the extent possible) direction, distance, shape, area, and correct angular relationships. A projection that preserves correct angular relationships is termed *conformal*. This property, or a close approximation to it, is essential if the chart is to be used for navigation.

No chart projection is fully adequate over a large area, but several are sufficiently so to be useful to the small craft navigator. For navigation charts, the spherical surface of the earth has been projected on a cylinder and, also, on a series of coaxial, tangent (touching the earth's surface at one point or along one line) cones to provide the Mercator and the polyconic projections, respectively. These are shown in Figure 3-2 as are the two key nautical chart projections. Each of these projections has its particular utility and each has limitations. A particular projection is chosen based upon the intended use. A Mercator projection, for example, distorts areas (particularly near the poles) substantially, and is unsuitable for depicting the relative size of countries. (Generations of students have grown up believing that Greenland, for example, is larger than the United States, because they have studied Mercator projections where this is apparently true. In actual fact, the United States is more than 4.3 times larger than Greenland.)

These projections, their development and use for small craft navigation are discussed in some detail in this section.

GENERAL CHARTS	Azimuthal-Equidistant Gall-Peters Goode Homolosine Lambert Azimuthal Equal Area Lambert Conformal Miller Cylindrical Mollweide Orthographic Polar Stereographic Polar Gnomonic Robinson Simple Conic Sinusoidal Van der Grinten
CHARTS OF PARTICULAR INTEREST TO THE MARINER	Mercator Polyconic

FIG. 3-1–Illustrative Projections

THE MERCATOR PROJECTION

This projection has been one of the most useful for navigation for over 400 years. It was developed by a brilliant Flemish geographer by the name of Gerhard Kremer (latinized to Gerhardus Mercator) who published a world chart constructed by his method in 1569. The Mercator projection is a cylindrical projection, ingeniously modified by expanding the scale at increasing latitudes, to preserve shape, direction, and angular relationships.

This projection is conformal, but distance and area relationships are distorted. Both the meridians and the parallels are expanded at the same ratio with increasing latitude. For the technically minded the expansion is equal to the secant of the latitude (secant H = 1/cos H), with a small correction to reflect the fact that the earth is not a perfect sphere. The projection does not include the poles and usually not even the uppermost 15° of latitude, because the value of the secant at these angles is too large, being infinity at Lat. 90° (N or S). Since the expansion is the same for all directions and angular relationships are correctly indicated, the projection is conformal and compass directions *(rhumb lines or loxodromes)* are shown as straight lines—properties of value to the mariner.

Distances can be measured directly, but not by a single distance scale for the whole chart (unless a large-scale chart is used, see below) or for large areas. Instead, the latitude scale is used along any merid-

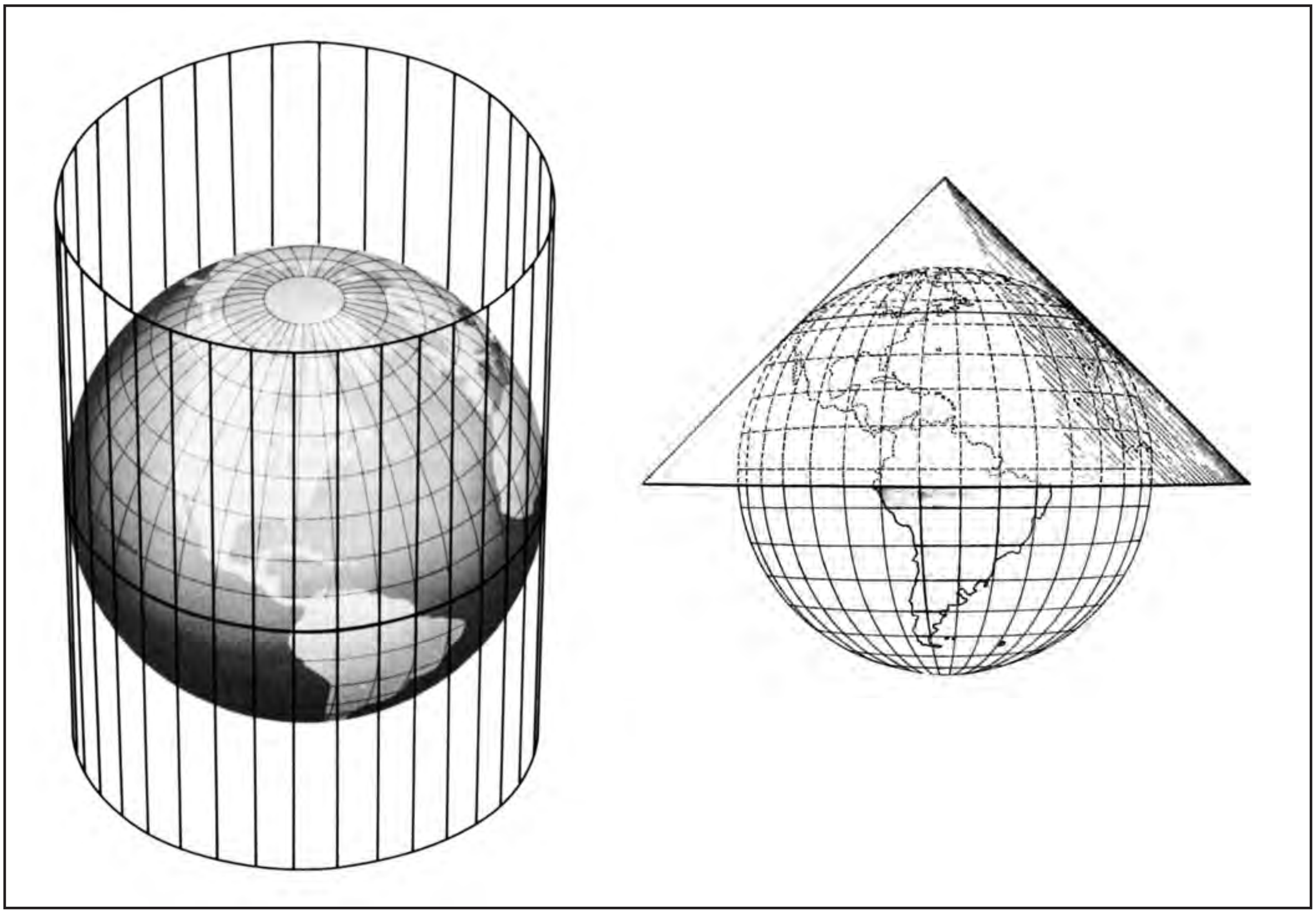

FIG. 3-2– Mercator and Conic Projections

ian. (Remember, 1° Lat. = 60 M, 1’ Lat. = 1 M.) Great circles appear as curved lines on the Mercator projection except for the meridians and the equator, which appear as straight lines. Note: The Mercator projection may also be made as an oblique projection (at an angle to the equator or meridian), using any great circle (rather than the equator) for the base line. Such a projection is termed an oblique Mercator projection and is used for special navigation applications, which are beyond the scope of this course.

COORDINATES FOR THE MERCATOR PROJECTION

The format for the Mercator projection is rectangular. Latitude and longitude are the coordinates used for the Mercator projection. The parallels of latitude usually appear as horizontal, straight lines, running from the right to the left (in the western hemisphere), with the projections oriented such that north is at the top of the chart and south at the bottom, east at the right margin, and west at the left. (There are some nautical charts based on Mercator projections where, for various reasons, north does not appear at the top of the page. The Australians, for example, sell Mercator projections in novelty shops with south at the top of the chart! Closer to home, some nautical charts of rivers are typically not aligned north up in the interests of saving space.)

The meridians appear as straight, parallel lines running from the bottom of the chart to its top. The scale for the meridians (longitude scale) is indicated on the top and bottom margins of the chart. The scale for the parallels (latitude scale) is provided on the right- and left-hand margins, and is also used for distance measurement. *Compass roses*, indicating true and magnetic directions, are

HISTORICAL FOOTNOTE

Mercator was active in the Protestant Reformation. His career nearly came to an end in 1544 when Mary, Queen Dowager of Hungary, had him imprisoned as a heretic. She issued an edict that all heretics should be put to death. Mercator was one of forty-three persons condemned at Louvain but was saved by the intercession of the parish curate, reportedly a clever man and shrewd debater. Fortunately for modern mariners, Mercator stuck to making maps after this experience. For more information, see Wilford (1982) in the references at the end of this chapter.

placed at convenient locations on the chart.

ESTABLISHING A POSITION USING THE MERCATOR PROJECTION

Since the Mercator projection results in a rectangular presentation, a rectangular coordinate system using latitude and longitude makes establishing a specific position on the globe an easy process on the chart:

- ❑ Using the latitude scale at the right or left margins (these scales are along meridians), simply take the latitude value and draw a light pencil line from this point across the chart parallel to the top, bottom, and other parallels on the chart. (Use of a parallel rule or paraline plotter makes this easy.) Every point on this line has that same latitude.
- ❑ To specify the position uniquely, now use the longitude scale at the top or the bottom of the chart (these scales are along parallels) to locate the desired longitude value and strike another light pencil line up or down, parallel to the meridians and the sides of the chart. All points on this line (itself, a meridian) are at the same longitude. Where the two light pencil lines intersect, the position is uniquely specified.

USE OF PARALLEL RULERS AND DIVIDERS TO PLOT A POSITION ON THE MERCATOR PROJECTION

Parallel rulers and the dividers help to minimize unnecessary marks on the chart while plotting a position. (Interrupt your reading of this chapter to take a few minutes to read about parallel rules and dividers in Chapter 4.)

A common task in navigation is to plot a position on the chart. For example, a navigator may read the vessel's present position in latitude and longitude from a *Global Positioning System* (GPS) or Loran-C receiver (see Chapter 9) and wish to plot this position on the chart. The technique is simple and is illustrated in Figure 3-3:

- ❑ Place the parallel rulers—which are two straight edges constrained to remain parallel as they are "walked" or "opened and closed"—with one edge along a parallel of latitude shown on the chart. Holding the base ruler along the parallel, swing the other ruler to the desired latitude value on the left or right scale. A light pencil line is drawn only in the vicinity of the approximate longitude, which is "eyeballed" or estimated from the longitude scale at the top or bottom of the chart.
- ❑ After the latitude line has been drawn, take the dividers and set their points so that one point falls on the nearest meridian of longitude and the other at the value of longitude desired. Now, bring the dividers, carefully so as not to disturb the setting, down along the meridian until the desired latitude line (parallel) is encountered. If the line crosses the meridian, simply measure along the latitude line (parallel) with the dividers from the meridian. Where the other point of the dividers falls is the desired longitude. The two coordinates now specify the vessel's position, uniquely. If the latitude line (parallel) does not cross the meridian, simply swing the parallel rulers (keeping the base ruler along the parallel) so that the other ruler falls along the desired parallel and crosses the meridian, as well. Then, as above, measure the increment of longitude from the meridian along the parallel ruler to the position.
- ❑ The process can also be used with the meridian first, and the dividers set off of the parallel and the latitude scale. In addition, the dividers may be used

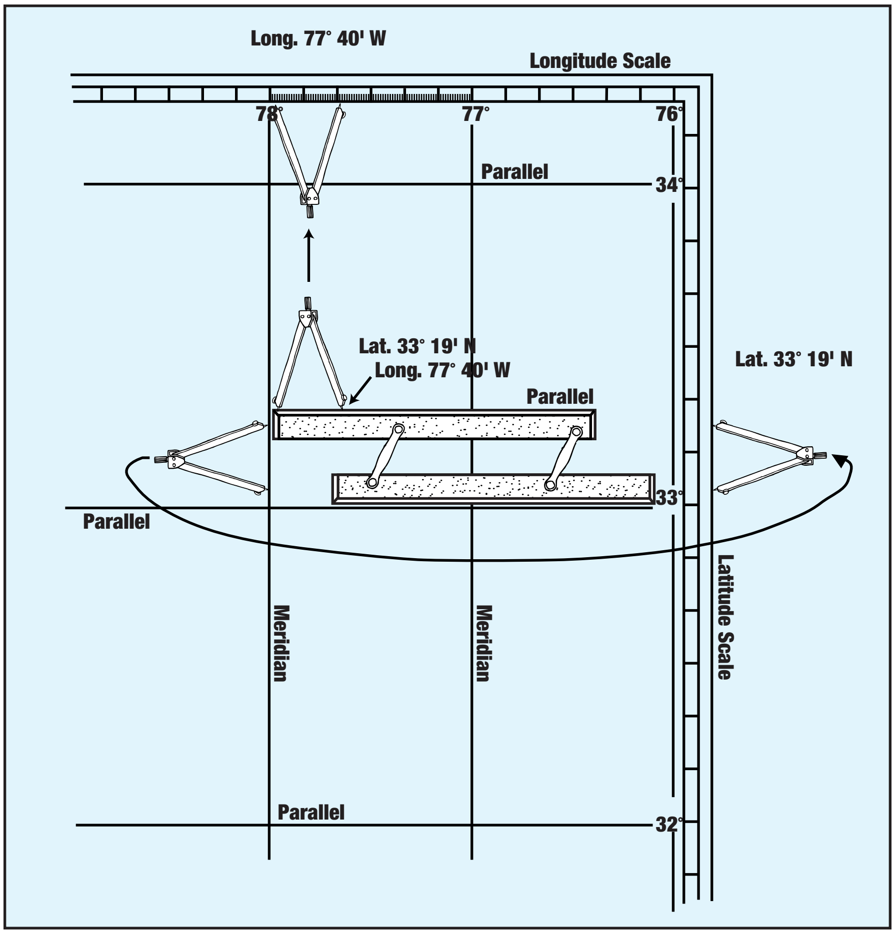

FIG. 3-3–Plotting a Position on the Mercator Projection Using Latitude and Longitude Coordinates

directly, without the parallel rulers, to locate the position. In this case, the dividers are maintained "parallel" to the meridian or parallel by eye—relatively easy to the practiced navigator—as the position is struck.

READING A POSITION FROM THE MERCATOR CHART

It is often of interest to reverse the above process—i.e., to find the latitude and longitude of some object on the chart. Taking (reading) such a position from the Mercator chart is a very simple process, similar to plotting one:

❑ At the desired position, walk the parallel rulers from a parallel of latitude. Measure the latitude increment *along* a nearby meridian with the dividers.

❑ Taking the dividers over to the latitude scale at the right or left margin of the chart, determine the value of latitude by measuring the length set on the dividers from the parallel up or down along the scale.

❑ Now, take the dividers and measure along the parallel rulers from the position to the nearest meridian. Take the set dividers to the top or the bottom of the chart and measure from the meridian along the longitude scale to determine the value of the longitude increment. Read the longitude directly under the point of the dividers.

❑ The dividers can be used alone, without the rulers, keeping them parallel by eye, as above. Practice with the rulers/dividers will develop sufficient confidence and familiarity with the process, to the point that the rulers will no longer be required, and the dividers can then be used alone.

MEASURING DIRECTION ON THE MERCATOR PROJECTION

A marine chart developed on the Mercator projection usually has several compass roses (true and magnetic) placed at convenient locations about the chart. Directions are measured from these roses using the parallel rulers, a paraline plotter, or other suitable method. The process is very simple:

❑ Align the parallel rulers along the course or bearing line to be measured. (It is helpful to put an arrow in the direction of the course line or the object. This helps to prevent making an error of 180° in reading the compass rose.)

❑ Holding the base ruler along the line, walk the rulers, keeping them parallel to the line, to the center of the rose, which is indicated by a small cross.

❑ With the ruler through the center cross, simply read the direction off of the true (or magnetic) rose in the desired direction. The reciprocal (180°) is read in the opposite direction.

Alternatively, if a paraline plotter is used, the plotter is aligned with the course and rolled to the nearest compass rose to measure direction, taking care not to disturb the alignment. The paraline plotter is, generally, easier to use if a large flat surface is available. Maintaining alignment is quite easy under these ideal conditions. If, however, the navigator's workstation is cramped and uneven, maintaining alignment is more of a trick. In any event, practice is necessary.

MEASURING DISTANCE ON THE MERCATOR CHART

The *latitude* scale, shown on either side of the Mercator chart, is used for distance measurement. Since one degree of latitude is equal in distance on the earth's surface to 60 nautical miles, and one minute of latitude is, therefore, equal to one nautical mile, the degrees and minutes and tenths of minutes or seconds markers indicating the latitude along the meridians on the sides of the chart provide excellent scales to measure distance on the Mercator chart.

Remember, however, that Mercator's projection *expands* the scale as latitude increases. So, it may be important where on the scale the distance is measured. (Unless a very small-scale chart is used, however, this scale expansion is largely of theoretical interest.) Distance is measured using a set of dividers. If the length of the course is shorter than the maximum extension of the dividers, the dividers are extended to the length of the course. The dividers are then moved (without changing their setting) so that they are aligned with one of the meridians at the right or left edge of the chart, and the length read out in minutes and tenths of minutes or minutes and seconds. Distance is determined by remembering that one minute is equal to one nautical mile. A distance of 10.7 minutes, for example, translates to 10.7 nautical miles. If a very small-scale chart is being used (see below) it is important to measure this distance at or near the midpoint of the course line. For coastal charts this refinement is unnecessary.

If the length of the course is longer than the maximum extension of the dividers, it is measured by setting the dividers to a convenient distance on the meridian (e.g., 2, 5, 10 nautical miles, depending upon the scale of the chart) and walked along the course in a series of "steps," mentally counting in multiples of the convenient distance. The final "step" will be shorter, and the dividers are reset to this length and the increment read on the meridian.

Alternatively, several of the plotters on the market are equipped with one or more distance scales. For example, the Weems and Plath parallel plotter is equipped with three distance scales, corresponding to chart scales (see below) of 1:80,000, 1:40,000, and 1:20,000, respectively. Using this type of plotter, the distance can be read directly from the appropriate distance scale. Be very careful, however, to note the exact scale of the chart to use the correct scale on the plotter. Otherwise, you have convenience at the expense of error! Trivial errors like this can easily arise if charts of more than one scale are used on the voyage, as for example, using both a coastal chart (see below) for the en route portion of the voyage and a harbor chart (see below) for the final approach. It is easy to make the mental error of continuing to use the coastal scale on the plotter for the harbor chart. (See Chapter 12 for a discussion of other "trivial errors" that have led navigators to grief!)

PHOTO COURTESY OF UNITED STATES COAST GUARD

▲ Use of Paraline Plotter.

THE POLYCONIC PROJECTION

Nearly all marine navigation charts for the Great Lakes are based on a polyconic projection—a series of cones concentric with the earth's axis and tangent to the sphere at different parallels of latitude. When a plane portion is taken from the polyconic surface, as shown in Figure 3-4, the meridians appear almost as straight lines, very slight-

TRUE OR MAGNETIC NORTH?

It is useful to comment on the appropriate choice of direction on nautical charts. In principle, directions can be measured or specified relative to true north or relative to magnetic north. (Compass north, as discussed in Chapter 2, has no place on the chart because compass deviation differs from vessel to vessel.) Traditionally, true north has been used for directional reference by the merchant marine and all navies of the world. More recently, some small boat navigators have (sometimes passionately) advocated the use of magnetic north as a reference.

Traditionalists point out that most celestial computations are carried out in terms of true north, marine gyrocompasses "point" to true north, the meridians on either Mercator or polyconic projections are oriented with respect to true north, tidal current data (see Chapter 8) are given with respect to true north, and, finally, that most ATON information (e.g., the bearings of ranges) is provided with respect to true north.

Advocates of the use of magnetic north argue that true directions must generally be converted to magnetic (and ultimately to compass north) before use, introducing the possibility of error in the TVMDC computations (see Chapters 2 and 12). Moreover, they add, nearly all commercial continental aircraft navigation is carried out without so much as a mention of true north. They concede that true north is appropriate for celestial, bluewater, or polar navigation, but argue that it has little relevance for the coastal small boat skipper.

Each side of this "controversy" has points in its favor. In truth, either system can be made to work for coastal navigation (at least in the lower latitudes) provided that it is used with intelligence. However, one system should be chosen, to avoid the confusion associated with a mixed system of units. Therefore, for purposes of this course, true north will be taken as the appropriate reference point. The choice is made largely because plotters that read off parallels or meridians measure relative to true north, and also because the ATON and tidal current information (see Chapter 8) is generally keyed to true north.

ly curved, *converging* northward beyond the top of the chart, toward the apexes of the cones.

Great circles appear as essentially straight lines and parallels of latitude appear as slightly curved, almost parallel lines intersecting the meridians at 90° angles and diverging as they approach the edges of the chart. Distortion is least along the central meridian and increases toward the sides of the chart, as the distance between parallels of latitude increases. Although the polyconic chart is not conformal, great circles do appear as essentially straight lines, and radio signals (following great circles) can be plotted as straight lines on this projection.

LATITUDE AND LONGITUDE SCALES ON THE POLYCONIC CHART

On the polyconic chart the parallels of latitude appear as slightly curved lines diverging toward the sides of the chart, and the meridians converge to an imaginary spot off the top of the chart. These "distortions" are readily apparent on a chart of a large area, but are virtually undetectable on the charts generally used by operators of small vessels. Figure 3-5, for example, reproduces a portion of the 14881 polyconic chart (produced in the original at a scale of 1:80,000). As a practical matter, latitude and longitude can be determined in the same manner as on a Mercator chart. For extremely accurate plotting, an interpolator is typically reproduced somewhere on the polyconic chart, as illustrated in Figure 3-6. (Because its use is so specialized, the interpolator is not discussed in this text.) Incidentally, bar charts

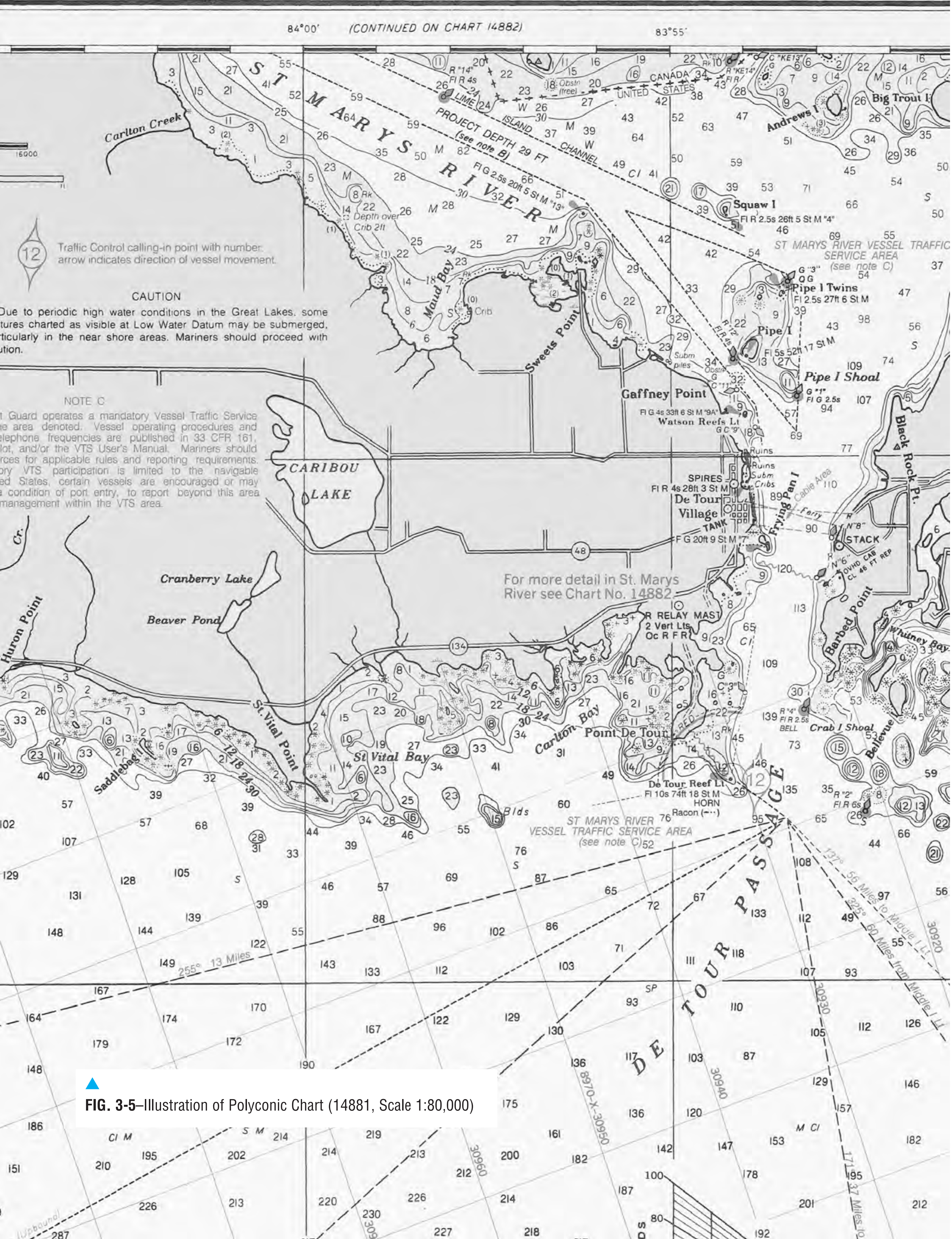

FIG. 3-5–Illustration of Polyconic Chart (14881, Scale 1:80,000)

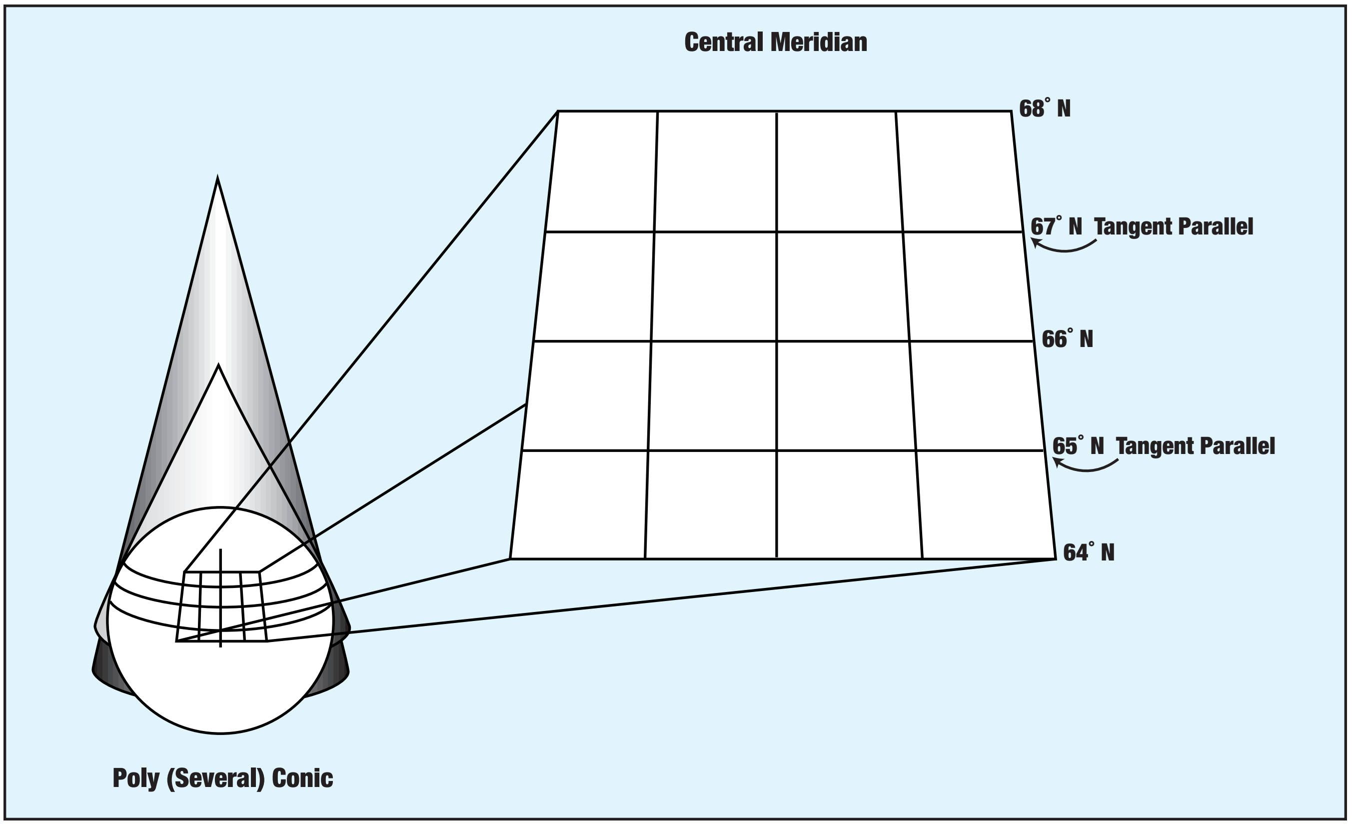

FIG. 3-4–The Polyconic Projection

for measurement of distance (in feet, yards, meters, and statute miles) are also shown in Figure 3-6.

DISTANCE ON POLYCONIC CHARTS FOR THE GREAT LAKES REGION

Distance on Great Lakes charts are indicated in *statute miles* (mi.) and not in nautical miles (M). Large-scale Great Lakes charts may also indicate distances in meters (m), yards (yd.), and feet (ft.). Bar graphs are provided for measuring distances as shown in Figure 3-6.

DIRECTION ON POLYCONIC CHARTS FOR THE GREAT LAKES REGION

Although the polyconic projection is not conformal, for the chart scales used by the small craft operator, any lack of conformality is practically unmeasurable. Compass roses are provided on charts of the Great Lakes, and the nearest rose should be used when measuring true and magnetic directions. Also, variation changes about one degree for every change of about a degree in longitude. Thus, for long east-west trips, corrections of magnetic and compass courses should be made about every 40 statute miles. When the distance over which the direction is to be measured is very long, and is in a predominately east-west direction, measure the course line angle at the charted meridian nearest the halfway point of the line between the two points of interest. Figure 3-7 summarizes the key differences between the Mercator and polyconic projections.

CHART SCALES

Since a chart is a representation of the physical and geographical nautical features of the earth's surface on a plain piece of paper, it is important to be able to relate distance on the earth's surface to distance shown on the chart. The term for this earth-to-chart distance relationship is scale. Scale is nothing more than the number of distance units on the earth's surface represented by the same distance unit on the chart. The unit may be inches, using the English (or American) system of units, or meters, if using the metric system, or any other units for that matter.

The scale on the nautical chart is expressed as a ratio of the units,

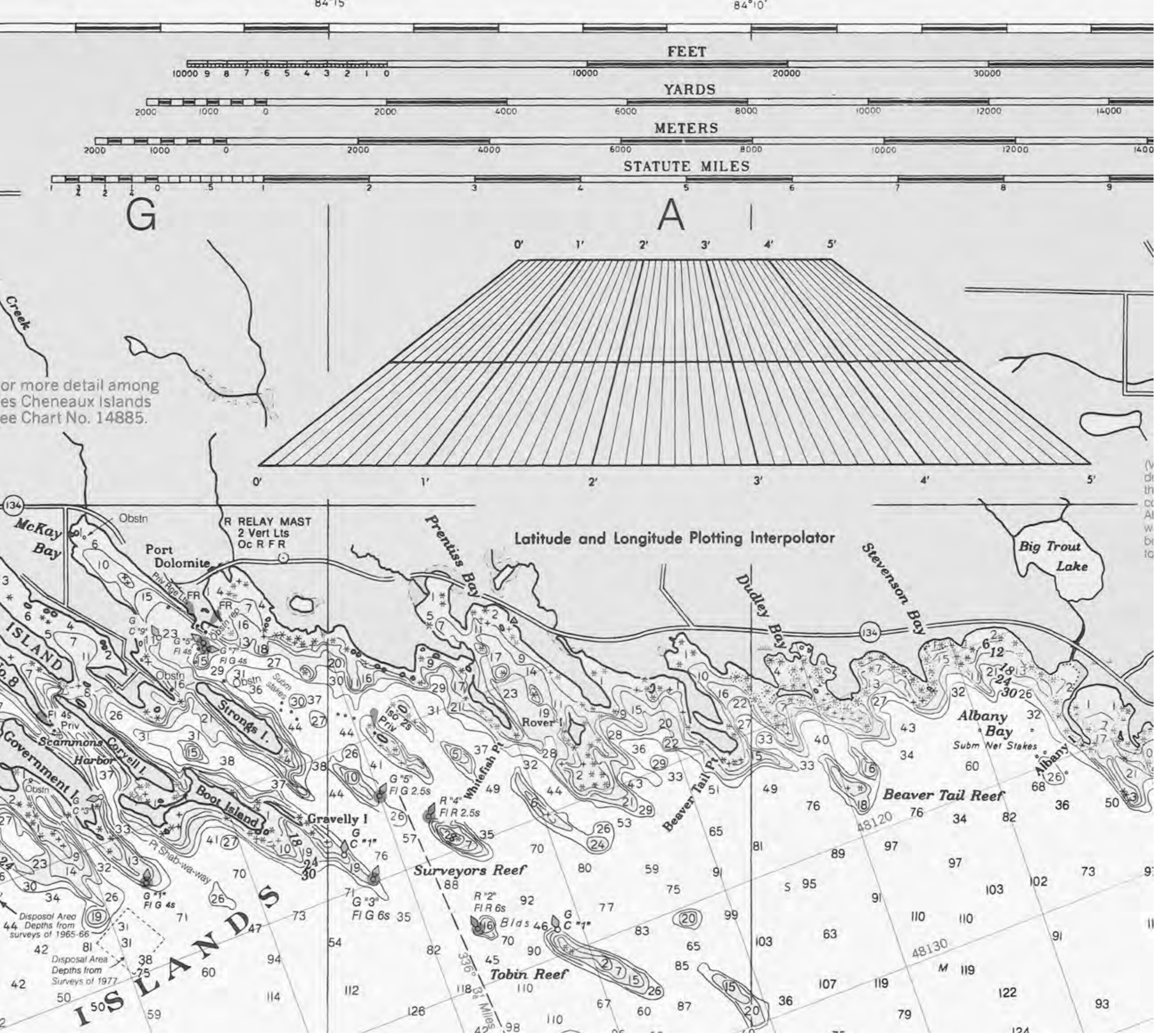

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FIG. 3-6–Plotting Interpolator included in Polyconic Chart.

such as 1 inch on the chart is equivalent to 2,500 inches on the earth's surface, written 1:2,500. There are several scales in use, depending on the area being charted and the detail to be included.

The relative size of the scale (large- or small-scale) is determined by the relative size of the ratio expressed as a fraction. The larger the value of the fraction, the larger the scale. A scale of 1:2,500 (expressed as a fraction, 1/2,500) has a much larger value than the scale of 1:5,000,000 where the fraction has a value of 1/5,000,000. Thus, a chart with a scale of 1:2,500 would be considered a *large-scale chart,* and a chart with a scale of 1:5,000,000 would be considered a small-scale chart. A large-scale chart covers a small area. A *small-scale chart* covers a large area. Put another way, a large-scale chart shows a large amount of detail, a small-scale chart contains a small amount of detail. *Always use the largest scale chart available for navigation to show the maximum detail*.

ATTRIBUTE	MERCATOR	POLYCONIC (Great Lakes)
Conformal	Yes	No
Distance scale	Variable, given in nautical miles (measure at mid-latitude)	Nearly constant, given in statute miles
Angle between parallels and meridians	90°	90°
Appearance of parallels	Parallel straight lines, unequally spaced	Arcs of nearly concentric circles nearly equally spaced*
Appearance of meridians	Parallel straight lines, equally spaced	Straight lines converging at pole
Straight line crosses meridians	Constant angle (rhumb line)	Variable angle (approximate straight line)
Great circle	Curved line (except at equator meridians)	Approximated by straight line
Rhumb line	Straight line	Curved line
Distortion of shapes and areas	Increases away from equator	Very little
Illustrative uses	Large-scale, coastal, and pilot charts	Great Lakes
How direction measured	Reference to any meridian, parallel, or compass rose	Direction at any point should be measured by reference to the meridian passing through that point or compass rose.

**Parallels are equally spaced only along the central meridian of the chart and are not concentric, but become farther apart toward the edges of the chart. However, these differences are not noticeable on large-scale charts.*

FIG. 3-7–Mercator and Polyconic Charts Contrasted

TYPES OF MARINE CHARTS

There are several types of marine charts. These are differentiated by their scale and their intended use. These types and their principal uses (refer to Figure 3-8) are:

- ❑ **SAILING CHARTS.** Scales of 1:600,000 and smaller. Used in navigation offshore, outside of coastal areas, or for sailing between distant coastal ports. The shoreline and topography are generalized. Offshore soundings, principal lights, outer buoys, and landmarks visible at considerable distances are shown. Detail needed for close-in navigation is lacking. Charts of this series are useful for plotting the track of major tropical storms, and/ or long voyages.
- ❑ **GENERAL CHARTS.** Scales between 1:150,000 and 1:600,000. Used for offshore, but within coastal zones of navigation outside of outlying reefs and shoals when the vessel is generally within sight of land or aids to navigation and its course can be directed by coastal piloting techniques.
- ❑ **COAST CHARTS.** Scales between 1:40,000 and 1:150,000. Used for inshore navigation of bays and harbors of considerable width and for large inland waterways and coastal passages. The 1210-Tr chart, for example, is a coast chart.
- ❑ **HARBOR CHARTS.** Scales larger than 1:40,000. Used in navigating harbors, anchorage areas, and small waterways. These charts show considerable detail, even to individual piers and slips.
- ❑ **SMALL CRAFT CHARTS.** Scales of 1:40,000 and larger (although some are at smaller scales). These are special composite type charts of inland waters, including the intracoastal waterways. The Mercator projection is used on these charts, but it may be skewed—north does not necessarily appear at the top—to fit the expanse of water on to the chart. A river, for example, would run lengthwise on the chart, and north could be toward the side. Small craft charts are printed on lighter weight paper and folded rather than rolled. These charts contain additional

PHOTO COURTESY OF NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION

Nautical Chart Catalogs

information of interest to small craft operators, such as data on marinas, tide predictions, and weather broadcast information. They are designed for use in open boats and runabouts.

It is noted above that you should use the largest scale chart available for navigation. Figure 3-9 illustrates this point by comparing Point Judith harbor of refuge as shown on the 1210-Tr chart (scale 1:80,000) with a harbor chart (scale 1:15,000) of the same area. Which of these would you wish to have aboard if headed for Point Judith? The harbor chart shows much more detail in the harbor of refuge area and in Point Judith Pond as well.

Soundings, discussed below, land details, and even individual houses can be seen on the harbor chart. In contrast, the coast chart provides only limited detail. Even the entrances to the harbor of refuge are difficult to see clearly on the coast chart.

WHAT CHARTS ARE AVAILABLE?

Nautical charts of U. S. waters are available from authorized *National Oceanic and Atmospheric Administration* (NOAA), *National Ocean Service* (NOS), and Coast Survey sales agents. The names and addresses of these agents are given in a *Nautical Chart Catalog* issued in several short volumes (charts themselves, really) that cover the entire United States. Volume 1, for example, is titled *"Atlantic and Gulf Coasts, including Puerto Rico and the Virgin Islands." Nautical Chart Catalogs* are available free of charge from the Coast Survey.

IMPORTANCE OF UP-TO-DATE CHARTS

The date of a chart is of vital importance to the navigator. When information becomes obsolete, further use of the chart for navigation may be dangerous. Natural and artificial changes, many of them critical, are occurring constantly, and it is important that navigators obtain up-to-date charts at regular intervals and hand correct their copies for changes published in the Notice to Mariners.

Charts are revised at regular intervals. Users should consult the pamphlet, Dates of Latest Editions, for the dates of current chart editions. This pamphlet is issued quarterly and available free from the Distribution Division (N/ACC3), National Ocean Service, Riverdale, MD, 20737-1199.

Other relevant information is provided for those with Internet access at NOAA's web site **(www.noaa.gov).** ***Notice to Mariners information can be found on the National Imagery and Mapping Agency (NIMA's) web site*** **(www.nima.gov).**

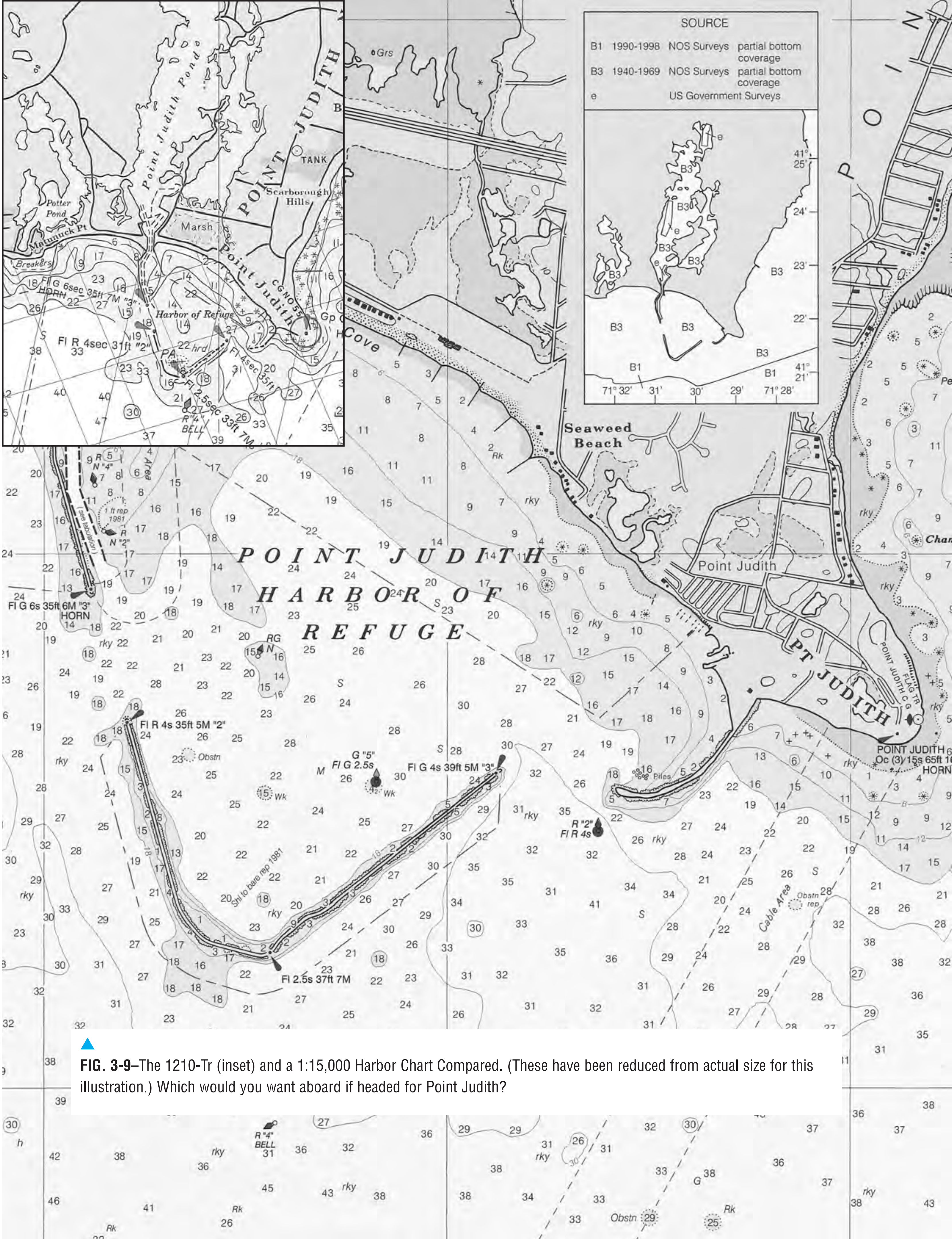

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FIG. 3-9–The 1210-Tr (inset) and a 1:15,000 Harbor Chart Compared. (These have been reduced from actual size for this illustration.) Which would you want aboard if headed for Point Judith?

These same chart catalogs list all the available charts and provide information on the chart scale, chart number, and price. For example, the area covered by the 1210-Tr chart (a special-purpose training chart) is actually covered by a coastal Chart Number 13218, at a scale of 1:80,000. (Portions of this area are also covered by sailing and general charts, as well as harbor charts.) Many marinas have copies of the chart catalog available, and it is a good idea to pick one of these up on your next visit. The NOAA web site provides information available from the *Nautical Chart Catalog*. This system (http://anchor.ncd.noaa.gov/noaa/noaa.html) is particularly easy to use. A small-scale map is displayed and, by clicking on the desired portion of the map, the image is "zoomed" until the rectangular outlines of available charts are shown. When an "identify" button is pressed, the desired chart name, number, scale, and latest edition and print date are displayed.

Several commercial firms produce nautical charts—actually reproduce Coast Survey charts. Some products are sold in chart books, containing portions of many charts. These may be convenient for the mariner. However, these charts are not supported by the Coast Survey and are not easy to update with information from the *Notice to Mariners* or the *Local Notice to Mariners*.

SOUNDINGS AND BOTTOM CHARACTERISTICS

Two of the most important types of information presented on a nautical chart are the depth of water and the bottom characteristics. This information is depicted by the use of a combination of numbers, underwater contour lines, color codes, and a system of standardized symbols and abbreviations.

The soundings (depth of water) on the chart represent the water depth as measured or estimated from a specified vertical datum. The vertical datum (not to be confused with horizontal datum) refers to the base line or plane from which

EQUIVALENTS TO CHART NUMBER 1

Most nations that produce nautical charts issue a chart that corresponds to Chart Number 1. For example, the Canadian Hydrographic Service issues Chart 1, Symbols, Abbreviations, and Terms and in the United Kingdom, the Hydrographic Office issues Chart 5011, Symbols and Abbreviations used on Admiralty Charts. Although chart symbols have been standardized to a large degree, mariners who use charts published by other governments should carry a copy of the analog to Chart Number 1.

SCALE OR REPRESENTATIVE FRACTION	1 INCH EQUALS APPROXIMATELY NAUTICAL MILES	STATUTE MILES	CHART CLASSIFICATION	
1:2,500 1:10,000 1:20,000	0.03 0.14 0.27	0.04 0.16 0.32	Harbor	Small Craft
1:40,000 1:80,000	0.55 1.10	0.63 1.26	Coast	
1:150,000 1:300,000	2.06 4.11	2.37 4.73	General	
1:600,000 1:1,500,000 1:14,000,000	8.23 20.57 192.01	9.47 23.67 220.96	Sailing	

FIG. 3-8–Chart Scales and Classification

a chart's depth measurements are made. Historically, different datum levels were used for charts of the East and West Coast. On the East Coast, the tidal datum was *mean low water* (MLW)—the average low tide over a long period. The tidal cycle on the East Coast generally produces approximately two low tides daily. But, these two low tides are of approximately equal height—and the chart datum, therefore, was MLW. On the West Coast, and at some other locations, the two low tides are generally of unequal depth, and the average of the lower of the two, designated mean lower low water (MLLW), was used for datum. However, this convention is being changed so that datum in either case will be MLLW in future editions of U. S. charts. (This datum change is only a matter of definition and will not, in and of itself, affect any of the charted depths on the East Coast. In any event, the specific datum selected will be noted on the nautical chart.)

The purpose of using a "low water datum" is to produce reasonable, yet "conservative," depth information for the chart. That is, the actual depth of water will typically be greater than the charted depth. But it is important to remember that average values are used in determining the chart datum. At any given time (see Chapter 8) in any location, the actual water depth may be lower or higher than the chart datum. So, although this depth convention is arguably conservative, the mariner is not relieved of the responsibility of considering the actual height of tide at the time of interest.

Contour lines connect points of equal depth and profile the bottom shape. These lines are either numbered or coded according to depth, using particular combinations of dots and dashes. Figure 3-10, for example, reproduces an illustration from *Chart Number 1 (Nautical Chart Symbols and Abbreviations, Tenth Edition,* November 1997, see the attached references), that shows some of the standardized symbols and conventions for soundings and depth information. Every mariner should have a copy of *Chart Number 1* for ready reference. The panels of this chart are also reproduced on the back of the 1210-Tr chart for instructional purposes. However, *Chart Number 1* is more convenient to have on your boat.

Charted depths of water may be given in feet, fathoms (1 fathom equals 6 feet), or, increasingly, in meters (1 meter equals approximately 3.3 feet). New charts will typically contain metric units. The chart legend, discussed below, informs the user of the depth units. In some cases, more than one set of units may be found on the same chart, so close inspection is necessary to interpret correctly the depth information given. Different colors or tints are used to convey depth information; refer to *Chart Number 1* for details.

Dredged channels are shown on the nautical chart by two dashed lines to represent the approximate horizontal limits of dredging. The controlling depth of the channel and date of measurement are shown on the chart near the lines enclosing the channel or in a separate data block on the chart. Figure 3-11, for example, shows a portion of the 1210-Tr chart depicting the Cape Cod channel and the accompanying data block that provides information on channel depths.

The nautical chart also provides information on the nature and "quality" of the bottom. Figure 3-10 also shows a selection of some of the many abbreviations (e.g., "rky," "S," "S/M," "M") that are used to describe the quality of the bottom. This information is useful in deciding where to anchor and which anchor to use in an unfamiliar harbor. For example, a "rky" (rocky) bottom generally presents difficulties in anchoring or removing the anchor, and a sandy bottom may present poor holding conditions, whereas clay ("Cy" or "Cl") is typically the best holding bottom.

Finally, the style of the lettering provides some additional depth-related information. Vertical lettering is used to represent features that are dry at mean high water, whereas leaning or slanting letters are used for water and underwater features that cover and uncover with tidal action.

HEIGHTS

Clearances of bridges and heights of landmarks are given in height above *mean high water* (MHW). This convention is analogous to using mean lower low water for soundings—the intent is to produce a "conservative" number in that the actual clearance is likely to be greater than the charted clearance. For example, a bridge height might be shown as 30 ft., but the mean tidal range might be 8 ft. (see Chapter 8), so the bridge height could range (on average) from 30 ft. to 38 ft. from the surface of the water. This could be of substantial

I Depths

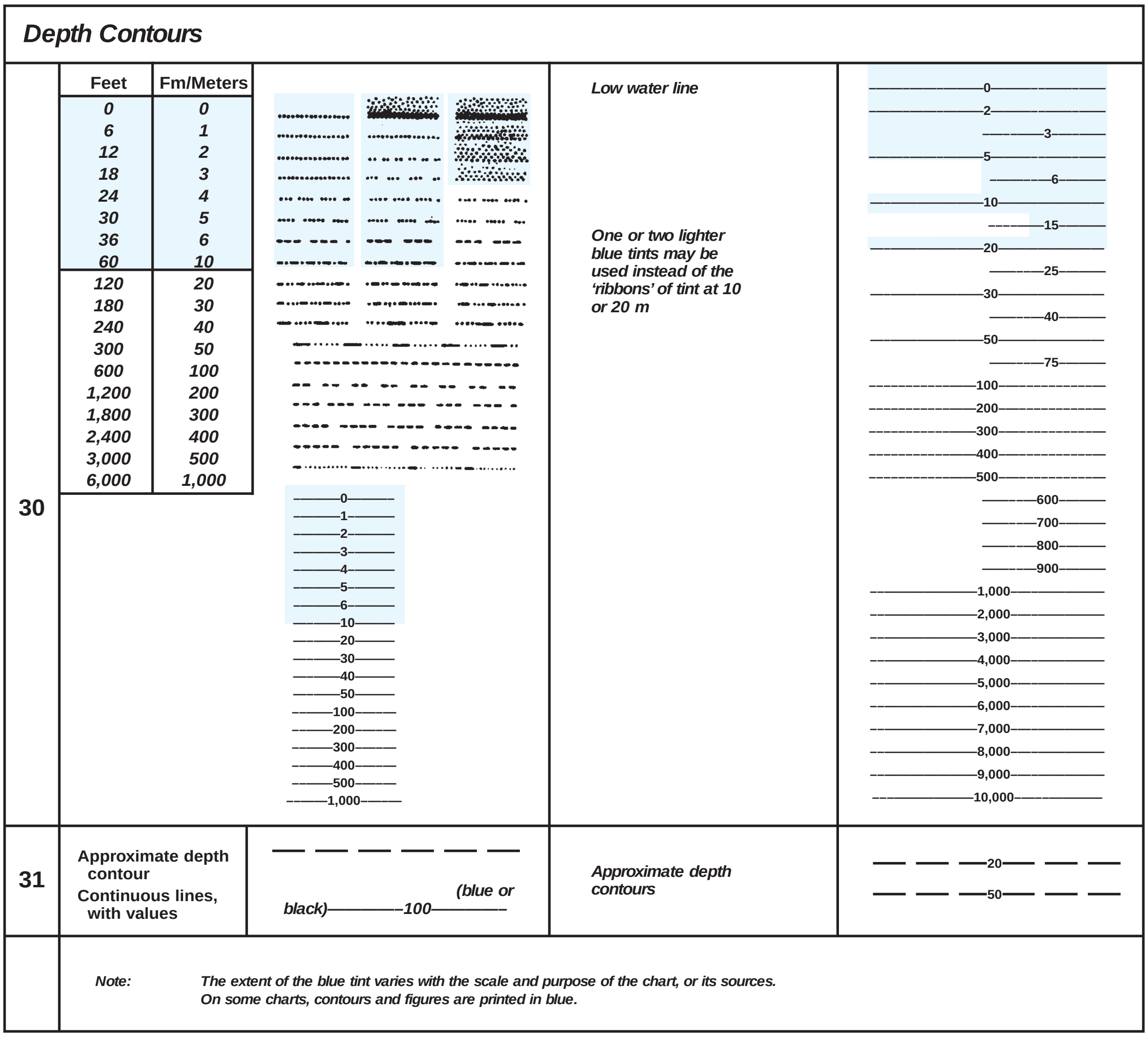


FIG. 3-10–Soundings and Bottom Characteristics

interest to the skipper of a sailboat with a 34-ft. mast. Once again, however, averages are used. On occasion, the tidal height may be higher than mean high water, so this convention does not excuse the mariner from consulting the appropriate references (see Chapter 8) to determine the actual clearance.

BASIC CHART INFORMATION

Essential Information

Essential chart information is contained in a number of places on a nautical chart. These are described below.

General Information Block (illustrated in Figure 3-12) contains the following items:

- ❏ The chart title, which is usually the name of the prominent navigable body of water within the area covered in the chart.
- ❏ A statement of the type of projection and the scale.
- ❏ The unit of depth measurement (feet, fathoms, or meters) and datum plane.

Notes: All notes should be read

J Nature of the Seabed

Types of Seabed			
Rocks → K			Supplementary national abbreviations: a – ag
1	S	Sand	S
2	M	Mud	M
3	Cy; Cl	Clay	Cy
4	Si	Silt	Si
5	St	Stones	St
6	G	Gravel	G
7	P	Pebbles	P
8	Cb	Cobbles	Cb
9	Rk; rky	Rock; Rocky	R
10	Co	Coral and Coralline algae	Co
11	Sh	Shells	Sh
12	S/M	Two layers, eg. Sand over mud	S/M
13.1	Wd	Weed (including Kelp)	Wd
13.2	Kelp	Kelp, Seaweed	
14	Sandwaves	Mobile bottom (sand waves)	
15	Spring	Freshwater springs in seabed	

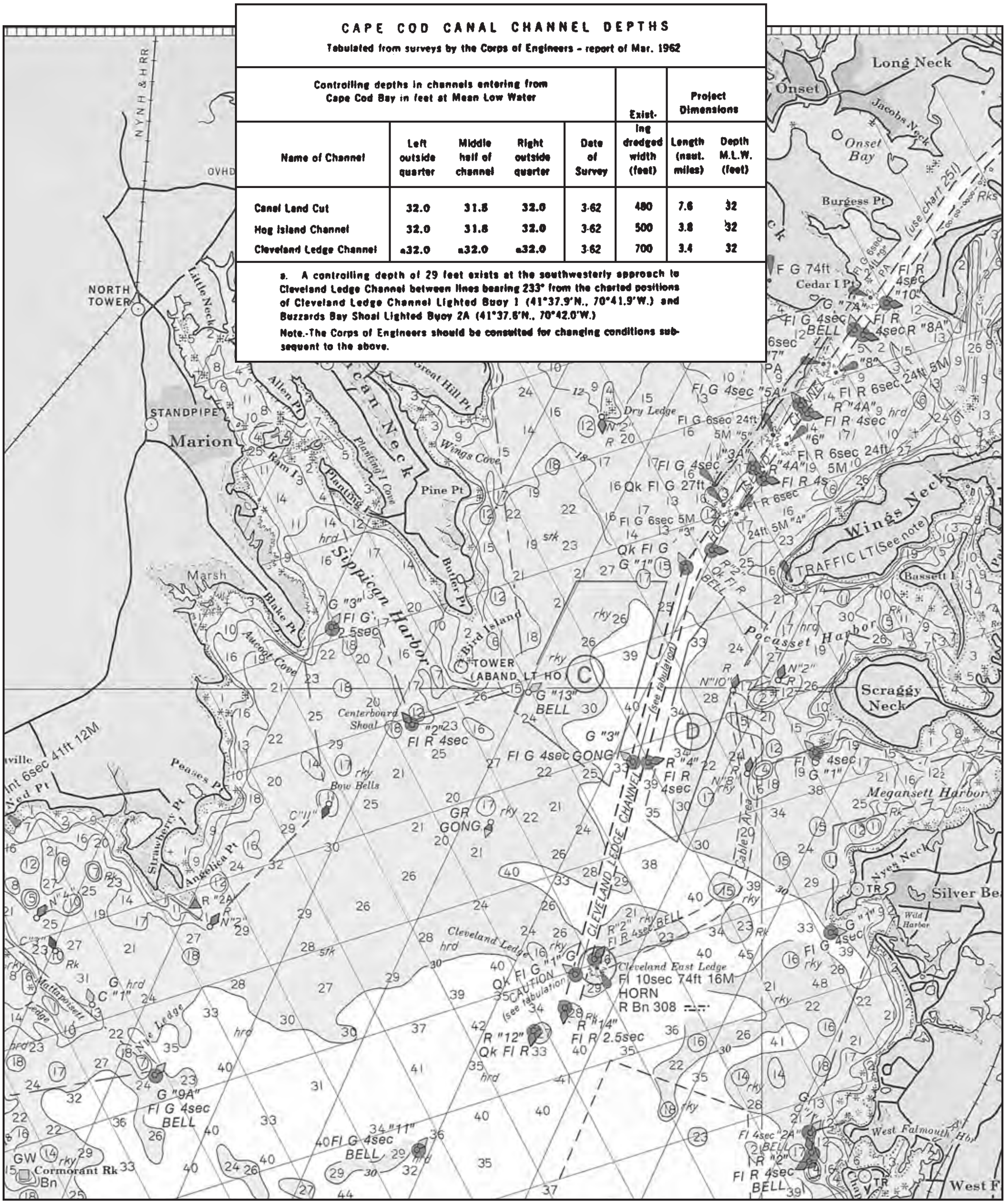
FIG. 3-10 (cont'd.)–Soundings and Bottom Characteristics

carefully because they contain information that cannot be presented graphically such as:

- ❏ The meaning of special abbreviations used on the chart.
- ❏ Special notes of caution regarding danger areas, prohibited areas, dumping areas, safety areas, firing areas, vessel traffic zones, etc.
- ❏ Tidal information.
- ❏ Reference to anchorage areas.

Edition Number. The edition and/or revision numbers of the chart provide information on how recently the chart was prepared.

- ❏ The edition number and date of the chart are located in the margin of the lower left-hand corner.
- ❏ In addition, handwritten notations may be placed on a chart incorporating corrections occurring after the date of issue, which were published in the *Notice to Mariners* (NM) or *Local Notice to Mariners* (LNM). Corrections occurring after the date of issue and published in this manner must be entered by hand on the



CAPE COD CANAL CHANNEL DEPTHS

Tabulated from surveys by the Corps of Engineers – report of Mar. 1962

Name of Channel	Controlling depths in channels entering from Cape Cod Bay in feet at Mean Low Water: Left outside quarter	Middle half of channel	Right outside quarter	Date of Survey	Existing dredged width (feet)	Project Dimensions: Length (naut. miles)	Depth M.L.W. (feet)
Canal Land Cut	32.0	31.8	32.0	3-62	480	7.6	32
Hog Island Channel	32.0	31.8	32.0	3-62	500	3.8	32
Cleveland Ledge Channel	a32.0	a32.0	a32.0	3-62	700	3.4	32

a. A controlling depth of 29 feet exists at the southwesterly approach to Cleveland Ledge Channel between lines bearing 233° from the charted positions of Cleveland Ledge Channel Lighted Buoy 1 (41°37.9'N., 70°41.9'W.) and Buzzards Bay Shoal Lighted Buoy 2A (41°37.6'N., 70°42.0'W.)

Note.-The Corps of Engineers should be consulted for changing conditions subsequent to the above.

▲

FIG. 3-11–The Cape Cod Channel as Shown on the 1210-Tr Chart

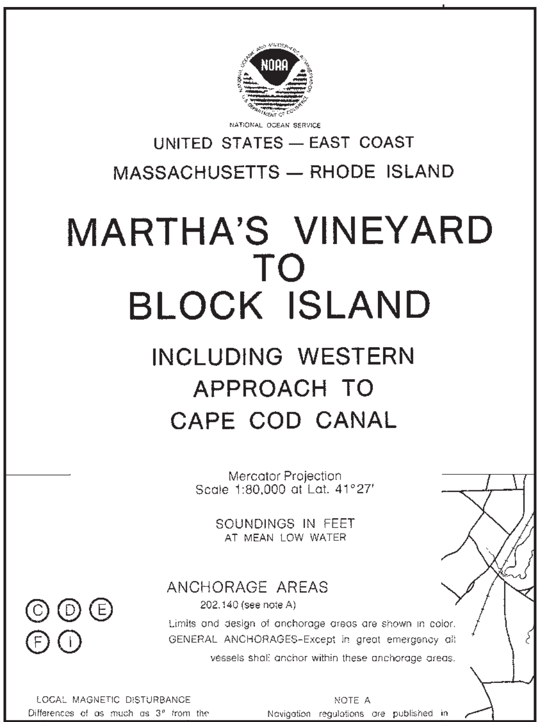


FIG. 3-12–General Information Block of 1210-Tr Chart

chart. This is the chart owner's responsibility. Note: no matter how recent a chart is, between the time of the survey and the time of printing and distribution, it is likely that some changes or updating needs to be made to ensure its accuracy.

Title notes also contain the *horizontal datum* used for the chart—this defines the horizontal coordinate system used for the chart. This information is very important to users of radionavigation systems such as GPS. The navigator should note the horizontal datum used for the chart (e.g., *North American Datum* of 1983 [NAD83]) and ensure that the GPS receiver is adjusted so that it presents positions based on this same datum—otherwise, material errors may occur.

Charts of the world's waters prepared by the *National Imagery and Mapping Agency* (NIMA) are being converted to the *World Geodetic System* 1984 (WGS 84) datum, which is equivalent to NAD 83.

CHART TERMS HAVE VERY SPECIFIC MEANINGS

Just a glance over a nautical chart will show that a very specialized vocabulary is used in connection with the chart symbols. For example, several terms are used to describe various landmarks, such as towers or similar structures on the island of Martha's Vineyard (refer to the 1210-Tr chart). There are radar towers, lookout towers, and spires. Just north, on the Elizabeth Islands and nearby mainland Massachusetts, can be found monuments, water towers, houses, cupolas, standpipes, stacks, tanks, and more lookout towers. Each term has a unique and specialized meaning. Although the differences among many of these terms are obvious, there are subtleties and specialized "terms of art" that are used. Figure 3-13, for example, shows a sampling of terms and associated definitions for man-made landmarks as used in the construction of nautical charts. (A more complete list can be found in Bowditch and other references given at the end of this chapter.) Compare, for example, the differences among the terms spire, cupola, and dome. All are found atop buildings, but each is recognizably

WHY CHARTED OBJECTS MAY BE MISSED

There are several reasons why objects shown on the chart may not be seen by the navigator. These include:

- ***The object may no longer be there. This can occur if buildings or other structures are demolished or moved and the chart has not yet been corrected.***
- ***The navigator may be looking in the wrong place.***
- ***Terrain or foliage may mask the object from a particular viewpoint.***
- ***The prevailing meteorological visibility may be too poor to see the object. This is often a problem with radio towers, power lines, or other objects that do not have a large visual cross section.***
- ***The navigator may not understand what to look for—his/her "mental template" may be wrong.***
- ***The navigator may not have read the chart correctly. For example, a stack may be charted (e.g., "tallest of 5") and the navigator is looking for a single isolated stack.***

Building or House—One of these terms, as appropriate, is used when the entire structure is a landmark, rather than an individual feature of it.

Spire—A slender pointed structure extending above a building. It is seldom less than two-thirds of the entire height of the structure, and its lines are rarely broken by stages or other features. The term is not applied to a short pyramid-shaped structure rising from a tower or belfry.

Cupola—A small dome-shaped tower or turret rising from a building.

Dome—A large, rounded, hemispherical structure rising above a building or a roof of the same shape.

Chimney—A relatively small, upright structure projecting above a building for the conveyance of smoke.

Stack—A tall smokestack or chimney. The term is used when the stack is more prominent as a landmark than accompanying buildings.

Flagpole—A single staff from which flags are displayed. The term is used when the pole is not attached to a building.

Flagstaff—A flagpole rising from a building.

Flag tower—A scaffold-like tower from which flags are displayed.

Radio tower—A tall pole or structure for elevating radio antennas.

Radio mast—A relatively short pole or slender structure for elevating radio antennas, usually found in groups.

Tower—A structure with its base on the ground and high in proportion to its base, or that part of a structure higher than the rest, but having essentially vertical sides for the greater part of its height.

Lookout station (watchtower)—A tower surmounted by a small house from which watch is kept regularly.

Water tower—A structure enclosing a tank or standpipe so that the presence of the tank or standpipe may not be apparent.

Standpipe—A tall cylindrical structure, in a waterworks system, the height of which is several times the diameter.

Tank—A water tank elevated high above the ground by a tall skeletal framework. The expression gas tank or oil tank is used for the distinctive structures described by these words.

SOURCE: Bowditch, N. *American Practical Navigator, An Epitome of Navigation,* Defense Mapping Agency, Bethesda, MD, 1995.

FIG. 3-13–Illustrated Definitions for Charted Landmarks

different. It is worth the time required to study the meaning of such specialized terms and to compare what is shown on the chart to what can be seen from a vessel. Experienced mariners have a mental picture of each of the items defined in Figure 3-13, which enables them to locate landmarks quickly from the chart descriptions.

There are numerous specialized conventions employed in the construction of charts to convey precise meanings. Continuing with landmarks as an example, a large circle with a dot at its center is the symbol used to denote selected landmarks that have been accurately located. Capital letters are used to identify the landmark, e.g., MONUMENT, CUP (or CUPOLA), DOME. However, a small circle, without a dot, is used for landmarks not accurately located. These are denoted by capital and lowercase letters, e.g., Mon, Cup, Dome. (In some cases, the letters PA, denoting position approximate, is also used to minimize ambiguity.) In other cases, only one object of a group is charted. This is denoted by a descriptive legend in parentheses, including the number of objects in the group, e.g., (TALLEST OF FOUR). The prudent mariner soon learns to use only accurately located landmarks to determine LOPs or fixes (see Chapter 6). Landmarks that are not accurately located can be used for recognition purposes and to form the visual context for identifying other accurately known landmarks for LOPs. For example, a MONUMENT might be located between a Cupola and a Dome. Observation of these latter objects could serve to identify the MONUMENT, which would be used for determination of an LOP.

These specialized definitions and conventions are used to save space and convey a wealth of information on the nautical chart. But, all this efficiency is to little avail if the mariner doesn't take the time to learn these definitions.

PRACTICAL POINTERS ON FINDING YOUR POSITION BY REFERENCE TO THE NAUTICAL CHART

The detail presented on the modern nautical chart is designed to facilitate piloting by reference to charted objects. Examination of the 1210-Tr chart shows a sample of the myriad of charted objects. But it requires substantial practice before mariners can rapidly and reliably orient themselves from a comparison of visual observations with what is depicted on the nautical chart. In principle, the process is easy. The mariner should have at least an approximate idea of the vessel's position. Plotting a fix (discussed in Chapter 6) is simply a matter of selecting two or more prominent objects shown on the chart, locating these visually, determining their bearings using a compass (either the vessel's main compass or a handheld compass), and plotting the bearings on the chart. The vessel's position is fixed at the point (or in the area) where these two (or more) bearings intersect. However, things are not always as simple as they seem. Visual detection and identification of charted objects often presents a challenge to the mariner. Some practical tips on this topic are offered here. Additional material can be found scattered throughout this text. The reader may wish to consult the interesting book by Eyges (1989) listed among the references for additional insights.

OBJECT DETECTION

To use charted landmarks for position determination it is generally necessary to detect (see) and identify (recognize) these objects. Object detectability is a complex function of size, shape, color, lighting, obstructions (masking), and other factors. A complete discussion of this topic is well beyond the scope of this course. However, some practical aspects are noteworthy.

An object generally needs to be visible to be detected (see below for some important exceptions.) Although this point may seem obvious, the implications are more subtle. The mere fact that an object is charted does not imply that it is visible from all distances, at all aspects, and at all times. For example, objects can be masked (blocked) by other objects, terrain, foliage, or simply the curvature of the earth. If the height of the object is given (as it is for most lights and selected other objects), calculation of the maximum distance at which it can be seen is relatively straightforward, as discussed in Chapter 6 (in general) and Chapter 10 (for lights in particular). If the observer is beyond this distance, the object cannot be seen. Terrain, foliage, meteorological visibility, and other factors also affect target detectability. Not all of these factors can be determined by inspection of the chart. In some cases, elevation contours are shown for terrain, and the mariner can make an approximate determination whether or not an object is likely to be visible. But, often these contours are not shown and/or the height of the object is not given. In these cases, the mariner cannot determine whether or not an object is visible. The fact that an object is charted generally means that it can be seen from some useful distance, and/or from some aspects, but it does not mean that the object can be seen from all aspects and from all distances. Refer to the 1210-Tr chart, for example, and look at Nashawena Island. Two objects are charted on this island, a monument and a house. No height is given for either object and no elevation contours are given for the island, so it is not possible to determine from the chart alone whether or not (and from what angle) either of these objects would be visible. As a matter of fact, the house on the island cannot be seen from a position to the southwest, and the monument is quite difficult to see at all, except at close range.

Objects may be masked (hidden from view) by trees or foliage as well as terrain or the earth's curva-

PHOTO COURTESY OF UNITED STATES COAST GUARD

The light is partially obscured by terrain and vegetation masking when viewed from this angle.


PHOTO COURTESY OF UNITED STATES COAST GUARD

"Home at last." Both the breakwater and the light will be shown on the chart. However, breakwaters are often not seen at great distances due to the curvature of the earth and the limited height of most breakwaters.

ture. Here again, the unwary navigator may have difficulty reconciling the observed scene with the chart. In the case of tree masking, many trees lose their leaves in the winter, and an object may be readily visible, but not so in the summer when the leaves shield the object. The color of the object and the lighting conditions also affects visibility. Objects that are backlighted or in shadow have a different visual appearance than when under other lighting conditions. This effect can be quite dramatic in some cases.

The size of the object is important for two reasons. First, objects can be masked by the earth's curvature (see Chapter 6). The maximum range that a 5-ft. buoy could be seen if the observer's height of eye were 10 ft. (based upon horizon distance calculations shown in Table 6-2) is 6.3 nautical miles. Beyond this distance, the buoy will be masked by the horizon. And, indeed, at night (depending upon the visibility and intensity of the light) the light on the buoy might be seen at this distance. During the daylight hours, however, the maximum distance that the buoy could be seen (at least with the unaided eye) is probably much less, say 1/2 to 1 nautical mile, give or take. So, the second reason why object height is important relates to the resolving power of the eye.

Object height, incidentally, is the chief reason why a harbor breakwater is often a poor reference mark in coastal navigation despite its relatively massive appearance on the nautical chart. Particularly at high tide, a breakwater may only be seen when quite close to the harbor entrance. Trainees in the *United States Coast Guard Auxiliary* (USCGAUX) boat crew program often waste time trying to spot harbor entrances by looking for breakwaters, and overlook otherwise conspicuous targets that could be used for position fixing.

Another important reason why a charted object may not be able to be observed is that it is no longer there! Charted structures may be demolished and/or removed. In due course, these changes are reported and chart corrections listed in the NM/LNM (see Chapter 10) and made in subsequent editions of the chart. However, either process is not instantaneous and there will be some time period when the chart does not exactly match reality. For example, look at Cuttyhunk Island on the 1210-Tr chart. A lookout tower is charted very near the "k" in "Cuttyhunk." This structure was there when the 1210-Tr chart was reissued. However, on the current chart of the 1210-Tr waters (Chart 13218) this structure is no longer shown. Instead, a tank is shown at approximately the same location.

Students often ask why roads are shown on the nautical chart. They reason that a road is most unlikely to be seen and, therefore, is a useless addition to the chart. In fact, roads can be useful to depict because, although the road itself may well be invisible, vehicles can often be seen. This is particularly true at night, when headlights or taillights are conspicuous.

IDENTIFICATION/ RECOGNITION

As noted, an object needs to be identified (recognized) as well as detected. Identification is almost as complex a subject as detection, but it is possible to provide some practical pointers.

- ❑ First, take the time to study the various object definitions and abbreviations to be found in *Chart Number 1* and related publications. As noted elsewhere in this chapter, the terms used often have very specific meanings, which are useful for recognition purposes. One day it may be very important for you to know the difference between a standpipe and a gas tank. Nonetheless, as precise as the cartographers attempt to be, some of the terms admit to various interpretations, and even diligent study of the definitions may be insufficient to solve all recognition problems. For example, consider the term "abandoned light house." This term is used in the technical sense to denote a lighthouse that is no longer functioning in that capacity. But, what does it look like? Aside from the fact that working lighthouses often differ considerably in appearance, abandoned lighthouses vary even more depending upon condition. In the Delaware Bay, for example, there is an abandoned lighthouse that is little more than a foundation. (The word "ruins" shown on the Delaware Bay chart might alert us to this, but also admits to various interpretations. The "ruins" of the temples of the sun and moon near Mexico City are massive structures that can be seen for miles!) Not all light structures are in the same state of collapse. The abandoned lighthouse off Sakonnet Point, shown as "Tower, Abandoned Lighthouse" on the 1210-Tr chart, is fully restored and (during daylight hours) looks just like an operating lighthouse. It takes time, experience, and local knowledge to become expert in identifying charted features. Descriptions of selected features (sometimes including photographs) can be found in the *United States Coast Pilot* (USCP) and many commercially published cruising guides. The USCP is discussed in more detail in Chapter 10.

❑ Second, it is useful to note that object identification is generally easier if the object is considered as part of an entire scene, rather than in isolation. For example, a tank located next to other prominent objects is often more easily recognized and identified than a lone tank. Nonetheless, the alert observer should anticipate the possibility that some of the surrounding objects shown on the chart may be hidden or difficult to recognize. The observer's "mental image template" may not match exactly the chart appearance. Incidentally, visibility plays a part in object identification as well as detection. If the visibility is poor, perhaps only one or two prominent objects may be visible and it may be difficult to locate oneself. Alternatively, if the visibility is greater, many objects may be visible and orientation much simpler.

❑ Third, notwithstanding the fact that objects generally need to be visible in order to be detected and identified, there are a few noteworthy counterexamples to this "obvious" truth. For example, in many locations of the world, large powerplants (typically shown on nautical charts if located near the shore) can be found. The steam exhaust from the cooling towers of these plants is often visible at a much greater range than the cooling tower itself. Although the steam cloud may not enable precise position fixing, it can assist in orientation. Airports serve as another example of an object generally shown on nautical charts that may not be directly visible. Although the control tower or the hangers may not be able to be seen from the bridge of a sport fisherman, aircraft descending to land can be observed. Just remember that the prevailing approach paths of aircraft may depend upon the wind direction, so some caution needs to be exercised.

❑ Fourth, it is often easier to recognize objects and determine your position if you are reasonably sure of it to begin with. This may sound foolish or, at best, obvious, but this is not a trivial statement. If you keep a good dead reckoning plot (Chapter 5) and take frequent position fixes (Chapter 6), you have a good (though approximate) idea of your position at all times. When you decide to fix the vessel's position again, it is not necessary to go hunting all over the chart to find the charted location of the two towers visible off the port beam! Sometimes, knowledge of your approximate position enables you to make a plausible identification of an object that cannot be identified directly. For example, many shoreside communities have conspicuous water towers. Unless the tower has the town name written on it (as many do), or presents some unique "scene," the identification of these towers may be difficult. If you have kept track of your position well, the tower might be plausibly identified because it is the only tower that is consistent with the vessel's approximate position. Conversely, if you are much less certain of your position, it's a much tougher job to match the chart with what can be seen. The same tower might conceivably be that belonging to any of several towns along the coastline.

- Fifth, beginning navigators often focus on man-made features shown on the chart for orientation and position determination. Landmasses can often assist in the identification of charted objects and/or be useful directly. Gibraltar ("The Rock" to many of WW II vintage) serves as a dramatic example of a land feature that is easily visible (in good weather) and readily identifiable. Closer to the 1210-Tr waters, it should be clear that Gay Head and the associated light should also be easily recognizable. Small hash marks shown on the chart near Gay Head suggest some sort of bluffs, and the elevation of the light (170-ft.) is unlikely to be the result of a very tall tower. This conjecture is correct; these 150-ft. palisades are very characteristic and easy to identify. Make sure that you familiarize yourself with the land features shown on the nautical chart. Object recognition is as much a mental as a physical activity, rather like putting together the pieces of a navigational puzzle. This point is made at several places in the chapters ahead.

AIDS TO NAVIGATION (ATONs)

The nautical chart provides information on ATONs, such as lights, buoys, daybeacons, beacons, radio/radar stations, and fog signals. In the case of lighted ATONs, for example, the nautical chart provides information on the location, markings or numbers, color (including sectors of various colors), light characteristics, nominal range, height of light, whether or not sound signals or a radio beacon are part of the same facility, and other pertinent information. Refer to *Chart Number 1* for details.

DANGERS TO NAVIGATION

The nautical chart provides a great deal of information on dangers to navigation, such as submerged rocks, reefs, pilings, snags, wrecks, and obstructions. Figure 3-14 contains a sample of the many separate symbols used to depict these dangers to navigation on the modern nautical chart. It is a good idea to highlight dangers along an intended route as a reminder.

OTHER CHART FEATURES

The nautical chart also contains a wealth of additional data on such items as the characteristics of the coastline, land, ports and harbors, topography, buildings and structures (as noted above and shown in Figure 3-15), and even tides and currents. Again, reference should be made to *Chart Number 1* for details.

ACCURACY OF CHARTS

A chart is only as accurate as the survey on which it is based. The prudent navigator must consider:

- The source and date of the chart are generally given in the title along with the changes that have taken place since the date of the survey. Earlier surveys often were made under circumstances that precluded great accuracy of detail. A chart based on such a survey should be regarded with caution. Except in well-frequented waters, few surveys have been so thorough as to make certain that all dangers to navigation have been found and charted.
- The scope of sounding data is another clue to estimating the completeness of a survey. Most charts seldom show all soundings that were obtained. However, if soundings are sparse or unevenly distributed in charted coastal waters, the prudent navigator exercises care.
- Large or irregular blank spaces among soundings may mean that no soundings were obtained in those areas. Where the nearby soundings are "deep," it may logically be assumed that in the blanks the water is also deep. However, when surrounding water is "shallow," or if it can be seen from the rest of the chart that reefs are present in the area, such blanks should be regarded with great caution. This is especially true in areas with coral reefs and off rocky coasts. Give such areas a wide berth.
- Everyone responsible for the safe navigation of a vessel must have a thorough working knowledge of the nautical chart. Select a chart you commonly use in navigating and (with this in hand) reread this chapter.
- The NIMA (NOS has a similar specification) specified accuracy for harbor, approach, and coastal charts is that features plotted on the chart will be with-

K Rocks, Wrecks, Obstructions

15	+ 35 Rk	35 Rk 35 R	Non-dangerous rock, depth known	21 R	35 R. +
16	Co 3₁ Reef line		Coral reef which covers	Co Co	
17	Breakers	Br	Breakers	5_8 19 Br 18	

Wrecks					
Plane of Reference for Depths → H					
20	Hk		Wreck, hull always dry, on large-scale charts	Wk	
21	Hk		Wreck, covers and uncovers, on large-scale charts	Wk	Wk Wk Wk Wk
22			Submerged wreck, depth known, on large-scale charts	5_2 Wk	9 Wk
23		Hk	Submerged wreck, depth unknown, on large-scale charts	Wk	Wk Wk
24			Wreck showing any portion of hull or superstructure at level of chart datum.		Wk Wk Wk
25	Masts Mast (10) ft Funnel	Masts	Wreck showing mast or masts above chart datum only	Mast	
26	5_7 Wk	5_2 Wk	Wreck, least depth known by sounding only	4_6 Wk 25 Wk	(9)
27	21 Wk 5 Wk	4_6 Wk	Wreck, least depth known, swept by wire drag or diver	4_6 Wk 25 Wk	21 Rk
28			Dangerous wreck, depth unknown		
29			Sunken wreck, not dangerous to surface navigation		
30	8 Wk	25 Wk	Wreck, least depth unknown, but considered to have a safe clearance to the depth shown	25 Wk	15

FIG. 3-14–A Sampling of Symbols Used to Denote Dangers on the Nautical Chart

PHOTO COURTESY OF UNITED STATES COAST GUARD

United States Coast Guard buoy tender servicing lighted buoy. Buoys and other ATONs are shown on nautical charts.

in 1 millimeter (1 mm) at chart scale with respect to the preferred datum, at a 90 percent confidence interval. For a large-scale chart of 1:15,000 scale, a 1-mm error equates to +/- 15 meters (16.2 yards), which is the same order of magnitude as the GPS error. For a smaller scale chart of 1:80,000 scale, the chart error is +/- 80 meters (86.4 yards), which will become the limiting factor in position plotting accuracy.

PRUDENT ADVICE REGARDING CHARTS

This is a good point in the narrative to inject some prudent advice on the use and storage of nautical charts from the point of view of the navigator.

❏ First, ensure that you always have on board the latest charts of the area to be sailed. The point is made at several places in the text that changes in landmarks, ATONs, and other charted features occur almost constantly. Charts are revised periodically to reflect these changes, so the latest charts need to be used. Additionally, changes are recorded in a publication, *Notice to Mariners,* available in both hard copy (see Chapter 10) and on the Internet. The prudent navigator notes these changes on the latest charts available.

❏ Second, ensure that you have charts at the proper level of detail or scale for the intended voyage. As a practical matter, this means that you should generally use the largest scale chart available for the waters cruised. Aircraft pilots (at least, those that are instrument rated) observe a useful distinction between what are termed en route charts, used for point-to-point navigation, and approach charts, used for the final approach to an airport. A similar categorization is appropriate to marine navigation. From the point of view of the coastal mariner, the nautical equivalent of an en route chart would be the coastal charts, and the equivalent to the approach charts would be the harbor and/or small craft charts. However, no competent instrument pilot would be content to fly with only en route charts and the approach chart for the intended destination. Pilots recognize that unanticipated difficulties (e.g., weather beneath landing minimums at destination, mechanical malfunction, unforecast headwinds, etc.) may require them to divert to alternate destinations. Indeed, under certain flight conditions, the specification of an alternate is legally required when an instrument flight plan is filed. The situation facing mariners is almost exactly analogous to that of aircraft pilots. Weather at the intended destination may be unacceptable; larger than anticipated currents (see Chapter 11) or other factors (e.g., standing by to assist a disabled vessel, towing a disabled vessel) may cause fuel to be expended at a greater rate than anticipated, mechanical difficulties (e.g., a rough running engine), and other factors may make a diversion to an alternate harbor attractive and prudent. However, the safety margin afforded by alternates could be seriously eroded if the right approach charts are not

E Landmarks

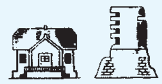
Plane of reference for Heights → H			Lighthouses → P		Beacons → Q
General					
1	TANK Tk		*Examples of landmarks*	Building Hotel	
2	CAPITOL DOME WORLD TRADE CENTER		*Examples of conspicuous landmarks*	FACTORY WATER TR HOTEL WATER TOWER	
3.1			*Pictorial symbols (in true position)*		
3.2			*Sketches, Views (out of position)*		
4		(30)	*Height of top of a structure above plan of reference for height*	(30)	
5		(30)	*Height of structure above ground level*	(30)	
Landmarks					
10.1		Ch	*Church*	Ch.	
10.2			*Church tower*	Tr. Tr.	
10.3	SPIRE Spire		*Church spire*	Sp. Sp.	
10.4	CUPOLA Cup		*Church cupola*	Cup. Cup.	
11		Ch	*Chapel*		
12			*Cross, Calvary*		
13			*Temple*		
14			*Pagoda*		
15			*Shinto shrine, Josshouse*		

FIG. 3-15–Building and Structure Symbols Shown on Chart No. 1

SOURCE DIAGRAMS

All U. S. nautical charts of scale 1:500,000 or larger produced after 1992 are required to include a source diagram. The source diagram provides details of the hydrographic surveys from which the chart has been compiled. It serves as a guide to navigators, is useful in the planning of routes, provides information on data quality, and allows users to make their own judgements of the data's fitness for a particular use. Source diagrams are also provided on certain foreign charts.

available. Suppose, for example, that you are voyaging in a twin engine sport fisherman on the waters covered by the 1210-Tr chart. You depart from some port on the Sakonnet River intending to head into the harbor at Point Judith (please refer to the 1210-Tr chart). Just off Brenton Reef (near Newport Neck), the port engine starts to run rough, and you begin to consider options available. The harbor at Newport is close by and likely to have marinas with repair facilities. But, a glance at the 1210-Tr chart shows this area in a uniform shade of blue, with no sounding detail whatsoever. (In ancient days, this area would have been labeled *Terra Incognita* and festooned with images of sea serpents and other unsavory characters!) The inset in the 1210-Tr chart indicates that these waters are covered in Chart Number 13221 (Narragansett Bay). As a prudent navigator, you should have foreseen this contingency and taken along the 13221 (and other) chart(s). If this chart were not on board, an otherwise routine diversion could have the makings of a real problem. All may end well, but the level of cockpit tension is sure to go up a few notches. This brief scenario also illustrates another point: charts should be stowed in a known and easily accessible location (see below). You should be able to find the 13221 chart in a hurry if necessary—now is not the time to have to rummage around the mayonnaise jars and cleanser (just behind the pickle relish) to find it.

- Third, take the time to study the charts (and related publications) when you plan a voyage—in the safety and comfort of your den or living room, rather than in a possibly cramped and wet cockpit. Although not every aspect of a voyage can be planned in advance, most can. Overall voyage legs, *time-speed-distance* (TSD) calculations (at least, for power vessels), fuel consumption, tides and currents, destination alternates, and even the landmarks and ATONs to be used for fixes can be evaluated before the vessel slips a mooring line. To simplify the logistics of planning, some mariners actually have two copies of the relevant charts and other publications, one set for their home or office, and another set for the vessel.
- Fourth, any chart discrepancies noted during the voyage should be reported to the appropriate agency. Mariners' reports are an important source of chart corrections and these are strongly encouraged.

In short, simply remember the four R's: charts should be Recent, at the Right scale, Readily accessible, and Reviewed beforehand.

CHART STORAGE

Most textbooks on large ship navigation include at least some passing remarks on chart storage. The advice usually reads that charts should be stored flat, to avoid creases, or "rolled-up." This idea is just fine if you own the Queen Elizabeth (either edition) or other large vessel. However, most of us do not have the luxury of a draftsman's storage cabinet and have to make do with much less space. It is virtually impossible to store charts flat on the typical recreational vessel. Therefore, it boils down to a choice of whether to roll or fold your charts. Either scheme has passionate advocates, odd for such a mundane issue. In truth, either scheme can work and the choice depends in part on the available storage and working space in the vessel. If the navigator's workstation will permit a chart to be laid out without folding, rolling might be a better idea. Plastic tubes can be purchased to store charts, often easily attached to the overheads of the cabin. If, however, the chart table is better suited to serving tea than navigation (as is true for many vessels produced today), charts will have to be folded, in any event. Folding is a better option for storage in this case. (If charts are folded, try to avoid putting sharp creases in the chart, this increases the difficulty of plotting and introduces weak points where tears can originate.)

More important than the "fold or roll" controversy, charts should be stored in a dry (well, relatively dry) location and arranged for easy access. Use gummed labels or some other method to identify the chart as filed; otherwise, it can be a chore to find the right chart. Also, take the time to lay out the charts necessary for each voyage beforehand.

Always check to ensure that you have the correct charts for the planned voyage (including alternate destinations) as part of the pre-voyage checklist. It is much easier to replace a chart at the marina than to discover it missing when en route.

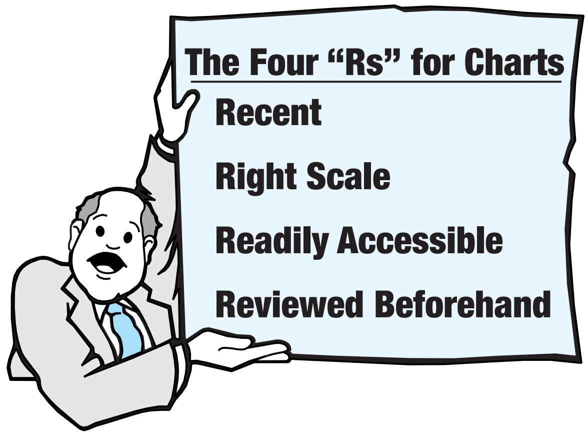


CHART AS A WORKING DOCUMENT

It is noted at the beginning of this chapter that a nautical chart is intended to be a working document, rather than a passive reference guide. In subsequent chapters of this book, dead reckoning and piloting are covered. Intended and actual voyage tracks are actually plotted on the chart. However, these are not the only annotations that can be made on a nautical chart. Here are some things that you might also wish to write on your chart:

- ❑ Names of marinas or yacht clubs that you might visit
- ❑ Areas of productive fishing
- ❑ Good anchorage areas
- ❑ Approximate locations of objects not depicted on the chart
- ❑ Drawbridge operating times and radio frequencies for communication
- ❑ Timing characteristics of foghorns (not shown on charts)
- ❑ Additional information on ATONs not shown on the chart that is relevant, such a description of particular lights, taken from other navigational reference publications or personal observation
- ❑ Probable arcs of visibility of certain lights
- ❑ Navigational hazards of particular relevance
- ❑ Written courses and distances
- ❑ Key items from the NM or LNM affecting your voyage (see Chapter 10)

With these additions, you customize the chart to reflect your particular needs and interests. Don't be afraid to write on the chart. It is intended for this purpose.

EPILOGUE: IF CHARTS COULD SPEAK, OH, WHAT TALES THEY COULD TELL

As the foregoing material shows, the modern nautical chart is a marvel. The compact symbols and format enable a chart to convey on one sheet of paper what would require volumes of written material to cover. Yet, the chart leaves fascinating stories untold, concealed by such compact symbols and text as: wreck, PA, or "Danger, unexploded depth charges." Part of the fascination of these charts is the fun of imagining or researching the stories behind these cryptic notations. Such chart research can be done during the long winter nights, poring over dusty volumes from the library or used bookstore. To introduce you to this sport, the following historical anecdote, taken from *The Navigator* (official publication of USCGAUX), is offered with respect to the waters covered by the 1210-Tr chart.

On 4 May 1945, Grossadmiral

Donitz, commander of the German submarine fleet, gave the order to cease hostilities. At this same time, the U-853, under the command of Oberleutenant Helmut Froemsdorf, was making a deep penetration of the Eastern Sea Command. So far, in fact, that the boat was in Rhode Island Sound. The U-853 was a Type IX-C, 750 tons, and snorkel-equipped, which meant that the submarine could remain submerged for extended periods. Unfortunately, it also meant that Oberleutenant Froemsdorf did not learn that the war was over.

In any event, on 5 May at 5:40 P.M., the U-853 torpedoed the *Black Point*, a British steamer of some 5,300 tons, breaking it in half. This was off Point Judith on a true bearing of 129 degrees and a distance of 5,910 yards. On the 1210-Tr chart a wreck symbol is located at coordinates 41° 19.7'N and 71° 25.8'W. This marks the final resting place of the Black Point.

The passing Yugoslav freighter *Kamen* sent out an SOS and the first vessel to arrive on the scene was the Coast Guard Frigate *Moberly*, commanded by LCDR L. B. Tollaksen, USCG. He was later joined by the Destroyer *Ericson* and the Destroyer Escorts *Amick* and *Atherton*.

By 7:20 P.M. the U-853 had been located and was depth-charged. The boat slipped away but was again detected at 11:37 P.M. A hedgehog attack by the *Atherton* settled the matter and the U-853 sank. Despite this, the attack continued until 1:10 A.M. on 6 May. Numerous vessels participated in this action. Later in the morning of 6 May, two blimps joined the surface vessels and the attack resumed. Finally one of the blimps reported a large oil slick and the action was broken off. One of the surface vessels recovered Oberleutenant Froemsdorf's cap and the chart table in the floating debris.

Over 200 depth charges were dropped in the area during this engagement. On the chart you will notice a two-mile diameter circle centered on coordinates 41° 14'N and 71° 25'W, marked "DANGER"—unexploded depth charge—May 1945." This was the general area of the attack.

Approximately three miles to the SE of this area is a wreck marked "PA." This is the final resting place of the U-853, the last German submarine to be sunk in WWII. As an exercise, take the time to plot the various positions and locate these on the 1210-Tr chart.

Readers interested in learning more about the wrecks shown on their charts can consult the *Automated Wrecks and Obstructions Information System* (AWOIS). NOAA has a searchable AWOIS database available on their web site (http://www.noaa.gov/).

SELECTED REFERENCES

Anon., (1986). The Secret of the Chart. *The Navigator*, USCG Auxiliary National Board Inc.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA), Marine Navigation Department web site (http://www.nima.mil/).

Brogdon, W., (1995). *Boat Navigation for the Rest of Us—Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Brown, L. A., (1977). *The Story of Maps,* Dover Publications Inc., New York, NY.

Committee on Map Projections of the American Cartographic Association, (1986). *Which Map is Best?* American Congress on Surveying and Mapping, Falls Church, VA.

Chriss, M., and Hayes, G. R., revised by Squair, W. H., (1994). *An Introduction to Charts and Their Use,* Fifth Edition, Brown, Son & Ferguson, Ltd. Publishers, Glasgow, Scotland.

Collinder, P. A., (1955). *History of Marine Navigation,* St. Martin's Press, New York, NY.

Eyges, L, (1989). *The Practical Pilot,* International Marine Publishing Co., Camden, ME.

Hewson, J.B., (1983). *A History of the Practice of Navigation,* Second Edition, Brown, Son & Ferguson, Ltd. Publishers, Glasgow, Scotland, UK.

Hinz, E., (1986). *The Complete Book of Anchoring and Mooring,* Cornell Maritime Press, Centreville, MD.

Lamb, J.C., (1981). *Chart Language—A Self-Teaching Course in Reading Marine Charts,* AquaTech, Chapel Hill, NC.

Maloney, E. S., (1983). *Chapman, Piloting, Seamanship and Small Boat Handling,* Hearst Marine Books, New York, NY.

Ministry of Defense (Navy) BR 45(1), (1987). *Admiralty Manual of Navigation,* Volume 1, Her Majesty's Stationary Office (HMSO), London, UK.

Mixter, G. W. (edited by D. McClench), (1967). *Primer of Navigation,* Fifth Edition, Van Nostrand Reinhold Company, New York, NY.

Naval Training Command, (1972). *A Navigation Compendium,* NAVTRA 10494-A, U.S. Government Printing Office, Washington, DC.

Schofield, B. B., (1977). *Navigation and Direction, The Story of HMS Dryad,* Kenneth Mason, Homewell, Hampshire, UK.

Wilford, J. N., (1988). The Impossible Quest for the Perfect Map, *The New York Times,* Tuesday, 25 October, New York, NY.

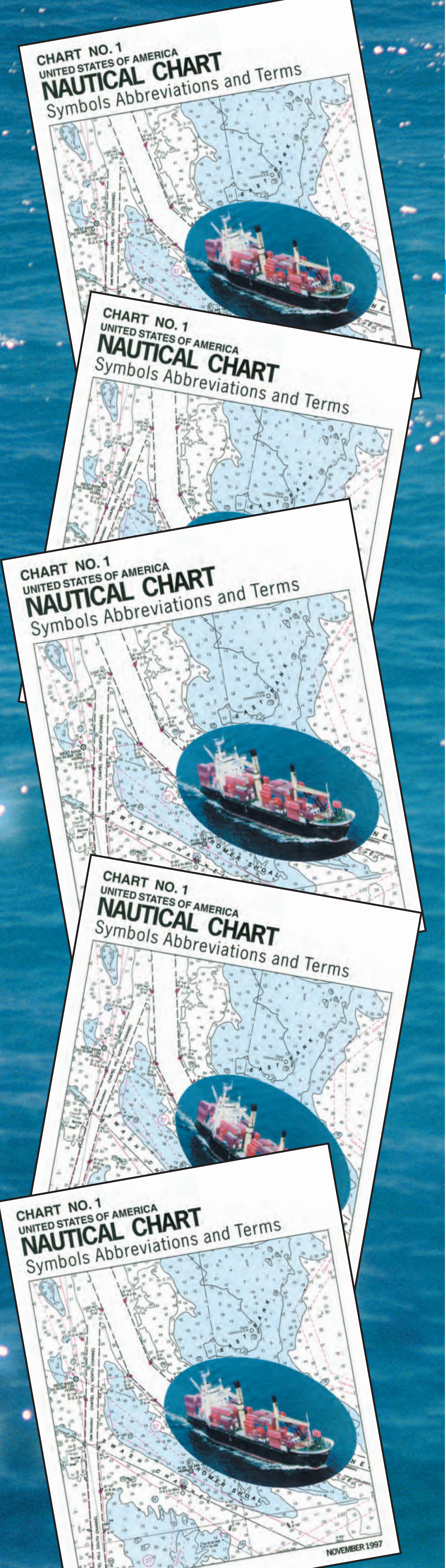
Wilford, J. N., (1982). *The Mapmakers, The Story of the Great Pioneers in Cartography from Antiquity to the Space Age,* Vintage Books, a Division of Random House, New York, NY.

Williams, J. E. D., (1992). *From Sails to Satellites, The Origin and Development of Navigational Science,* Oxford University Press, Oxford, UK.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, and Department of Defense, National Imagery and Mapping Agency, (1997). *Chart No. 1, United States of America Nautical Chart Symbols and Abbreviations,* Tenth Edition, Washington, DC.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, (1997). *Nautical Chart User's Manual,* First Edition. Washington, DC. This publication is available electronically at the NOAA web site (http://www.noaa.gov/).

U.S. Departments of the Air Force and Navy, (1983). *Air Navigation,* AFM 51-40, NAVAIR 000-80V-49, U. S. Government Printing Office, Washington, DC.



CHAPTER 4

THE NAVIGATOR'S TOOLS & INSTRUMENTS

"Man is a tool-using animal…Without tools he is nothing, with tools he is all."

–Thomas Carlyle

"Out of the ruck we have now instruments of beautiful precision, and much greater capabilities than heretofore. It would, however, be wrong to infer that thereby the duties of the navigator had been rendered less arduous…"

–Squire Thornton Stratford Lecky

INTRODUCTION

In addition to the magnetic compass, charts, parallel rules, and dividers mentioned in the foregoing chapters, navigators of small craft may use several other tools or instruments. This chapter provides brief descriptions of several tools used by the navigator, including plotters, drafting compass, pencils, the nautical slide rule, electronic calculator, personal computer, hand-bearing compass, binoculars (conventional and stabilized), night-vision equipment, the marine sextant, charts and reference publications, tools for measuring water depth (electronic and manual), VHF-FM homer, radio, and electronic navigation systems. With the exception of the VHF-FM homer and radar, this equipment is made in small and lightweight versions. Indeed, nearly all the tools/devices listed in this chapter can fit into one carry-on bag. Many navigators routinely carry a kit or "flight case," whether aboard their own vessels or as guests.

Most of the tools described in this chapter are relatively inexpensive, particularly in comparison to the obvious benefits of their use. Accuracy depends on good quality, but also upon familiarity and good technique in the tool's use. A navigator is encouraged to obtain the best tools for the money and projected use. The most expensive tools, however, are not necessarily the best, nor are the least expensive a bargain.

Just as any artisan knows, good tools cost money—but quickly prove their worth. For example, novices rapidly find, to their dismay, that the inexpensive student-drafting compass and dividers (made of plated, stamped steel) quickly fall apart or rust in the marine environment. But, the same tools made of marine brass prove their worth by long and dependable service.

Remember that the marine environment (salt or fresh water) is harsh, and only well-designed and constructed devices survive its test. A selection of tools, which the navigator may find useful, is described below. Not all are appropriate for each and every small vessel. Loran-C, for example, would not be appropriate for use in an area with no loran coverage, and radar too costly and inconvenient to mount for use on very small vessels operating in fog-free areas during daylight hours. Nonetheless, these are discussed briefly in this chapter (and in more detail in Chapter 9) for the sake of completeness.

Marine electronics have been miniaturized substantially in recent years. For example, numerous handheld *Global Positioning System* (GPS) and Loran-C units are on the market. Most are not much larger than a pocket calculator and weigh only a few ounces. One company even makes an integrated wristwatch-GPS unit! The appeal of miniaturized units is great. However, it is important to consider ease of use when buying these units. Very small electronic calculators, for example, have displays that are difficult to read and the keys are placed so close together that it is difficult to avoid data-entry errors when used aboard a pitching or rolling vessel.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❑ ***Which tools are particularly useful to the navigator?***
- ❑ ***What are the uses of these tools?***
- ❑ ***What criteria should be used in selecting these tools?***

The first two editions of this text did not include GPS because the system was not fully operational and receivers cost thousands of dollars. Now multi-channel handheld units sell for little more than $100 (discounted)—less than the price of a good ship's compass. Formerly, GPS and Loran-C receivers were carried only on naval and commercial ships. Now the well-equipped recreational vessel may carry several GPS units-including the ultra-accurate *Differential GPS* (DGPS) and receivers equipped to process *Wide Area Augmentation System* (WAAS) signals. Even hikers carry handheld GPS units and some rental car companies now offer vehicles equipped with GPS units.

Technology useful for marine navigation has advanced rapidly. Chapters in navigation texts written only 20 years ago typically covered the parallel rule, divider and drafting compass, pencils, a simple handheld compass, a binocular, a timepiece, and a sextant. Night-vision apparatus, handheld radios and navigation receivers, and personal computers were the exclusive province of the military or the dreams of inventors.

PLOTTERS

A plotter is one of the most common and important of the tools used by the navigator. The basic purpose of a plotter is to be able to draw straight lines on the nautical chart and to measure the angle of these lines with respect to either the parallels of latitude or the meridians of longitude. For example, a common task is to draw a course line (or intended track line) on the chart and to measure the true or magnetic direction of this course. Plotters are also used to draw *lines of position* (LOPs) to represent visual or electronic bearings. Finally, plotters are used, in lieu of the mileage scales on the nautical chart, to estimate the distances involved over the course legs drawn. (These uses are discussed in Chapters 5 and 6 following.)

The device traditionally used by navigators for plotting is a set of *parallel rules* (also written parallel rulers), and many mariners still prefer this tool. But, there are several

PHOTO COURTESY OF USCG AUX

▲ Now, the well-equipped recreational vessel carries several GPS units.

other plotting devices in common use by small craft operators. One such tool that is particularly easy to use is the "paraglide" or Paraline® plotter. This is a graduated rule, with protractors and parallel lines, attached to a roller, constrained to roll such that the rule always (well, nearly always) remains parallel as it is moved on a chart. With this tool, the user has the option of either:

- ❏ rolling the sliding rule from the course line over to a convenient compass rose and taking the reading from the rose directly along the edge of the rule, or
- ❏ rolling the rule from the course line over to a meridian or parallel and reading the direction using one of the protractors inscribed on the face of the rule.

Both methods are suitable and easy to use on many small craft, provided that there is a large enough flat surface available to spread the chart. There are other plotting devices, termed "coursers," which are similar to the "paraline-type" plotter, without the roller, but with many parallel lines scored lengthwise. These are used in the same manner as the rolling type only rather than roll; the parallelism is maintained by eye relative to the multiple parallel lines printed on the plotter.

Another tool used for basic plotting consists of two identical drafting triangles (30° 60° 90°) arranged, hypotenuse-to-hypotenuse, to form two parallel lines which can be expanded by sliding the triangles together until the compass rose center is touched (see Figure 4-1). Although drafting triangles have their supporters, most navigators find these inconvenient

KEEPING AND MARKING TIME, AN HISTORICAL ASIDE

Measurement of time has always been essential to accurate navigation. An accurate estimate of the ship's speed and the elapsed time were the essential requirements to estimate distance traveled. In the era of the Spanish Armada, the lilting of ship's boys rather than the sounding of bells marked the passage of time. According to Felipe Fernandez-Armesto (The Spanish Armada, The Experience of War in 1588, Oxford University Press, Oxford, New York, NY, 1989), one boy's job was to mind the sand clock, which measured time in glasses each of one half hour duration. (Early mariners believed in redundancy—each ship carried several glasses, including spares!) Each turn of the sand clock "was announced by a traditional lilt, probably similar to or identical to those recorded by Eugenio de Salazar on a voyage to Santo Domingo is 1574. After the first half hour of every watch, for instance, the cry rang out:

"One glass has gone.

Another's a-filling.

More sand shall run.

If God is willing.

To my God let us pray.

To make safe our way.

And His Mother, Our Lady, who prays for us all.

To save us from tempest and threatening squall."

During the night, the boys had the additional duty of exchanging calls with members of the watch to ensure that each was awake.

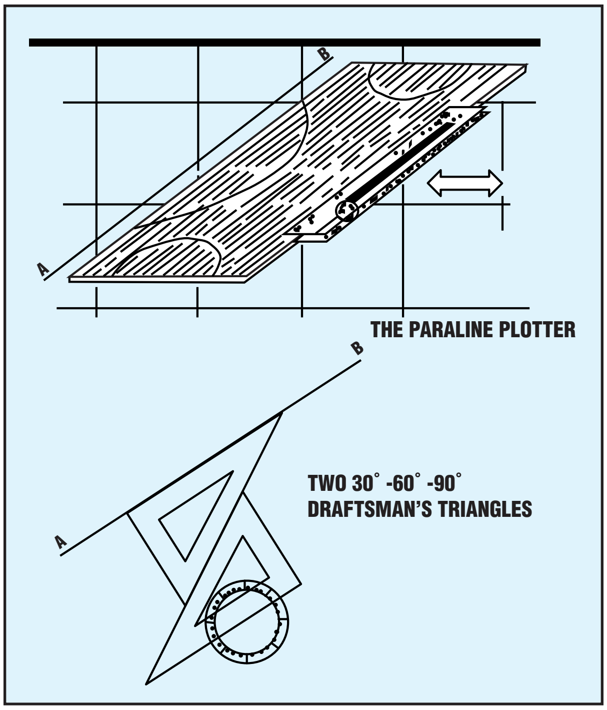


FIG. 4-1–The "Paraglide" or "Paraline" Type Plotters and the Draftsman's Triangles Used to Determine Direction

to use on small vessels. These are better suited for voyage planning in your office or den.

There are many other novel devices for plotting. (Descriptions and advertisements for these can be found in many of the popular boating magazines.) Some have the capability of solving current sailing problems (see Chapter 7), relative bearing problems, and other navigational tasks. As these are typically relatively inexpensive, you can try several before settling on the plotter of choice.

DRAFTING COMPASS

The drafting compass is an instrument similar to a pair of dividers, except that one leg has a pencil lead attached. This tool is used for swinging arcs and drawing circles on charts or maneuvering boards. The many uses of the drafting compass are detailed in Chapters 6, 7, 9, and 10 and include drawing circular LOPs, solving current triangles, and drawing arcs of visibility of lights.

Dividers should also be carried for measuring distances on the nautical chart. Dividers and drafting compasses are often sold as sets in a convenient carrying case. So-called "one-handed" dividers are made. These are particularly easy to use when underway.

WRIST WATCH (OR OTHER ACCURATE TIMEPIECE)

Time is one of the basic dimensions of piloting. Throughout history, numerous devices have been used for this purpose, from hourglasses (see sidebar) through chronometers. A reliable timepiece is essential. Without a means of telling time, dead reckoning navigation, running a search pattern, or identifying the proper characteristic of an aid to navigation are impossible. Every crew member should get in the habit of wearing a wristwatch when under way. The wristwatch should be waterproof and be able to indicate hours, minutes, and seconds. Digital electronic watches with stopwatch features are fully satisfactory for piloting and navigation work. It is also convenient to use a watch that has the option of displaying time in the 24-hour format, as this eliminates the need to convert from one time system to another.

Several firms manufacture small but easy-to-read electronic timers. These can be used in the "count-up" (for measuring elapsed time) or "count-down" (to give time to go) modes. Some portable GPS or Loran-C receivers also have this function.

WRITING ON CHARTS

As another historical aside, the modern practice of drawing course lines and LOPs on charts is of relatively recent origin and reflects the widespread availability and relatively low cost of the modern nautical chart. Charts used by early mariners were extremely valuable and difficult to acquire, and most of what is now termed chartwork—such as the simple task of maintaining a DR plot discussed in Chapter 5—was done by laborious calculation rather than simple drafting. Cutting up charts to produce the many illustrations in this text is a procedure that would have left Columbus and his peers aghast!

PENCILS

An ample supply of pencils (and sharpener) or a mechanical pencil (with spare lead) is required for chart work. Pencils are used to draw courses, LOPs, fixes, and for chart labels. It is important to use a correct type of pencil for plotting. The pencil should leave a line which is easy to see, does not smudge, and is easy to erase completely without leaving a permanent mark on the chart. (Erasures, incidentally, do not arise solely because of errors in plotting. Many mariners reuse charts and erase the previous voyage plots.) A medium (No. 2) pencil is best. Keep your pencils sharp; a dull pencil can cause considerable error in plotting a course and will also smudge up the chart. A 0.5-mm mechanical pencil is excellent for chart work.

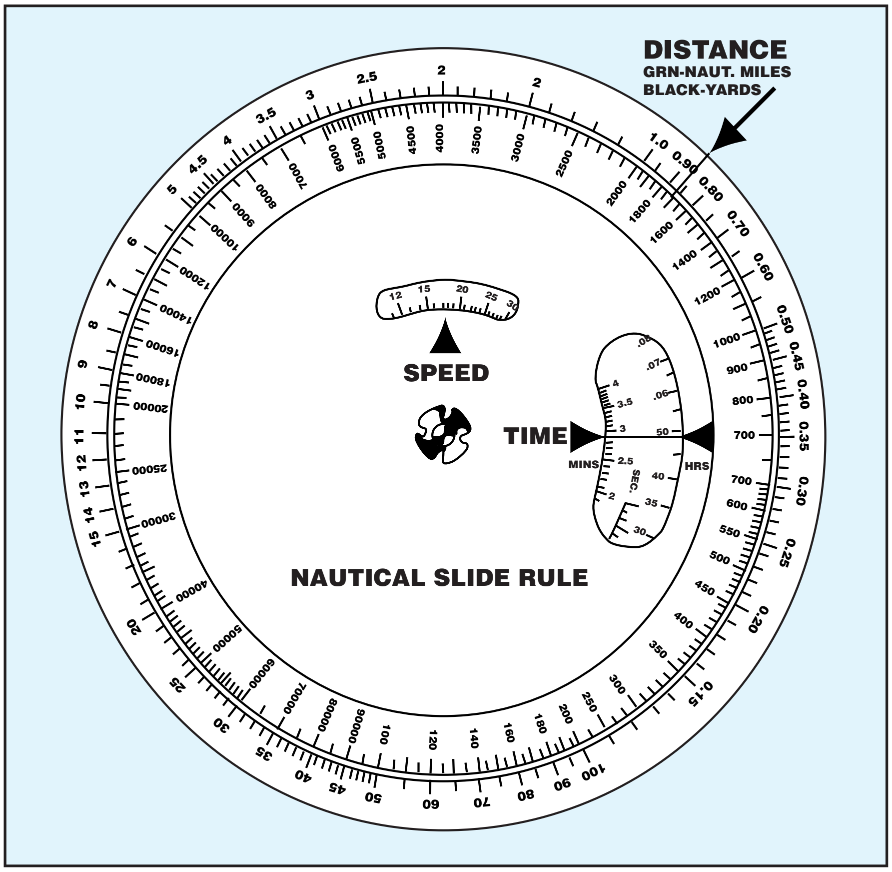


FIG. 4-2–The Nautical Slide Rule

NAUTICAL SLIDE RULE

The purpose of the nautical slide rule is to solve *time-speed-distance* (TSD) problems quickly and accurately (see Chapter 5). Although there are many varieties of nautical slide rules available, they all function in the same manner. For any two values of a TSD problem, the third value can be readily determined. Figure 4-2 illustrates a nautical slide rule. The nautical slide rule is constructed of waterproof and durable plastic. It has three clearly labeled scales: speed, time, and distance. By adjusting the appropriate dials, values can be independently set into the indexes. With values set into any two scales, the third, or unknown value, will automatically appear at the appropriate index. Directions supplied with the rule should be consulted for details of operation. Note: with the advent of inexpensive electronic calculators, the nautical slide rule is now obsolescent. However, a nautical slide rule does not require batteries and is a useful backup tool.

CALCULATORS AND COMPUTERS

The electronic digital handheld calculator is also quite satisfactory for navigation purposes, and use of such devices is encouraged. Calculators with engineering or scientific (e.g., ability to do square roots and trigonometric functions) capability are particularly useful. It is also a good idea to place the calculator in a small plastic bag that can be sealed. With practice, the calculator can even be used while inside the plastic bag, which makes you appear eccentric but can prevent water damage.

Personal computers (PCs) have a variety of possible uses on board a vessel. These include:

- ❏ PCs are used to perform numerous navigation calculations, from simple TSD problems through celestial navigation calculations. (PCs are particularly useful for computing tide heights and tidal currents, discussed in Chapter 8.)
- ❏ PCs are used to display and manipulate electronic charts.
- ❏ PCs are used to download waypoint information from GPS and Loran-C receivers and manipu-

late these data by use of database management programs.

- ❏ PCs can interface with shipboard electronics, such as a GPS receiver, and display real-time position information.
- ❏ PCs (equipped with appropriate software) can perform most of the voyage planning tasks, including determination of courses, distances and bearings between waypoints, estimated time en route, and fuel planning calculations.
- ❏ PCs are used for vessel maintenance logs and other "clerical" functions.
- ❏ PCs with access to the Internet enable the navigator to access valuable information.

Laptop PCs are particularly convenient, although it may be difficult to read screens in bright sunlight. Moreover, these units do not respond well to being dropped, jostled, or splashed with water. Special-purpose, rugged, and water-resistant PCs are manufactured. These reportedly work well, but are costly. Although laptop PCs can use battery power, running time on batteries is limited. For this reason it is more convenient to use these on vessels with a reliable supply of *alternating current* (AC).

HAND-BEARING COMPASS

A hand-bearing compass is convenient for taking bearings to landmarks and *Aids to Navigation* (ATONs). This is not a required tool if the steering compass may be readily used for this purpose. In most cases, however, bearings accurate enough for a precise fix cannot be determined with a steering compass unless the boat is first pointed at the object or the boat is equipped with a pelorus and/or has been carefully calibrated for beam bearings. This is particularly true if an electronic compass is used as the boat's standard compass. (Depending upon the boat's design, it may or may not be convenient to mount a pelorus.) A hand-bearing compass is a valuable backup unit and should be carried in every navigator's carry-on case.

The hand-bearing compass may be moved anywhere on the vessel by the navigator, independent of the steering compass. Care should be exercised, however, to ensure that the handheld compass is not influenced by nearby magnetic fields set up by masses of ferromagnetic (iron, steel) metals, such as the vessel's standing rigging, rails, anchors, engines, and electrical equipment. It is often assumed that the hand-bearing compass is free of deviation. However, this assumption should be verified on your boat (see below).

Hand-bearing compasses are produced in a wide variety of sizes, shapes, and prices. The traditional liquid-filled magnetic compass with vane sighting has been joined by other, more novel, compass types. One popular, though still traditional, type is termed a "hockey puck," because of the similarity in appearance to its namesake. The hockey puck type is liquid filled and contains a tritium gas capsule to provide light for reading under conditions of restricted visibility. Additionally, this compass projects the image of the compass card to infinity, so that the compass can be held close to the eye and read, eliminating parallax error. It does take a few seconds for a liquid damped compass to reach equilibrium, however, and requires some practice before accurate bearings can be read from a rolling or pitching vessel.

A newer type of hand-bearing compass is the fluxgate electronic compass. As discussed in Chapter 2, the fluxgate compass is a revolutionary development of the 1920s and extensively used in aircraft during World War II. Unlike the traditional compass, it does not use magnets but, rather, accomplishes the same function by electronically sensing the magnetic field. Rapid innovation has now made this technology accessible in a device that can fit in the palm of your hand!

Several different handheld fluxgate compasses are sold. One model features digital readout of bearings (to within plus or minus 2 degrees accuracy when used by an experienced mariner) that are stored in memory whenever a bearing is taken. Several memory locations are available, so that an entire round of bearings can be taken rapidly while on deck and later recalled for plotting at the navigator's station. Many models also include a stopwatch for leg timing, estimation of a running fix (see Chapter 6), or other purposes. The handheld fluxgate compass has many advantages, but there are two disadvantages that should be noted. First, this and other fluxgate compasses require a power source. Therefore, batteries are required and spares should be carried. Second, unless the fluxgate compass is gimbaled, take care to hold it as level as possible; otherwise, bearing errors up to several degrees could result. The navigator should practice taking bearings, first under ideal conditions (e.g., in calm or protected waters) and later under more challenging circumstances, before routine use of this hand-bearing compass.

A more sophisticated variant of the handheld fluxgate compass is shown in Figure 4-3. This particular device combines a 5 x 30 mm monocular, fluxgate compass, electronic range finder, and timer into one convenient unit. The range finder enables the vessel's "distance off" to be determined by using the known height of an object sighted (e.g., a lighthouse) and its relative size (as seen in the monocular) to determine the object's range. Figure 4-4 shows how this is done. First, the height of the object is entered into the instrument. Next, the observer looks through the monocular and adjusts the height of the horizontal bars to match that of the object. The distance off is read in the digital display in the same units as used to enter the object height. (Circular LOPs resulting from this type of observation are discussed in Chapter 6.) This particular model is gimbaled, which minimizes any error arising from failure to hold the compass perfectly level. Additionally, the device enables average bearings to be read directly, increasing the precision of the bearings taken.

As noted above, it is often assumed that the handheld compass is free of deviation. The prudent navigator should take bearings from several locations on the vessel and compare these to the vessel's known position (e.g., on a published range) to test the validity of this assumption and to determine the location(s) on the vessel where the handheld compass is relatively free of deviation. Particularly on a power vessel, the mass of metal in the engine(s) may cause appreciable compass deviation if bearings are taken while standing over or near the engine(s).

BINOCULAR

A good 7 x 50mm binocular (see Figure 4-5) is very useful for locating and identifying visual landmarks and ATONs. For example, the identifying numbers or letters on buoys can often be read using a binocular at a much greater distance than with the unaided eye. A binocular is also useful for *search and rescue* (SAR) work to identify disabled vessels. (Incidentally, although the term "a pair of binoculars" is commonly used, this is not technically correct. A binocular denotes an optical device with two lenses. The plural form "binoculars" refers to more than one device.)

The meaning of the numbers 7 x 50 used above, is as follows: 7 represents the "power" or magnification of the binocular and 50 mm is the diameter of the objective (front) lens in millimeters. Magnification is the ratio of the size as seen with the unaided eye compared to the apparent size when viewed through the binocular. If a binocular has 7x magnification, for example, an object will be enlarged 7 times. A buoy 700 yards away will look only 700/7 = 100 yards distant.

Unless these are image- or gyro-stabilized (see below), avoid binoculars with greater magnification than 7 power, as these are nearly impossible to hold steady enough

PHOTO COURTESY OF KVH INDUSTRIES, INC.

FIG. 4-3–Handheld monocular (KVH Datascope®) combines a fluxgate compass, timer, and range finder.

by hand alone. Also avoid smaller objective lenses, as these have too limited a field of view and gather too little light to be useful in the operational environment—particularly at night. The 7 x 50 mm is the standard binocular in use by most of the world's navies. Rubber-coated binoculars are recommended. Some mariners prefer a model with a self-contained illuminated bearing compass. A good binocular is waterproof or, at least, water-resistant. The best binocular is filled with dry nitrogen or some other inert gas to prevent condensation and fogging.

Some binoculars have a built-in hand-bearing compass and/or a range finder. Though convenient, the hand-bearing compass comes with a weight penalty. The simplest range finder on a compass is a series of calibrated reticles. If an object of known width or height fills one 10-mil unit marking on the horizontal reticle and is known to

PHOTO COURTESY OF KVH INDUSTRIES, INC.

FIG. 4-4–Use of KVH Datascope® to Measure Range from Object of Known Height

be 20-meters wide, the object is 1,000 meters away. The formula to calculate the range is 1,000 times the known size divided by the number of mils.

Quality binoculars allow users to focus the left and right eyes separately, a real benefit to users who wear eyeglasses.

Weight is an important consideration in the selection of a binocular. Various models weigh as little as 3 - 7 ounces for a compact set, to 48 ounces or more for larger binoculars. Borrow someone else's binocular to develop a sense of what weight is comfortable for you. Form your judgement on comfort only after wearing the binocular for several hours' use—not from a few minutes in a marine supply store.

PHOTO COURTESY OF STEINER-OPTIK GMBH

FIG. 4-5–High Quality 7 x 50 Binoculars

Remember, also, that it takes patience and experience to learn to use the binocular effectively. For example, reading the numbers or letters for identification of a buoy is sometimes more difficult than you might think. In conditions of poor visibility or haze, it may be very difficult to establish a positive identification using the binocular—even at short range. Even in good visibility, it may still be difficult to do, particularly if the buoy is backlighted in hazy sunlight. Use of a binocular will only make the silhouette of the buoy larger, rather than making the writing legible. In this visibility condition, it may be necessary to use other observable cues and contextual information to assist in identification of an object. Suppose, for example, that reference to the chart indicates that a buoy is isolated, without prominent landmarks or other buoys nearby. A sweep of the area with a binocular could verify that no other buoys are in the vicinity. This evidence, in concert with estimates of the vessel's probable position or an electronic fix, could be adequate to confirm a provisional identification. Now suppose that the buoy were one of a pair marking the lateral limits of the channel. The binocular could be used to locate the matching buoy. The point of these examples is to illustrate that several types of information can sometimes be integrated to establish the identification of an unknown object, even if it cannot be verified using direct means. Novices are sometimes disappointed that they cannot "see more" through binoculars. But it is important to note that you see "with your mind" as well as through your eyes.

Although there are different points of view on the subject, experience shows that it is tiring to use a binocular to scan the horizon continually. Instead, it is preferable to use the binocular to examine and identify an object already detected by the unaided eye.

STABILIZED BINOCULAR

Image-stabilization (IS) technology similar to that used in video cameras is now employed by one manufacturer (Canon) of marine binoculars. The big advantage of IS technology is that binoculars of substantially greater magnification (e.g., powers of 10-15 rather than 7) can be used on the vessel without objectionable blurring. Because of greater magnification, these binoculars can detect and/or identify objects at substantially greater ranges than is possible using conventional binoculars, depending upon prevailing visibility.

Despite the use of advanced technology, models now on the market weigh between 21 and 36 ounces, roughly comparable to weights of conventional binoculars. Figure 4-6 illustrates an IS (Canon) binocular.

IS binoculars are more expensive than conventional models (but, not greatly so) and require batteries. Nonetheless, the additional magnification is a substantial benefit.

Another manufacturer (Fujinon) produces a stabilized binocular by using technology similar to that used on big-ship systems. This binocular has a high-speed internal gyroscope to damp image motion. As of this writing, this particular model has comparable performance, but is heavier and more costly than those based on IS technology.

Mechanical IS technology (a so-called Cardanic Suspension system) has also been developed. Technology is likely to advance rapidly, however, which may change the relative costs and benefits of these and other technologies.

NIGHT-VISION EQUIPMENT

Night-vision equipment was once the sole province of the military. In recent years, however, the cost (and weight) of this equipment has decreased dramatically. New units are available that weigh in the range of 16 - 26 ounces—lighter than many binoculars! Figure 4-7 shows a lightweight handheld model. Night-vision devices are battery powered.

Night-vision equipment uses a lens to focus available light on a sensitive plate (photocathode). The photocathode plate turns the energy from photons into electrons that are amplified by a microchannel plate and impact upon a phosphor screen visible to the eye. Civilian users have access (as of this writing) to three generations of night-vision devices. Generation III units are the best, but also the most expensive.

A night-vision scope amplifies minute amounts of ambient light (even starlight) to give the appearance of daylight—albeit a greenish daylight—rather like living in a futuristic smog-shrouded city. Night-vision devices enable mariners to observe channel markers, nearby boating activity, and floating obstructions (e.g., logs, crab trap markers, half-submerged containers) under low light conditions. The latest devices are not toys, but precision equipment. If these prevent one grounding, allision, or collision they will have paid for themselves many times over.

OTHER PARAPHERNALIA

Other tools that might be considered by the coastal navigator include an optical range finder and a sextant.

As noted, an optical range finder is used to determine the distance between the vessel and an object of known height. In this way, a circular LOP can be determined, as discussed in Chapter 6. Range finders differ in features, cost, and ease of use. It is recommended that experience be gained in using these devices before any purchase decision is made. Many mariners purchase these from glossy Christmas catalogs, try these once or twice, and then, frustrated, consign these to a garage sale.

A marine sextant is typically used for measuring vertical elevations of celestial bodies for celestial LOPs and fixes—a subject beyond the scope of this text. But, sextants can also be used for measuring horizontal angles. These, in turn, can be employed to fix the vessel's position. In principle, extremely accurate two-angle fixes can be determined using a sextant. The *United States Coast Guard* (USCG), for example, used horizontal sextant angles to place its buoys in this manner. (More recent practice is to position buoys using DGPS.) In practice, it requires both

PHOTO COURTESY OF CANON USA

FIG. 4-6–IS binoculars reduce motion and enable greater magnification to be used.

PHOTO COURTESY OF ITT NIGHT MARINER

FIG. 4-7–This third generation night vision device is lightweight and powerful.

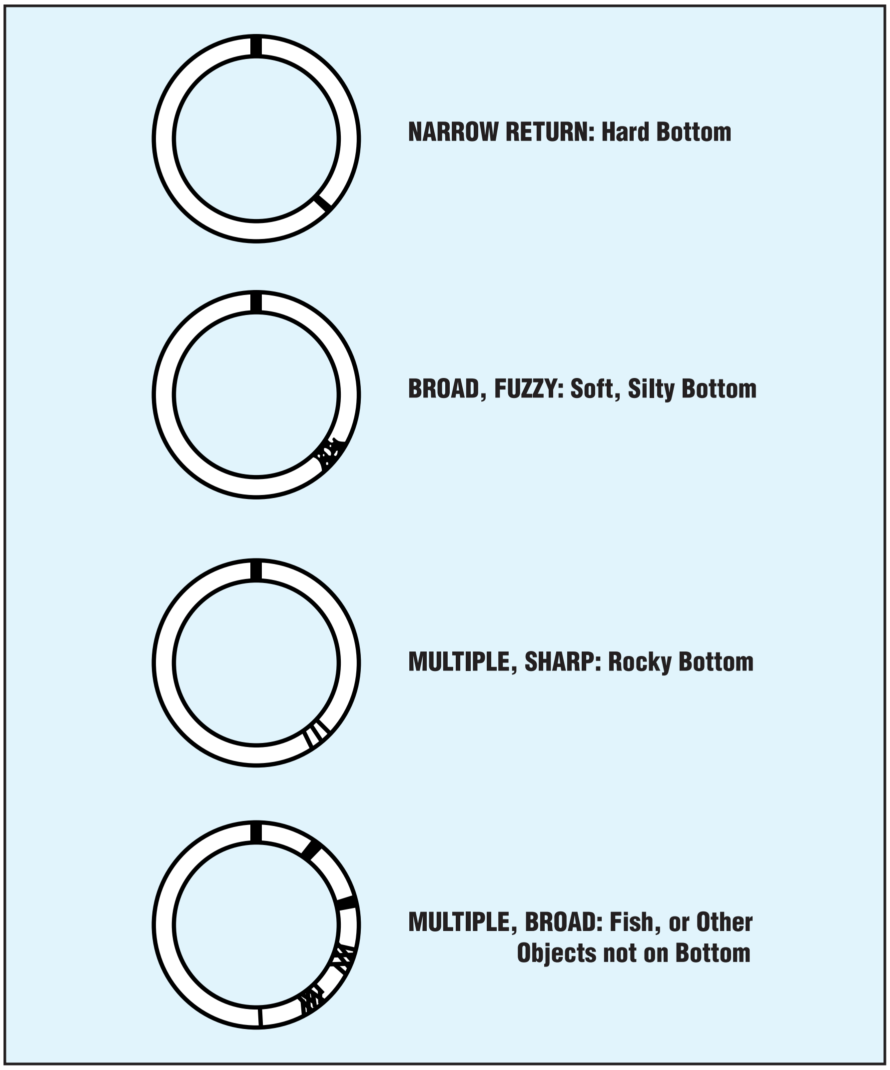


FIG. 4-8–Interpretation of Depth Sounder Flash Returns

training and experience before reliable positions can be determined from sextant measurement of horizontal angles. Even the selection of the proper objects to sight, so as to maximize the accuracy of the resulting fix, is a sophisticated subject. Readers interested in this topic are directed to the sources listed in the bibliography at the end of this chapter. Suffice it to say that few coastal navigators use a sextant for this purpose. Space and scope constraints preclude a more complete discussion here.

CHARTS AND REFERENCE PUBLICATIONS

Although not, strictly speaking, tools of navigation, appropriate nautical charts and navigation reference publications are essential. With respect to charts, ensure that all necessary charts are carried and that the largest scale charts are available, as noted in Chapter 3. Ensure, also, that you have the latest editions of the nautical charts, because the use of obsolete charts can be dangerous. Natural and man-made changes, many of these critical, are occurring constantly, and it is essential to have access to the latest information. Additionally, the charts should be updated by reference to *Notice to Mariners* (see Chapter 10) to insert changes to the charts before a new edition is issued. These updates are important because it may be years before a new edition of a chart is issued. As of this writing, for example, there are numerous charts that are as many as ten years old. Although the number of changes in these older charts may be insufficient to justify publication of a new edition, the likelihood that there are no material changes over a ten-year period is small indeed.

Chart Number 1 (see Chapter 3) fits easily into a navigation case and should be carried.

Other publications of use by the navigator include the *Light List, Tide and Tidal Current Tables,* and the *U.S. Coast Pilot* (USCP). These, too, are discussed in Chapter 10 and should be studied carefully by the navigator as part of the pre-voyage planning process and, of course, carried aboard the vessel.

FLASHLIGHT/MAGNIFIER

A small flashlight (with red lens) is helpful to read charts on a darkened bridge. As well, a magnifier is sometimes helpful to read the small print on charts or navigational reference publications.

Finally, it is appropriate to include some electronic devices among the navigator's tools. These include a depth sounder, portable radio, and radio navigation apparatus such as GPS, Loran-C, and radar units. These latter aids are described in more detail in Chapter 9, but mentioned briefly below. In particular, there are several relatively inexpensive, light weight, and easily portable GPS and Loran-C receivers on the market. These make great backup units for the vessel's main receivers and fit easily into the navigator's kit.

DEPTH SOUNDER

The depth of water is one of the key variables that a navigator considers in safety of navigation. (It can also be used to provide a "reality check" on positions determined by other means.) Groundings have accounted for approximately 10% of recreational boat incidents in recent years, according to USCG SAR statistics. Although a depth sounder, *per se,* does not prevent a grounding incident, intelligent use of depth information can help to lower the frequency of these incidents.

The depth sounder is an electronic instrument designed to provide information on a continuous basis through the transmission of pulses of high frequency sound waves that reflect off the bottom and return to the receiver. The reflected waves or echoes are converted to electrical signals and read from a visual scale or indicating device. A device called a transducer transmits the sound waves. The transducer is usually mounted above the low point of the hull (often on the stern). Therefore, this distance must be subtracted from all readings to determine the actual water depth below the boat's hull or propeller. (Some models of depth sounders can be adjusted to compensate for differences in mounting location to provide an accurate depth under the keel or propeller(s).)

PHOTO COURTESY OF FURUNO, USA

FIG. 4-9–Multi-functional Navigation Display

Water depth is indicated on a screen by a flashing spot on a circular dial, on a recorder by a trace or, with modern, digital devices, directly as numbers on an electronic indicator. With practice and experience, you can also tell what the bottom characteristics and conditions are, which is useful in selecting an anchorage. Illustrative readings from an older model are shown in Figure 4-8.

More modern depth sounders use *Light Emitting Diodes* (LED), *Liquid Crystal Displays* (LCD), or video screens and may combine a variety of other functions in addition to providing depth information. For example, these depth sounders may include a temperature probe to determine seawater temperature, a speedometer to give the vessel's *speed through the water* (STW), a log to indicate the total distance covered with respect to the water, and a "fish-finder." Digital displays are easy to read, but the numbers often jump around, which can cause confusion.

PHOTO COURTESY OF STANDARD COMMUNICATIONS CORP.

FIG. 4-10–Submersible Handheld VHF-FM Radio

Some of the more elaborate models have the capability to interface with other electronic equipment on board, such as a GPS, DGPS, or Loran-C receiver and chart link system, to enable other specialized navigational tasks to be accomplished. Figure 4-9, for example, illustrates an integrated four-in-one navigation system. This unit can display information from radar, GPS, a chart link system, and a depth sounder/fish finder. The split screen, evident in Figure 4-9, shows electronic chart and depth information. The ability to display a depth history (even over only a short period) is useful. This provides information on the rate of change of depth, which is potentially important. Many models have the capability of displaying depth in various units, such as feet, meters, or fathoms. This is a con-

MARKINGS ON THE LEAD LINE

Historically the "leadsman" had to learn to recognize marks in the lead line by feel as it was brought aboard. These markings were standardized. For example, 2 fathoms (1 fathom equals 6 feet) was marked by two strips of leather, 3 by three strips of leather, 5 by a white cotton rag, 7 by red woolen bunting, 10 by a piece of leather with a hole in it, etc. Markings on the line were called "marks" and the estimated intermediate fathoms between the marks called "deeps." The leadsman used a quaint phraseology to sing out the sounds. "Mark Twain" (two fathoms), "By the deep six" (six fathoms), "Less a quarter 5" (4 3/4 fathoms), are examples. The American author Samuel Langhorne Clemens (1835-1910) adopted "Mark Twain" as a pseudonym.

venient feature that can be used to match the units with those on the nautical chart being used. Constant vigilance is necessary, however, to avoid misinterpreting depth information. Several groundings have resulted when the navigator assumed that the display was reading in one set of units (e.g., fathoms), when another (e.g., feet) was programmed.

At least one manufacturer makes a battery-powered, handheld depth sounder, roughly the size of a conventional flashlight.

This text does not explain how to operate electronic equipment, because the information would be model-specific, in most cases, and quickly become out of date due to the rapid technology advances in the marine electronics field. Refer to the owners' manuals for these details.

HANDHELD LEAD LINE

The handheld lead line may be used to measure depths of water when the depth sounder is not available or usable, such as around a grounded vessel, perhaps from a dinghy. The lead line should be used periodically to check the accuracy of the electronic depth sounder.

The lead line consists of a line marked in feet or fathoms and a lead weight, hollowed at one end in which tallow can be inserted (called "arming the lead") to gather samples of the bottom. As noted in Chapter 3, bottom characteristics are charted and this information can sometimes be used to assist in fixing the vessel's position. At one time, there were a stylized set of markings on the lead line (see sidebar). Now most lead lines have plastic inserts with numbers displayed.

A lead line is difficult to use except in relatively shallow, calm water, at slow speed. Nonetheless, keep a lead line neatly stowed and ready for use at all times in the event the depth sounder becomes inoperative or electrical power is lost and soundings are required.

Historically, the lead line was considered one of the most important navigator's tools. Waters (1958) noted that text descriptions of the lead line appeared as early as 1584. Aczel (2001) reported that the lead line was regarded as so critical to navigation that ships detained in port for nonpayment of duty or other infractions had their sounding lines confiscated by the authorities—a practice that continued even after ships carried more modern instruments. For those intent on escape without payment of fees, this is an early example of the benefits of carrying spares!

VHF-FM DIRECTION FINDER

A *very high frequency* (VHF)-*frequency modulated* (FM) homer (direction finder or homing device), although not generally considered a piloting tool, *per se*, allows zeroing in on the source of any VHF-FM radio signal being received. Each time a signal is received, the relative bearing of the transmitting station can be measured and read on a digital display. Errors in relative bearing are least when the transmitting station is on the homer-equipped vessel's bow, and within plus or minus 5 degrees to 20 degrees for other orientations. (These accuracy figures are specific to each model. However, accuracy is typically greatest at zero relative bearing.) Direction finding gear is especially useful for SAR work to locate the position of a vessel in distress, but can be a useful tool for navigation as well. Fishing vessels use this gear to determine the bearing of other vessels that are reportedly catching fish.

HANDHELD RADIO

Lightweight and compact VHF-FM handheld radios are manufactured that are excellent backups for the vessel's principal radio equipment. Most have weather channels that provide weather broadcasts from the *National Oceanic and Atmospheric Administration* (NOAA). Weather information is essential to the safety of navigation.

Handheld radios can be used for

PHOTO COURTESY OF ICOM AMERICA, INC.

FIG. 4-11–Family Radio Service Handheld Receiver

both conventional and distress communications. Figure 4-10 shows a typical marine-band handheld radio. The manufacturer claims that this model can withstand submersion up to one meter for thirty minutes—a handy product feature. As with all VHF radios, communications are limited by line-of-sight constraints. Operation of marine-band VHF-FM band radios (base station or handheld) is regulated by the *Federal Communications Commission* (FCC). FCC rules must be observed. While not unreasonable, these rules do place certain limits on within-ship, ship-to-ship, and ship-to-shore use.

The FCC has established a new *ultrahigh frequency* (UHF) *family radio service* (FRS) to satisfy the need for FM clear-quality, short-range communications between any individual or organization without any FCC licensing requirements. The FRS is free from many of the marine-band rules. Handheld FRS receivers, such as that shown in Figure 4-11, enable communications over water at distances in excess of three miles. These are also very handy for crew communications on larger recreational vessels. For example, the skipper on the flybridge can communicate clearly with crew hauling in the anchor or releasing lines.

LORAN-C

Loran is an acronym that stands for *long-range navigation* and, to civilian users, is one of the technology "spin-offs" of World War II. Details of this system are provided in Chapter 9. But, briefly, a loran receiver enables a user to determine a highly accurate position fix with-

PHOTO COURTESY OF GARMIN INTERNATIONAL

FIG. 4-12–Handheld GPS unit is versatile navigation system.

in the areas of loran coverage that include (among others) virtually all of the coastal waters off the continental United States. The modern loran receiver is typically integrated with a self-contained navigation computer so that, in addition to the vessel's position, other relevant voyage parameters can be displayed. For example, the vessel's speed and course over the ground can be calculated. Additionally, the user is able to establish electronic "waypoints" (which could be buoys, other ATONs, turnpoints, or arbitrary locations) to mark the various legs of the voyage. The loran receiver can display distance to the waypoint, miles off a direct course to the waypoint (so-called *cross track error* [XTE]), average *speed over the ground* (SOG), velocity to the next waypoint, estimated time until the waypoint is reached (sometimes termed *time-to-go* [TTG]), current set and drift (see

PHOTO COURTESY OF GARMIN INTERNATIONAL

FIG. 4-13–Another Handheld GPS Unit with Navigation Database

Chapter 7), and a host of other relevant navigational information. Finally, a series of adjustable alarms can alert the navigator to arrival at a waypoint, penetration of a preselected track, an XTE of more than a predefined amount, or even the fact that the anchor is dragging!

GPS

GPS operates on a different principle than loran (see Chapter 9), but the receiver has the same display capabilities. Unlike Loran-C, GPS is a worldwide system and is presently scheduled to replace Loran-C.

Small, portable, and inexpensive GPS receivers are produced—most have the capability of displaying chart or map information and serving as full-function navigation instruments. Figure 4-12 provides a photograph of a modern handheld GPS unit. This small unit is also a full-function navigation receiver. For example, the user can enter 500 waypoints and 20 routes of up to 30 waypoints each. An adapter enables this unit to be connected to a PC and electronic charting systems. The handheld model shown in Figure 4-13 has cartographic capabilities. It includes a base map and has "up-loadable" detailed map data available from *compact disks* (CDs) or "down-loadable" from Internet sites.

A portable GPS receiver makes a great backup for the vessel's principal navigation receiver(s) and can easily be carried in the navigator's bag.

RADAR

Radar, an acronym for *radio detection and ranging*, is also an outgrowth of World War II. Radar is also discussed at length in Chapter 9, but briefly described here. It consists of a transmitter and a highly sensitive receiver. It transmits and receives in rapid succession and, by measuring the time until the reflected signal is received, converts this time to a distance, and shows an electronic image of the radar target on a display screen termed a *plan position indicator* (PPI). Radar is used both for navigation, to provide an all-weather electronic image of the vicinity of the vessel, and for collision avoidance. Radar can also be used to detect and warn of areas of precipitation (e.g., rain, hail, or snow). Radar can be coupled with GPS, Loran-C, and other onboard electronics. Even as recently as a few years ago, the mere thought of including radar in a course designed for small boat navigation would have been foolish. But rapid technological progress has brought down the price of radar, to the extent that this device is affordable by many small boat operators. The lowest priced radar sets are in the $1,000 to $2,000 price range as of this writing.

SPARE BATTERIES

The portable electronic tools described in this chapter typically use batteries as a source of power, although some are equipped to use the boat's power supply. To ensure the availability of these portable electronics, it is necessary to carry a plentiful supply of spare batteries of appropriate sizes. Some equipment requires special-purpose batteries that are not typically available at marinas or local stores.

ANCHOR

Except in unusual circumstances (e.g., when running an inlet), it is possible to stop the boat to give the navigator time to think, consult publications, and make deliberate decisions. Running a boat is fundamentally different from piloting an aircraft in this regard. When faced with continuing uncertainty over the vessel's position, proximity to navigational hazards, or the proper course of action, the wisest choice is to stop and think. In this sense, it is appropriate to consider the vessel's anchor as one of the navigator's most important tools!

CONCLUDING COMMENTS

The tools and instruments listed above span a great range of uses, sophistication, and prices. (Compare a ten cent No. 2 pencil with modern radar!) Navigators must choose which tools are appropriate to their needs and budgets.

Relevant factors include the size and configuration of the vessel, waters cruised, prevailing weather, and the availability of ATONs. At a minimum, a watch, charts, relevant publications, pencils, plotter, dividers, a hand-bearing compass, a slide rule or calculator, portable navigation receiver, and some device for measuring water depth should be on board.

Student reaction to the extensive list of equipment presented in this chapter and, indeed, the formal navigation techniques presented elsewhere in this text is sometimes skeptical. A commonly heard remark is to the effect, "I don't need all of this gear or to use such formal techniques; I either remain in inland waters or venture only a few miles offshore." The most cogent response is to note that, according to USCG SAR statistics, fewer than 10% of all SAR cases occur more than ten miles offshore. More than 90% of SAR cases occur on inland waterways or within ten miles of shore. Staying close to shore does not eliminate incidents or the need to navigate with precision. Indeed, bluewater sailors know that just the opposite is true. The most accurate navigation is necessary in coastal waters, a point made in Chapter 1.

Of course, mere possession of a sophisticated navigational tool or instrument does not guarantee its proper use or confer immunity from trouble. Nonetheless, the proper tools and instruments used with skill and judgment certainly lower the likelihood of incident. **This said, the most important navigator's tool is an alert and inquiring mind, and the most important quality is constant vigilance.**

SELECTED REFERENCES

Aczel, A. D., (2001). *The Riddle of the Compass, the Invention That Changed the World*, Harcourt, New York, NY.

Anonymous, (1996). Battle of the Level Binoculars, Canon is our choice for self-stabilizing binoculars over the heavier and more costly Fujinon. *Powerboat Reports,* Volume 9, Number 3.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA) Marine Navigation Department web site (http://www.nima.mil/).

Brogdon, W., (1995). *Boat Navigation for the Rest of Us—Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Budlong, J. P., (1977). *Shoreline and Sextant, Practical Coastal Navigation,* Van Nostrand Reinhold Co., New York, NY.

Coote, Capt. T. O., (1988). *Yacht Navigation—My Way,* W. W. Norton & Co., New York, NY.

Eyges, L, (1989). *The Practical Pilot,* International Marine Publishing Co., Camden, ME.

Lecky, S.T.S., revised and enlarged by Bowen, G.P., (1942). *Wrinkles in Practical Navigation,* Twenty-Second Edition, D. Van Nostrand Company Inc., New York, NY.

Maloney, E. S., (1983). *Chapman, Piloting, Seamanship and Small Boat Handling,* Hearst Marine Books, New York, NY.

Markell, J., (1984). *Coastal Navigation for the Small Boat Sailor,* Tab Books, Blue Ridge Summit, PA.

Melton, L., (1987). *Piloting with Electronics,* International Marine Publishing Co., Camden, ME.

Norville, W., (1975). *Coastal Navigation Step by Step,* International Marine Publishing Co., Camden, ME.

Waters, D. W. (1958). *The Art of Navigation in England in Elizabethan and Early Stuart Times,* Yale University Press, New Haven, CT.

Wright, F. W., (1980). *Coastwise Navigation,* Jason Aronson Inc., New York, NY.

Van Heyningen, M. K., (1987). The Evolution of the Modern Electronic Compass, *NMEA News,* Jan/Feb.

CHAPTER 5

DEAD RECKONING

"The greatest hazard to navigation is a bored navigator."

–Anonymous, quoted in Schlereth (1982)

Pettingill said he never plots anything on a chart and rarely refers to them. "I don't have to plot; I just know it all by heart"

(Capt. Joseph Pettingill, skipper of the *Little Gull,* who ran the tug aground in four- to five-foot surf off Brigantine, New Jersey, in November 1992, as quoted in *Professional Mariner,* Vol.1, No. 1, 1993.)

INTRODUCTION

Dead Reckoning (DR) is a rather forbidding name given to one of the simplest and most basic techniques of navigation. The origin of this term is lost in antiquity. Some believe that the word "dead" should be written "ded," a contraction for "deduced," because the method deduces the future position of a vessel from a present (or past) known position and knowledge of the course steered and speed maintained (see Hewson, 1983). The Dutch equivalent, "ruwe berekening" (rough estimate) and the French "route estimée" are clearer in this regard (Hewson, 1983).

Others believe that the term originated with the activity of throwing a piece of wood (a so-called Dutchman's log) in the water from the vessel's bow, and measuring the length of time taken for the vessel's stern to pass the log (which was, by hypothesis, "dead" in the water) to form a crude estimate of the vessel's *speed through the water* (STW). Still others with a more macabre sense of humor believe that "dead" is used to describe your future condition if you don't follow this procedure carefully!

Whatever the origin of the term, professional navigators believe that DR is one of the most important navigational techniques. Piloting and electronic or celestial navigation are not in themselves complete systems of navigation—just names given to describe ways of checking the accuracy of DR positions. It is important to remember that sophisticated electronics can (and do) fail, cloud cover can prevent observation of celestial bodies, and poor visibility can prevent *aids to navigation*

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WHAT YOU WILL LEARN IN THIS CHAPTER

- ***Definition of dead reckoning***
- ***How to prepare DR plots***
- ***Definition of various terms related to course, heading, bearing, and speeds***
- ***Rules of construction of DR plots***
- ***Time-speed-distance calculations***
- ***How to prepare and interpret a speed curve***

(ATONs) or other visual references from being seen and identified. In such circumstances, it is particularly important to be able to estimate a vessel's position. An estimate derived from DR may be all that is available.

DR is a relatively simple, some would even say crude, method of navigation. Crude though it may be, history shows that it is possible to accomplish great feats of navigation solely by means of DR. The great Genoese navigator, Christopher Columbus, for example, was by all accounts a superb DR navigator, and his historic voyages were completed almost solely by the use of DR. Even today, with all the advances in the art and science of navigation, from computers to use of navigational satellites, the ability to maintain a competent DR plot is considered one of the essential skills of the navigator.

This chapter provides the basics of DR, nomenclature, symbols, conventions (rules) for preparing DR plots, and a discussion of how a vessel's speed curve is prepared and used. The material in this chapter is closely related to that presented in Chapter 6. Therefore, it is a good idea to read through both chapters briefly before studying this chapter in detail.

NOMENCLATURE AND PLOTTING CONVENTIONS

Much of the material in this and the next chapters is concerned with nomenclature and conventions for constructing DR plots. There is, unfortunately, no universal agreement on these definitions and conventions. Plotting symbols employed in Great Britain, for example, differ substantially from those used in the United States or Canada. (Once again, we appear to be divided by a common language.) Even within the United States, there are differences in practice and convention—as any careful comparison of the excellent texts given in the references for this chapter will reveal. The *United States Coast Guard Auxiliary* (USCGAUX) and the *United States Power Squadrons* (USPS) have agreed to a common set of plotting conventions that are presented in this text.

Definitions and conventions are sometimes tedious reading, and many a student is tempted to try expedient shortcuts, or to become impatient with an instructor who "nitpicks." Resist this temptation! It is important that a common set of definitions is employed and, likewise, important that common plotting conventions are used. After all, when you hand over the watch to another navigator, it is essential that he/she be able to understand chart notations, the log, and other pertinent voyage information. Take the time to be disciplined, to prepare neat plots, and to record all pertinent information when obtained. The midnight to 4 A.M. watch is no time to have to reconstruct earlier plots or to sort out whether a particular chart notation represented a DR position, estimated position, or fix! As you gain experience (or develop a "seaman's eye", as discussed in Chapter 12), you will be better able to judge just how much information to record and the appropriateness of various shortcuts. For the present, take the time to study this material carefully until the preparation of DR plots is second nature.

UNITS, SIGNIFICANT FIGURES, AND PRECISION

Before discussing DR and plotting conventions, it is useful to address the question of accuracy, precision, and significant figures used in small boat navigation. These are related but distinct concepts. Accuracy refers to the closeness of a measured or estimated value to the true (but often unknown) value. Precision correctly refers to the repeatability of a measurement, but is used here to denote the "fineness" of the degree of measurement, or number of decimal places, if you will. Table 5-1 presents the generally accepted limits of precision used for small boat navigation. A vessel's speed (and related speed terms defined in this

GENERIC CONCEPT	ILLUSTRATIVE QUANTITIES	MEASURED OR REPORTED TO
Position	Latitude Longitude	Nearest 0.1'
Direction	Course/Heading Bearing Deviation Variation Current Set	Three digits to nearest whole degree
Speed	Speed Speed Through Water Speed of Advance Drift	Nearest 0.1 knot or statute mile per hour
Distance	Distance Cross-Track Error	Nearest 0.1 nautical or statute mile unless otherwise specified
Time	Time to Go Fix Time Estimated Time of Arrival	Four digits to nearest minute unless otherwise specified

TABLE 5-1–Standards of Precision Used in Small Craft Navigation

chapter), for example, is generally taken to the nearest 0.1 knot (or statute mile per hour where this unit is employed). Thus, the value 4.0 knots is written to distinguish it from, say, 3.9 knots or 4.1 knots. Technically, 4 knots as written means any number between approximately 3.5 and 4.5 knots and, therefore, is different from 4.0 knots. Those who insist on being formally correct label charts with the precision of the measurements shown in Table 5-1. This text is less formal and, for example, would use 4 knots and 4.0 knots interchangeably (it being understood that, unless otherwise specified, speed is measured to the nearest 0.1 knot). (In some of the numerical examples presented in this text, a greater number of decimal places may be shown to enable the reader to follow the calculations or to avoid round-off error. In the end, however, all values should be rounded to the limits given in Table 5-1.)

DEAD RECKONING DEFINED

The practice of estimating position by advancing a known position for courses and distances run is called *dead reckoning* (DR). It is generally accepted that the *course* (C) known to have been steered and the *speed* (S) or *speed through the water* (STW) are used in the preparation of a DR plot. The DR plot is always started from a *known position* or fix and always restarted at the time another fix is determined.

The effects of current and wind drift are not considered in determining a position by dead reckoning. A position determined by use of course and speed alone is termed a *dead reckoning position* (DR position). The term dead reckoning is sometimes erroneously used to refer to the determination of a predicted position by use of the course and speed expected to be made good over the ground taking into consideration the effects of wind and current. Although positions determined by consideration of these other factors might be superior in some respects, they are properly termed *estimated positions* (EP), and not DR positions.

DR plots are used for two basic purposes:

❏ First, a DR plot is used for overall voyage planning. Voyage planning includes the determination of the overall course(s) and speed(s) to be run, identification of checkpoints or waypoints where courses or speeds are to be changed or the vessel's position determined, fuel or amenity stops, or points of interest. In short, the voyage plan describes the intended trip in general terms sufficient for planning purposes. These plans are developed in sufficient detail to ensure adequate fuel reserves (see Chapter 11) and safe passage. The plan is best made in the comfort of your home or office or on the vessel while still at the dock.

❑ Second, a DR plot is maintained while underway to reflect the vessel's actual progress and position. This tactical DR plot reflects all the factors that may alter plans—a late start, unplanned diversions, winds or currents different than anticipated. This on-the-water tactical DR plot may not be as elaborate or neat as the voyage plan (or planning plot) but makes up in accuracy for what it loses in appearance. Both types of plots are included in this discussion.

ELEMENTS OF DEAD RECKONING

In the process of dead reckoning, courses are drawn on the chart as solid lines from a known position (usually a point of departure) or a fix. Course lines are identified by their true direction, which is written preceded by a "C" on top of, and parallel to, the course line in the usual three digits (e.g., 000 for North); the degree sign (°) is implicit and is omitted. Unless otherwise specified, courses are measured relative to true north. If the course is specified relative to magnetic north, an "M" is written after the course.

Beneath the course line is written the speed being run by the vessel. As noted, the vessel's speed is normally written in nautical miles per hour, knots using an "S" followed by one, two, or three digits. Speed can generally be measured to the nearest tenth of a knot and, so, one decimal place is used. The speed may also be indicated in statute miles per hour if distances are customarily measured in statute miles on the chart being used. The abbreviation kn., kt., or mph is not necessary and is omitted. The distance to the next objective (e.g., the end of a course leg, turn point, or other waypoint) may be written next to the speed with a "D" followed by the distance (to the nearest 0.1 mile).

The position where the vessel would be expected to be, after running a specified course at a specified speed for a particular length of time (expressed in hours and minutes), is calculated, the resulting distance is marked off on the course line, and the DR position is plotted. The DR position is labeled by a dot surrounded by a semicircle (or partial circle) and the time, using the 24-hour system, is written on the chart at an angle to the horizontal.

As a historical aside, Pérez-Reverte (2000) quotes Gabriel de Ciscar in *Curso de Estudios Elementales de Marina* as follows, "The location at which the ship finds itself as a result of prudent judgement only, or of data about which there is considerable uncertainty, is called the reckoning point." Elsewhere in this same book, he notes that in the era of sail mariners termed a position determined solely by dead reckoning the "point of fantasy." Whatever its limitations, the DR position provides a useful indication of the vessel's positon.

BEGINNINGS: ILLUSTRATIVE DR PLOTS

Figure 5-1 shows an illustrative DR plot that might be suitable for a powerboat. This plot shows a portion of a voyage in Buzzards Bay on the 1210-Tr chart. At 1:00 P.M. (1300), the vessel fixes its position using a *Global Positioning System* (GPS) receiver (see Chapter 9) in the vicinity of buoy "BR" (Qk Fl G) north of Quicks Hole. A circle with a dot in the center is used as the symbol for a fix, with the figure 1300 (to denote the time) written parallel to one of the chart axes, and the letters GPS to denote the basis of the fix. The vessel proceeds on course 000 true at a speed of 6.1 knots as shown by the labels above and beneath the course line respectively. (As discussed below, the direction is taken to be with respect to true north unless otherwise specified; so it is not necessary to use a special chart label to denote true. Likewise, as noted above, "degrees" are understood to be the unit of angular measurement unless otherwise specified; so, no degree symbol is employed.) A DR position is plotted at 1335, written at an angle to the course line, to show the time when the vessel changes course (or will change course) to 057. The DR position is shown by the semicircle. For route segments that involve course changes, as is

▲ **FIG. 5-1**–An Illustrative DR Plot

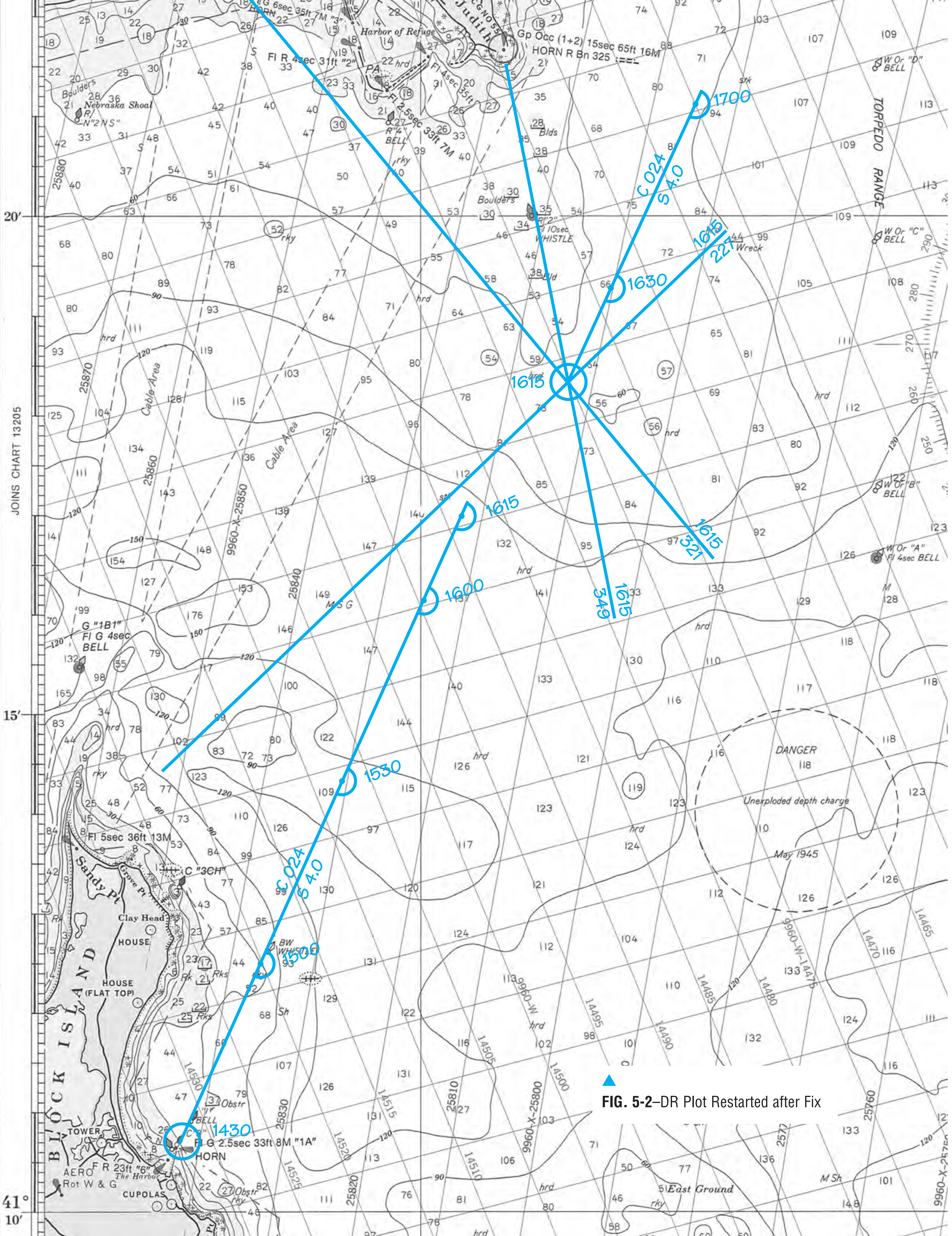

FIG. 5-2–DR Plot Restarted after Fix

DATE: **VESSEL:** **NAVIGATOR:**

	Position		Course			Speed		
Time	**L:**	**Lo:**	**Compass**	**Magnetic**	**True**	**RPM**	**STW**	**Remarks**

TABLE 5-2–An Illustration of a Ship's Log Format

the case in Figure 5-1, a partial circle is used. At 1426, another DR position is plotted where the vessel changes course to 152 (speed maintained at 6.1 knots). At 1447, another DR position is plotted at the course change to 228 for the return trip. At 1518 the vessel's speed is slowed to 4 knots (written 4.0 on the DR plot), shown by the semicircle, etc. This simple DR plot shows the DR positions, course legs, times, and speeds for each leg of the voyage.

For clarity, the turn points in the DR plot shown in Figure 5-1 were drawn in the open water. In well-marked waters, it is convenient to plan course "legs" so as to begin or end near buoys, along the lines defined by ranges, or at other locations where the vessel's position is easily determined. For example, the 1426 turn point shown might be difficult to verify in practice (without a GPS or Loran-C receiver aboard). But that is getting ahead of the story. The purpose of Figure 5-1 is simply to illustrate DR plotting conventions.

Figure 5-1 illustrates many of the symbols and conventions employed for DR plots. Normal practice is to start the plot at a point of departure, denoted a circle with a dot in the center. Courses and speeds are appropriately labeled, and DR positions (and times) are plotted at each course or speed change. Although not shown on Figure 5-1 to avoid a cluttered appearance, DR positions would also normally be plotted at regular intervals (typically every half hour or hour) and whenever a fix or line of position (see below) is determined. Finally, Figure 5-1 omits writing a course and speed on the leg beginning at 1606, as this is only an excerpt from the DR plot.

Figure 5-2 shows another DR plot. The voyage begins at Block Island. Here there are no planned course or speed changes, and DR positions are shown on the hour and half hour as would be more typical for small craft navigation in pilot waters. At 4:15 P.M. (1615), the vessel is able to fix its position by taking three bearings on land-based objects. (Fix labels and plotting techniques are discussed in Chapter 6). Accordingly, the position represented by the fix is plotted as a circle with a dot in the center. For reasons that will be apparent in Chapter 7 on current sailing, a DR position is typically plotted at the time of the fix. Finally, the tactical DR plot is renewed (started again) *from the fix determined at 1615 and not from the 1615 DR position*. The

IS ALL THIS REALLY NECESSARY?

Students frequently ask this question. They note from their experience that most recreational boaters do not go to the trouble of making a DR plot and updating it with fixes. The short answer is "not always." Cruising in familiar and easy-to-navigate waters may not require formal plotting. However, in more challenging waters or those less familiar to the navigator, some planning and plotting is essential. "Navigating by Seaman's Eye", as it is called, can have disastrous consequences. The magazine, Professional Mariner, has a semiregular feature "maritime casualties" which chronicles such misadventures. Failure to maintain a DR plot is a common explanation for accidents. Here are a few samples:

- ❑ The mate of a Reinhauer tugboat drove a loaded barge up onto the rocks outside of New London, Connecticut, in December 1992. He was navigating by eyeball and became confused over the identity of buoys and reportedly did not fix his position on a chart nor plot a course into the harbor.
- ❑ The Norwegian cruise ship *Starward* ran aground on the island of St. John (U.S. Virgin Islands) in February 1994. Among the causes of this grounding, according to *United States Coast Guard* (USCG) sources, was the failure of the crew to plot DR positions or to determine set and drift of current.
- ❑ The mate of the 989-foot freighter *Indiana Harbor* drove directly into the Lansing Shoals Light in September 1994. According to USCG sources, the mate was navigating by "eyeball" without plotting his position and failed "somehow" to notice the lighthouse ahead of the ship.
- ❑ The first mate of the 207-foot cruise ship *Camden* grounded his ship on rocks in Penobscot, Maine, in September 1992. The mate lowered the vessel's speed, sounded fog signals, and monitored progress by radar. Nonetheless, he did not plot the ship's position nor maintain a DR track.

Each of these incidents was preventable. Each resulted in regulatory action to suspend the license of the mariners involved. Presumably, none of these officers would now ask the question, "Is all this really necessary?"

practice of restarting a tactical DR plot at a fix increases the accuracy of subsequent DR positions, to minimize cumulative errors arising from factors neglected in the preparation of the DR plot.

SHIP'S LOGS—A COMPLEMENT TO THE TACTICAL DR PLOT

The above examples show that a properly prepared DR plot can be both self-contained and informative. Even so, a ship's log is a useful complement to the DR plot. There are probably as many proposed formats for pages in a ship's log as there are textbooks on navigation. The essentials of the log are summarized in Table 5-2. In addition to the "header" entries, columns are provided for time, position (latitude, longitude), course (compass, magnetic, true), engine speed (in *revolutions per minute* [RPM]), vessel speed, and a space for remarks. (Remarks could include weather information, a brief discussion of the impertinence of Mr. Christian, and plans for subsequent disciplinary action.) The time-honored ship's log is the official record of the voyage. Later in Chapter 7 on current sailing, a somewhat more elaborate worksheet is presented, but the essentials are shown in Table 5-2.

The log provides space for noting relevant calculations (in the "remarks" section), and other information that is not shown on the DR plot. Normally, the log book entries and the tactical DR plot are prepared at the same time. In some circumstances, for example, on long distance cruises, the helmsman will make entries into the ship's log, and

INFORMAL LOGS

Many recreational boaters do not prepare a formal log as discussed in this chapter—or for that matter a DR plot. Nonetheless, even if a formal log or DR plot is not justified, it is important to write down, at least, the courses, times, and fixes. The entries in this abbreviated log will be sufficient to get you home. Professional skippers always have an approximate idea of their vessels' positions. Skippers who don't note courses and times are likely to become lost unless in very familiar waters.

the navigator or captain will update the DR plot at a later time. But normally, the entries in the ship's log and the updating of the tactical DR plot are contemporaneous.

DR PLOTS FOR SAILING VESSELS

(This section is somewhat more technical and may be omitted without loss of continuity.) The preparation of DR plots for sailing vessels presents some novel aspects. This is because, unlike power vessels that can choose courses and speeds almost at will, sailing vessels have some unique operating restrictions. In particular, sailing vessels cannot sail directly against the wind nor, for that matter, usually any closer than within approximately plus or minus 35° to 45° of the direction from which the wind is blowing. The sailing vessel's speed through the water is a complex function of the boat length, design, sail trim, sea state, wind speed, and direction of the wind relative to the course. (For a fixed wind direction, a so-called *polar diagram* that varies with the wind speed and is unique to each vessel design describes the relation between boat speed through the water and course.) Therefore, when proceeding in an upwind direction, the sailor traverses the overall course in a series of "tacks"—short legs off the wind an appropriate number of degrees. The determination of the proper angle of these tacks relative to the desired overall track line is a matter for optimization. Small angles act to minimize the extra distance covered, but boat speed is adversely affected if the vessel sails too close to the wind. Large angles increase the average speed through the water but also increase the total distance that needs to be covered relative to the rhumb line course. For any given vessel, prevailing wind, and current, there is an optimal tack sequence that minimizes the time taken to travel between any two points. The determination of this optimal sequence is a sophisticated topic well beyond the scope of this course in navigation, but is addressed (at least implicitly) in some of the texts referenced at the end of this chapter.

For purposes of this chapter, it is sufficient to note that the various tacks can be diagramed on a DR plot, which presents a "hemstitched" (zigzag) appearance as shown in Figure 5-3. This figure assumes that the desired track is directly upwind (e.g., overall course is 090 and the wind is from 090) and that the vessel cannot sail any closer to the wind than 45°. In this illustration each separate tack is identified with course, speed, and DR positions at the turn points. In this case, the DR positions on the hour and half hour coincide with the turn points. Additionally, DR positions should be plotted whenever a fix, running fix, or LOP is determined. If the tacks are short, as would be the case, for example, in a narrow river, this detail is generally omitted and factored instead into a reduced speed through the water. But, if the tacks are of appreciable length, diagrams such as shown in Figure 5-3 should be used. In blue-water or ocean sailing, depending upon the circumstances, individual tacks could be quite long, a matter of several hours or even days. In such cases it would be particularly important to plot these tacks as actually sailed. On courses that are not directly upwind, the sailing vessel would be functionally equivalent to a power vessel, and so, too, would be the resulting DR plots.

When a sailboat has to tack upwind, the actual distance sailed between any two points can be substantially greater than the rhumb line (straight-line) distance. If a sailboat were forced to tack at an angle, theta, to the desired track line, the actual distance covered compared to rhumb line distance will be increased by a factor

FIG. 5-3–DR Plot for a Sailing Vessel Showing Individual Tacks

1/cos[theta]. Thus, for example, if theta were 45°—as it is in the illustration in Figure 5-3, the actual length of the "hemstitched" course through the water would be greater than the rhumb line distance by some 41%. Consequently, the speed made good (absent current or leeway) along the rhumb line would be only approximately 71% of the speed through the water. In fact, the actual situation is somewhat worse than the idealized diagram in Figure 5-3 would indicate. This is because the wind tends to blow the boat farther downwind of the course steered. The angle between the course steered and the course over the ground due solely to wind effects is termed leeway and can amount to 5 degrees or more. (Leeway or current would not be shown on a DR plot but would affect the overall ground speed attained. Power vessels are also affected by leeway, which can be particularly important for slow-moving vessels with a large surface area above the waterline. Consult the references at the end of this chapter for details.) Sailboats take longer to complete a voyage than power craft, not only because of their hull design and generally slower speeds through the water, but also because of the additional track length required for tacking upwind. Because the extra distance covered can be material in certain circumstances, it is necessary to go to the trouble of factoring tacks into the DR plot. Laying out the tacks is also important to ensure that the sailing vessel remains in safe waters. If there is not sufficient safe water (sea room) to accommodate these tacks, the sailing vessel has little alternative but to await more favorable winds or turn on the "Iron Genoa" (engine).

Finally, winds are often quite variable and, therefore, the tacks may have to be adjusted from those originally planned. Consequently, the navigator aboard a sailing vessel may have to make frequent revisions to the DR plot to "stay with the vessel." Navigators aboard power vessels also have to adjust DR plots, but with less frequency. Little wonder, then, that sailboat navigators get to stay in practice!

DEAD RECKONING TERMS DEFINED AND ILLUSTRATED

There are several important terms used in the practice of dead reckoning. These terms are defined and explained below:

- ❑ ***Course*** (C): Course is the average heading and the horizontal direction in which a vessel is intended to be steered, expressed as the angular distance relative to north, usually from 000 at north, clockwise through 359 from the point of departure or start of the course to the point of arrival or other point of intended location. The reference direction is true and if so used, need not be labeled. However, some navigators find it more convenient to also use magnetic courses. These magnetic courses are labeled after the three-digit direction with the letter "M." Others have advocated going one step further and indicating compass courses, labeling them with the letter "C." This practice is discouraged, since a compass course depends upon the value for deviation on that heading. Deviation can change with time as discussed in Chapter 2. The result is that course lines left on charts for long periods of time may bear no relation to the correct value if they have been labeled as compass courses and the deviation has changed.
- ❑ ***Course of Advance*** (COA): This indicates the direction of the intended path to be made good over the ground.
- ❑ ***Course over Ground*** (COG): This indicates the direction of the path actually followed by the vessel over the ground, usually an irregular line.
- ❑ ***Course Made Good*** (CMG): This indicates the single resultant direction from a point of departure to a point of arrival or from waypoint to waypoint. (Synonym: Track Made Good)
- ❑ ***Current:*** The horizontal velocity (speed and direction) of water over ground. (See Chapter 7 for a more complete definition.)
- ❑ ***Dead Reckoning*** (DR) **Position:** A position determined by dead reckoning.
- ❑ ***Dead Reckoning Plot:*** A DR plot is the charted movement of a vessel as determined by dead reckoning.
- ❑ ***Drift:*** The speed in knots at which the current is moving. Drift may also be indicated in statute miles per hour in some areas—the Great Lakes, for example, or other areas for which nautical charts are based on units of statute miles. This term is also commonly used to

mean the speed at which a vessel deviates from the course steered due to the combined effects of external forces such as wind and current.

- ***Estimated Position*** (EP): An improved position based upon the DR position and which may include, inter alia, factoring in the effects of wind and current, or a single line of position.

- ***Line of Position*** (LOP): A line of bearing to a known origin or reference, along which a vessel is assumed to be located (see Chapter 6, Line of Position). An LOP is determined by observation (visual bearing) or measurement (e.g., radar). An LOP is assumed to be a straight line for visual bearings, or an arc of a circle (radar range), or part of some other curve such as hyperbola (loran). LOPs resulting from visual observations (magnetic bearings) should be converted to true bearings prior to plotting on a chart.

- ***Fix:*** A known position determined by passing close aboard an object of known position or determined by the intersection of two or more LOPs adjusted to a common time, determined from terrestrial, electronic, and/or celestial data (see Chapter 6). The accuracy, or quality of a fix, is of great importance, especially in coastal waters, and is dependent upon a number of factors. LOPs must be based on known and/or identified sources. Fixes determined based on the charted positions of buoys need to be regarded with particular suspicion (conservative navigators would not regard these as fixes at all), because floating aids may be off station. (See Chapter 6 for more details.) The angle between the intersecting LOPs is important. For two bearings, the ideal angle is 90°. If the angle is small, however, a slight error in measuring or plotting will result in a relatively large error in the plotted position. LOPs from visual bearings to nearby objects are preferable to those obtained from objects at a distance. The most accurate visual fix is obtained from three objects above the horizon 50° to 70° (or 110° to 130°) apart in azimuth. A dead reckoning plot is always renewed at a fix or running fix.

- ***Heading*** (HDG): The instantaneous direction of a vessel's bow. It is expressed as the angular distance relative to north, usually 000 at north, clockwise through 359. Heading should not be confused with course. Heading is a constantly changing value as a vessel yaws back and forth across the course due to the effects of sea, wind, and steering error. Heading is expressed in degrees of true, magnetic, or compass direction.

- ***Position:*** On the earth, this refers to the actual geographic location of a vessel defined by two parameters called coordinates. Those customarily used are latitude and longitude. Position may also be expressed as a bearing and distance from an object, the position of which is known.

- ***Running Fix*** (RFIX): A fix obtained by means of LOPs taken at different times and adjusted to a common time. This practice involves advancing or retiring LOPs as discussed in Chapter 6.

- ***Set:*** The direction in (towards) which the current is flowing. This term is also commonly used to mean the direction in which a vessel is being deviated from an intended course by the combined effects of external force such as wind and current.

- ***Speed*** (S): The rate at which a vessel advances relative to the water over a horizontal distance. When expressed in units of nautical miles per hour, it is referred to as knots (kn. or kt.). One knot equals approximately 1.15 statute miles per hour.

- ***Speed Made Good*** (SMG): Indicates the average speed actually accomplished relative to the ground.

- ***Speed of Advance*** (SOA): Indicates the speed intended to be made relative to the ground along the track line.

- ***Speed Through the Water*** (STW): The apparent speed indicated by log-type instruments or determined by use of tachometer and speed curve or table, at a particular point in time.

- ***Speed over Ground*** (SOG): The actual speed made good at any instant in time with respect to the ground.

- ***Track*** (TR): The intended horizontal direction of travel with respect to the ground. (Synonym: Intended Track, Track Line)

SUBTLETIES IN THE DEFINITIONS LISTED ABOVE

On quick reading, many of the terms listed above may appear quite similar—and, indeed, some are nearly identical. But, there are some subtle differences that are drawn. This section explores some of the similarities and differences among the above terms.

The basis for distinction among some of these terms relates to the difference between average and instantaneous values. For example, course relates to the average direction of travel. A helmsman may attempt to maintain a course of 090 degrees but, for a variety of reasons (e.g., motion of the sea, collision avoidance), the heading of the vessel might vary from 080 to 100 degrees. The course steered may average 090, but at a given instant in time the heading might be 097. The average of the heading values will equal the course steered, however. The reader may be puzzled by the subtlety: is this a distinction without difference? Emphatically not! The course (090 in this illustration) is the appropriate variable to be plotted on the DR plot. But, suppose a relative bearing of an ATON were observed to be 045 while the vessel was heading 097. You need to add the vessel's magnetic heading (not the course) to the relative bearing to calculate a magnetic bearing (142 in this example, assuming no deviation). When taking such a bearing and calling "mark" to the helm, the helmsman should answer 097 (the heading), not 090 (the course)—hence, the need to distinguish between these concepts. Not all such distinctions are equally meaningful, however. The distinction between speed (average speed) and speed through the water (instantaneous speed) is less important for most applications and, therefore, these terms are used interchangeably in this text. Strictly speaking, it is speed, rather than STW, that should be shown on the DR plots, but this distinction is academic.

Another basis for distinction between the concepts defined above is the plane of reference. Course, for example, is defined relative to the average heading. But, CMG refers to the average progress relative to the ground or earth. Likewise, speed is defined relative to the water, whereas SMG is relative to the ground. You steer a course and maintain a speed, but these are elements of relative motion. The CMG and SMG refer to the vessel's actual progress relative to the earth and, hence, refer to what is termed true motion. (Current accounts for the difference between these two concepts—the horizontal flow of water relative to the earth as is discussed in Chapter 7 on current sailing.) As with CMG and SMG, COG and SOG are defined relative to the ground, but COG and SOG relate to the actual

WHAT IS A POSITION?

In this chapter, a position is defined in terms of coordinates (latitude and longitude). Some experienced mariners would challenge this definition as being excessively narrow. To them, a position only has relevance when plotted on a chart and correctly interpreted. For example, does the position described by the fix indicate that the vessel is along the intended track at the "proper" time? If so, there are no currents or these currents have been correctly compensated for in the selection of the course. Does the position indicate that the vessel is standing into danger? If so, adjustments must be made to avoid the danger and return the vessel to the intended track. Does the position indicate that an intended turn point is near? If so, preparations are made to change the vessel's course.

Professional navigators know the approximate position of their vessel at all times—regardless of whether or not they know the specific coordinates of this position. Moreover, professional navigators have situational awareness—they are aware of the position of the vessel with respect to their intended track and possible hazards to navigation. If hazards are close by, the professional navigator pays much more attention to the vessel's exact position.

(often irregular) path of the vessel's progress with respect to the earth, while CMG and SMG relate to the average course and speed traveled with respect to the earth. As a practical matter, COG and SOG are relatively unimportant—CMG and SMG are the key terms here.

The basis for distinction between yet other terms defined above refers to the distinction between *anticipated or planned events* and *actual events*. The terms track and COA are synonymous and refer to the planned route for the vessel with respect to the ground. So, too, does CMG, but the distinction between these terms is that COA is an intended path, whereas CMG is what has actually occurred. Thus, on the basis of forecast or estimated currents, a course may be set in order to achieve a certain track or COA, but the net result with the actual currents is the CMG. If the forecast or estimate was accurate, then the COA and CMG will be virtually identical. Otherwise, these will be different, and the difference is meaningful. Similarly, the SOA is the intended or estimated speed along the track with respect to the ground, but the SMG is the actual ground speed determined after the fact.

In subsequent chapters, the meaning and use of these terms will become more familiar. For purposes of this chapter, the key terms needed are speed, course, DR position, LOP, and fix or departure point.

ACCURACY OF DR PLOTS

Students frequently ask about the accuracy of DR plots, so it is appropriate to address this topic. Unfortunately, there are no hard and fast rules for determining the accuracy of a DR position. Brogdon (1995) notes that the USCG estimates that the probable error in a boat's DR position is approximately 15% of the distance traveled—but this rule of thumb is very approximate.

The factors contributing to error in DR positions include all the elements of current (see Chapter 7) such as leeway and helmsman's errors. These factors vary with the circumstances of the voyage. Tidal and other currents often affect river voyages. These are typically oriented along the intended track, so that lateral errors in position are not large—even if the vessel is ahead of or behind schedule. Experience shows that it is difficult to maintain a constant course. The necessity to avoid traffic, to avoid taking seas at an uncomfortable angle, and helmsman's inattention/distraction all contribute to the variability of the course steered. Hewson (1983) cites an excerpt from early text by John Davis (*Seaman's Secrets*, 1594), which said that one of the reasons why the results found in navigation so often differed from those expected was "the stredge (steerage) may be so disorderly handled so that thereby the Pylote may be abused."

The effects of these errors (current and helmsman's error) over the time period since the vessel's last known position are relevant to the accuracy of DR. Therefore, to a large degree, the navigator can control the accuracy of the DR positions by taking more frequent fixes. Other factors being equal, the accuracy of DR positions will be twice as good if fixes are taken every 30 minutes than if these are taken hourly. Fixes should not be viewed as "happenstance", or chance occurrences, but rather should be deliberately planned for in any voyage considering the location of ATONs, other suitable charted features, and available navigation equipment on board the vessel (e.g., GPS, Loran-C, radar). When you examine a chart and lay out a course to your destination, get in the habit of preplanning fix opportunities. Indeed, the availability of suitable fix opportunities should be one of the important factors in route selection. This subject is developed more thoroughly in Chapter 6.

DR position accuracy is also related to the care taken by the navigator in the preparation of the DR plot. In the age of electronics, where a fix can be taken with no more effort than reading the display of a navigation receiver, there is a temptation to pay less attention to more traditional methods of navigation. Overreliance on automated systems should be avoided, however. It deprives the navigator of the opportunity to maintain necessary skills and (as boaters soon learn) automated systems can fail. Columbus could certainly have benefited from GPS, Loran-C, and radar. But, odds are he would have been a better navigator than most of us equipped with the same tools because he knew well how to live without these advances. (See Morrison, 1942, for a discussion of DR in the age of Columbus.)

SUMMARY OF THE RULES FOR CONSTRUCTION OF DR PLOTS

At this point it is appropriate to

summarize some of the key conventions in the preparation of DR plots. First, with respect to symbols:

- ❑ The circle with a dot inside is used to denote a fix, or running fix. Each DR plot must begin with a circle. The time (4 digits and 24-hour time) is written next to the known position, preferably parallel to one of the chart axes.
- ❑ Courses are drawn with a solid line. The course steered is written above the line beginning with a capital "C" and followed by the true course (in degrees to three digits without the degree symbol). If a magnetic course is written, the letter "M" should follow. Refrain from writing compass courses on the chart, although these should be noted in the ship's log. The speed should be written beneath the course line beginning with a capital "S" and the speed to one decimal place, if known.
- ❑ DR positions are denoted with a semicircle (or partial circle) with a dot inside, and the time (4 digits and 24-hour time) noted at an angle to the course line written nearby.

Second, with respect to plotting conventions:

- ❑ DR positions are to be based solely on the course steered and speed using TSD calculations (see below), and not upon any allowance for current or leeway.
- ❑ DR positions should be plotted at appropriate time intervals (e.g., every hour or every half hour on the hour and half hour, or more frequently if necessary).

HISTORICAL ASIDE— DR PLOTS IN THE AGE OF COLUMBUS

Christopher Columbus used DR almost exclusively. Charts were made of sheepskin. Courses and times were noted. However, charts were not drawn upon. Rather, a divider was used to place a pinprick at the calculated DR position. The process was called by the Spanish fazer or echar punto (to make, or apply the point), or cartear (do the chart). According to Morrison (1942), this was called "pricking the chart" or "pricking it off" by English mariners in the same period.

- ❑ DR positions should also be plotted whenever a fix, running fix, or LOP is determined.
- ❑ DR positions should also be plotted whenever a course or speed change takes place. In the event that numerous course or speed alterations, fixes, or LOPs are performed, the hourly or half-hourly DR positions may be omitted for clarity.
- ❑ A new DR plot should be started whenever a fix or running fix is obtained.

Third, and more generally:

- ❑ Make every effort to produce a neat, uncluttered, and easy-to-understand plot. Measure courses and distances carefully.
- ❑ Keep the plot up to date by recording and annotating fixes and LOPs, etc., as these are taken. Note relevant data and appropriate remarks in a log as well as maintaining the plot on the nautical chart.

REPRISE: VOYAGE PLANS AND TACTICAL DR PLOTS

As noted above, DR plots are prepared both for planning purposes (the voyage plan) and to keep track of the vessel's actual progress (the tactical DR plot). Now that the details of DR plots have been covered, it is appropriate to discuss these plots and their purposes again.

The voyage plan is prepared prior to leaving the dock. It is a complete plot, covering the entire length of the planned voyage, prepared in sufficient detail to ensure that enough fuel is carried, en route and arrival time estimates are approximately correct, a safe route is chosen, and other planning objectives are satisfied. But, because no fixes or LOPs are available at the time that this DR voyage plan is prepared, this plot contains only DR positions (not fixes or lines of position), courses, and other annotations deemed suitable by the navigator. Both times and positions shown on this DR plot may later turn out to be in error. In particular, because the starting time is often uncertain, the navigator may find it more convenient to represent time as elapsed time (e.g., hours and minutes after trip start), rather than clock time.

The tactical DR plot is prepared "as you go" and reflects the actual starting time, actual fixes when determined, and the vessel's actual (as opposed to planned) progress. The tactical DR plot is updated and started again after each fix and shows DR positions whenever an LOP or fix is determined. (See sidebar on fast boat navigation for alternatives to the tactical DR plot.) On a voyage with many legs where numerous course or speed changes are planned, it is not convenient to replot the entire subsequent voyage on the tactical plot whenever a fix is determined, because the chart could become impossibly cluttered. (Moreover, much of this work may be wasted, because additional fixes require renewing the tactical DR plot.) Therefore, the navigator usually plots only the next (few) DR position(s) in sequence on the tactical plot. In short, the navigator uses the tactical DR plot simply to monitor progress and "stay ahead of the vessel." The original DR voyage plan serves as a reference plot, if needed. Of course, if the tactical DR plot shows the vessel to be "impossibly" behind schedule or out of position, it may be necessary to rethink and revise the entire plan. For example, the fuel calculations in the voyage plan may be predicated on the assumption of catching an incoming tide (which will stretch the available fuel as discussed in Chapter 11). A delay in getting started could mean that adverse currents would be encountered. In this situation, it may be wise to redo the fuel budget to ensure

NAVIGATION AT SPEED

Navigation in fast boats (say those capable of 15 knots or more) offers additional challenges and opportunities. These boats often lack the navigational "amenities" such as a chart table, are typically more "lively" (making underway plotting more difficult), but are less affected by current (which increases the accuracy of the planning chart). Operators of fast boats borrow tricks used by aircraft pilots and compensate for the difficulty of maintaining a tactical DR plot by: (1) taking more care in the preparation of the planning chart (greater use of annotations), (2) "precomputing" fix opportunities, and (3) relying on navigational electronics to a greater extent. Thus, for example, mariners will program routes into their navigation receivers made up of a sequence of waypoints (see Chapter 9) and choose courses to minimize the indicated cross-track error (XTE) displayed on the GPS or Loran-C receiver. Preplanned fixes are checked to ensure that bearings, depths, or other readings are "where they are supposed to be." If not, the mariner always has the opportunity to slow down or stop and reassess the situation. Because speeds can be chosen at will, these are selected to facilitate mental calculations. For example, at 30 knots the vessel covers a mile in 2 minutes, at 20 knots, 3 minutes, at 15 knots, 4 minutes. Running at one of these speeds makes it easy to estimate times en route or times to the next waypoint without formal calculation. For useful discussions of fast boat navigation, see Brogdon (1995), Bartlett (1992), Pike (1990), and Kettlewell (1993).

that sufficient fuel remains and, if necessary, divert to alternates to take on additional fuel. Alternatively, courses may have to be recalculated (see Chapter 7) if currents turn out different than anticipated.

It is a matter of judgment and individual choice how these plots are prepared and used. Some navigators lay out the original voyage plan on the chart and maintain the tactical plot on a transparent overlay. Others may use separate charts for this purpose (a more expensive option). Yet others use plotting sheets available in blank pads with only latitude and longitude shown. (This practice is not recommended for coastal navigation, however, because a blank pad does not provide information on hazards to navigation.) Finally, some navigators "rough out" the voyage plan on a series of worksheets and draw the tactical DR plot only on the nautical chart (this practice requires that there is sufficient space on the vessel for plotting). With experience, a satisfactory method can be chosen.

TIME, SPEED, AND DISTANCE

Dead reckoning is accomplished by calculating distance (D) run, or to be run, speed (S) of the vessel, and time (T) of the run. Distance is measured to the nearest tenth of a nautical mile, speed to the nearest tenth of a knot, and time to the nearest minute. If any two of these three quantities are known, the third can easily be computed using the three forms of the basic TSD formula shown below.

- ❑ To calculate distance from speed and time, use the formula,
  D = ST/60,
  where:
  D = Distance (nautical miles),
  S = Speed (knots), and
  T = Time (minutes).
- ❑ To calculate speed from distance and time, use the formula,
  S = 60 D/T.
- ❑ To calculate time from distance and speed, use the formula,
  T = 60 D/S.

It is important to note that the time used in the above equations is the time of the run, or the elapsed time between two DR positions. Since DR positions are to be labeled with their appropriate time, the interval is easy to determine. As noted above, time is indicated in the twenty-four hour system, where 1:00 P.M., for example, is 1300. To determine the interval between two times, simply subtract the smaller time from the larger, by hours and minutes. Remember, however, that there are 60 (and not 100) minutes in each hour. If you do not have enough minutes from which to subtract, "borrow" 1 hour or 60 minutes. If you cross into another day, and pass 2359, reverting back to 0000, then borrow 24 hours from that day, and add them to the old day to make the calculation. Examples of TSD calculations are provided below to illustrate the process of computation and determination of the proper time interval.

Example #l. Solving for distance when speed and time are known: Suppose you are running at 10 knots, how far will you travel in 20 minutes?

Since speed and time are known, the formula to use is:
D=ST/60

Insert the values for S (Speed = 10 knots) and T (Time = 20 minutes):
D = (10) (20) / 60

Carry out the arithmetic:
D = 200 / 60 = 3.3 nautical miles

Example #2. You can make it from your present position to the shipping channel in 3 hours and 45 minutes if you maintain a speed of 10 knots. What is the distance to the shipping channel?

You must use minutes to solve the TSD formula. Convert the 3 hours and 45 minutes to minutes. To do this, multiply 3 hours by 60 (60 minutes in an hour), which is 180 minutes, and then add 45 minutes. Time (T) is 225 minutes.

Write down the appropriate formula: D = ST/60

Compute using information you have for the appropriate variable:
D = (10 knots) (225 minutes)/60
D = 2250 / 60 = 37.5 miles (nearest tenth)

Example #3. Solving for speed when time and distance are known. Assume that it took you 40 minutes to travel 12 miles, what is your speed?

Since distance and time are known, Distance = 12 miles, Time = 40 minutes, use the equation S = 60 D/T = (60) (12) / 40

Carry out the arithmetic:
S = 720 / 40 = 18.0 knots

Example #4. A second problem solving for speed when distance is known and time can be calculated: Your departure time is 2030. The distance to your destination is 30 miles. You want to arrive at 0000 (2400). Obtain the speed you must maintain.

Find the time interval between 2030 and 2400 (2400 will not be displayed on a 24-hour clock. Nonetheless, 0000 is logically equivalent to 2400). To do this, subtract 2030 from 2400. Remember you are subtracting "hours" and "minutes." Determine the time interval as follows (note that 23 hours and 60 minutes is equivalent to 24 hours and 00 minutes):

hr	min	hr	min
24	00	23	60
-20	30	-20	30
		3 hr	30 min

Remember, you use minutes to solve the TSD equation. Convert the 3 hours and 30 minutes to minutes. To do this, multiply 3 hours by 60 (60 minutes in an hour), which is 180 minutes. Add the 30 minutes remaining from step 1. Time (T) = 210 minutes.

Write down the appropriate formula, S = 60D/T, and compute using the information you have for appropriate variables.

S = (60) (30 miles) / 210 minutes

S = 1800/210 = 8.6 knots (as rounded to the nearest tenth)

Example #5. Solving for time when speed and distance are known: You are cruising at 15 knots and have 12 miles to cover before arriving at the next waypoint. What is your estimated time en route (ETE)?

Since distance and speed are known, use this formula:

T = 60D/S where D = 12 miles and S = 15 knots.

Substitute the appropriate values for D (Distance = 12 miles) and S (Speed = 15 knots):

T = (60) (12) / 15 = 48 minutes.

SPEED CURVE

In order to be able to do TSD calculations, it is necessary to be able to have an accurate value for speed. Even if the small craft is equipped with a log of some kind to provide speed indication directly, this device must be calibrated against known speeds to determine any deviation of the indicated speed from actual speed. Small *paddle-wheel* sensors can become fouled, which introduces errors in the indicated speed. For boats equipped only with engine speed indicators (tachometers), some means must be provided to convert engine *revolutions per minute* (RPM) into speed through water. The mechanism used to accomplish calibration of speed logs or tachometers in terms of actual speed through the water is the development of the speed curve, a graphic plot of observed speed versus RPM.

The procedure is simple. A measured distance (often, but not necessarily, one nautical mile) is run at various engine speeds (RPM), in both directions over a set course, and the speeds are measured (calculated from the TSD formula). Ideally, the speed curve is developed on a day when the wind is calm to eliminate wind effects.

The purpose of running the course in both directions is to average out the effects of any current to produce an estimate of the vessel's speed through the water. A plot is made of RPM, usually in increments of 250 RPM, 500 RPM (or other convenient interval), over the range of available engine speeds, against the average measured speed. The resulting curve can be used to predict the resulting speed corresponding to any RPM, or the appropriate RPM for any desired speed. As a by-product for boats capable of getting on plane, this point is clearly evident as a discontinuity in the curve, and the most economical speeds are quickly indicated. This subject is explored in Chapter 11.

It is important to realize, however, that such a speed curve is valid only for the conditions as tested. If the hull is degraded by additional drag from marine encrustation, for example, the speed curve applying to the clean hull is no longer applicable. The hull must be restored to its initial condition or a new curve must be developed. For smaller craft, which are sensitive to load, it may be necessary to develop separate speed curves for different load conditions (e.g., fuel carried and crew aboard).

The speed curve is developed as follows:

- ❑ A measured mile or other measured course is located on the chart or laid out on the shore so that it is visible in an area safe enough for conducting speed trials. Usually, each end of the speed course is denoted by visible range markers, for example, diamond shapes at one end and squares or circles at the other. These ranges form perpendicu-

COURSE DESCRIPTION: ____________________ DATE:
VESSEL:
COURSE LENGTH: 1.00 NAUTICAL MILES HULL CONDITION:
FUEL QTY:
WATER QTY:
NUMBER CREW:

RPM	"OUT" LEG MIN	SEC	CALCULATED SPEED (KNOTS)	"BACK" LEG MIN	SEC	CALCULATED SPEED (KNOTS)	AVERAGE SPEED (KNOTS)	CALCULATED CURRENT (KNOTS)
250	22	24	2.7	19	35	3.1	2.9	0.2
500	20	30	2.9	17	55	3.3	3.1	0.2
750	18	6	3.3	15	48	3.8	3.6	0.2
1000	15	15	3.9	13	15	4.5	4.2	03
1250	12	15	4.9	10	35	5.7	5.3	0.4
1500	9	45	6.2	8	20	7.2	6.7	0.5
1750	7	49	7.7	6	45	8.9	8.3	0.6
2000	6	23	9.4	5	35	10.7	10.1	0.7
2250	5	14	11.5	4	44	12.7	12.1	0.6
2500	4	1	14.9	3	45	16.0	15.5	0.5
2750	3	23	17.7	3	13	18.7	18.2	0.5
3000	3	23	17.7	3	12	18.8	18.2	0.5

NOTE THAT SPEEDS, AND NOT TIMES, ARE AVERAGED. SPEEDS ARE AVERAGED TO THE NEAREST 0.1 KNOT. CURRENTS ARE CALCULATED AS WELL, NOT FOR SPEED CALCULATION PURPOSES BUT RATHER TO ENSURE THAT THE COMPUTATIONS ARE PLAUSIBLE. NOTE HERE THAT ESTIMATED CURRENTS FIRST INCREASE, THEN DECREASE SLIGHTLY, AS MIGHT BE EXPECTED WITH A TIDAL CURRENT.

TABLE 5-3–Illustrative Speed Table

lars to the measured distance course to be run. Alternatively, natural ranges, ATONs, etc., can be used, but the distance between these must be measured on the chart.

- ❑ A table is made up prior to conducting any speed runs. The table consists of several columns: RPM, time of run in initial direction, calculated speed in initial direction, time of run in reciprocal direction (in minutes, or minutes and seconds), calculated speed in reciprocal direction, and the average of the two speeds. For this discussion, rows are indicated for increments of 250-RPM engine speed from 250 RPM up to the maximum permissible engine RPM. The rest of the columns will be filled in during the speed trial.
- ❑ The speed trial is conducted. The boat is taken out to the course, which is determined from the chart, and the direction converted from true to compass for the initial course and from true to compass for the reciprocal course. (Note that each course is developed individually. Remember that the deviation depends on the compass or magnetic heading, and reciprocal headings do not necessarily have the same deviation!)

When the boat is approaching the speed course, it is brought up to the RPM desired and turned on to the course. A stopwatch is started when the vessel at speed crosses the first range and continued until the vessel crosses the second range, when it is stopped. The time is noted on the table, the resulting speed calculated, and the reciprocal course is then run. (If seconds are recorded, these must be converted to decimal minutes by dividing by 60 and adding this fraction to the minutes.) Again, the watch is started upon crossing the range and stopped when crossing the next range. The time is again noted and the resulting speed calculated and entered into the table. The two speeds are averaged and the resulting value entered into the last column in the table. Speed runs are done in each direction to account for the effects of any current. Thus, you end up with a so-called "out" and a "back" leg (terms such as "upwind" or "downwind" are sometimes used). The speeds for each leg are calculated and these speeds averaged. Do not average times and then calculate a single speed. As a plausibility check on the speed curve, compare the calculated current with the estimated current using the methods of Chapter 8.

- ❑ The process is continued for each value of RPM desired, until the table is completely filled out (see Table 5-3).
- ❑ The speed curve is then plotted.

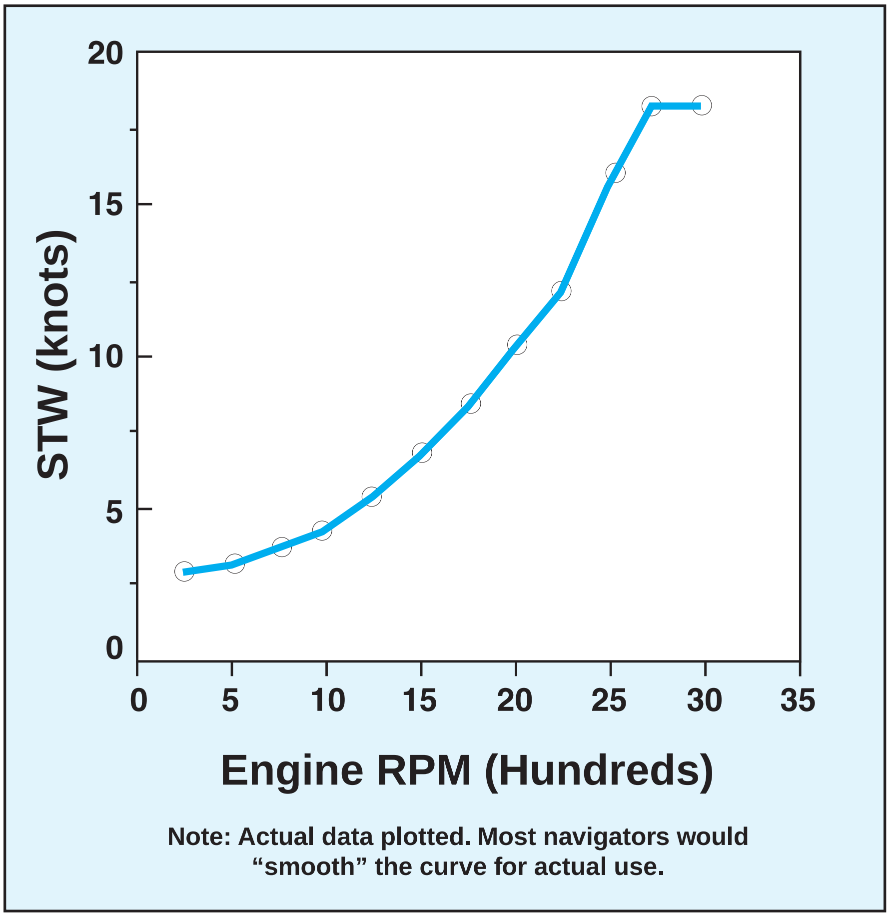

FIG. 5-4–Illustrative Speed Curve Based on Data Taken from Table 5-3

A graph is drawn in an X-Y coordinate system (see Figure 5-4). The X, or horizontal axis, is calibrated for RPM, and the Y, or vertical axis, is calibrated for speed in knots. The values of RPM and Speed are plotted for each pair of RPM/Speed values in the table. Any symbol can be used for the plot. A "smooth" curve may be developed (possibly by eye) through the data points, to refine the estimates, but this is omitted here. Either the graph or the table may be used, subsequently, to determine the speed, which would result for a specific RPM or the RPM, which must be made to accomplish a specific speed. Note that the speed indicated from the curve is speed through the water (STW), not speed over the ground, because the ground speeds have been averaged.

Speed read from the speed curve can be used in the TSD calculations to develop your DR plots. For boats with two engines, it is useful to plot a speed curve for single- as well as twin-engine operation. In the event of engine failure, the curve can be used for estimation of speed. Consult your owner's manual before making single-engine speed runs. There may be limits to allowable RPMs for single-engine operation.

If your vessel is equipped with a navigation receiver (GPS or Loran-C), many of the above steps can be simplified. All (or nearly all) receivers in production today have an option of reading *speed over the ground* (SOG) directly. All that is necessary is to run the out and back legs as discussed above and read the SOG or SMG directly from the display. The out and back leg speeds are averaged as discussed in step 3, above. However, care must be used to ensure that the correct speed is taken from the unit. (Most receivers have the capability to display several speeds including, for example, SOG, SMG, velocity towards destination, and velocity along route. SOG comes the closest to that required for development of a speed curve.) Additionally, depending on the receiver's quality and technical features, such as the averaging time for calculation of SOG, the receiver's estimate may be less precise than if the "timed speed run" method discussed above is employed.

SELECTED REFERENCES

Anderson, J., (1987). *Exercises in Pilotage*, David & Charles, London, UK.

Bartlett, T., (1992). *Navigation at Speed*, Fernhurst Books, Briton, UK.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA), Marine Navigation Department web site (http://www.nima.mil/).

Brogdon, W., (1995). *Boat Navigation for the Rest of Us—Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Collinder, Per., (1995). *A History of Marine Navigation,* St. Martin's Press Inc., New York, NY.

Gotelle, P., (1979). *The Design of Sailing Yachts,* International Marine Publishing Co., Camden, ME.

Henderson, R., (1970). *The Racing Cruiser,* Reilly and Lee Books, Chicago, IL.

Hewson, J.B., (1983). *A History of the Practice of Navigation,* Second Edition, Brown, Son & Ferguson, Ltd. Publishers, Glasgow, Scotland, UK.

Hobbs, R. R., (1974). *Marine Navigation 1, Piloting,* Second edition, Naval Institute Press, Annapolis, MD.

Johnson, P., (1972). *Ocean Racing and Offshore Yachts,* Second edition, Dodd Mead & Co., New York, NY.

Kane, G. R., (1984). *Instant Navigation,* Second edition, Associated Marine, San Mateo, CA.

Kettlewell, J. J., Ed., (1993). *Reed's Nautical Companion,* Thomas Reed Publications, Boston, MA.

Maloney, E. S., (1985). *Dutton's Navigation and Piloting,* 14th edition, Naval Institute Press, Annapolis, MD.

Marchaj, C. A., (1988). *Aero-Hydrodynamics of Sailing,* Revised and Expanded Edition, International Marine Publishing Co., Camden, ME.

Marden, Luis., (1986). The First Landfall of Columbus, *National Geographic,* Vol. 170, No. 5, November, pp. 572, et seq.

Mixter, G. W. (edited by D. McClench), (1967). *Primer of Navigation,* Fifth edition, Van Nostrand Reinhold Company, New York, NY.

Morrison, S.E., (1942). *Admiral of the Ocean Sea, A Life of Christopher Columbus,* Little, Brown and Company, Boston, MA.

Pérez-Reverte, A., (2000). *The Nautical Chart,* (translated from the Spanish), Harcourt, Inc., New York, NY.

Pike, D., (1990). *Fast Boat Navigation,* Adlard Coles Nautical, London, England.

Pocock, M., (1986). *Inshore-Offshore: Racing, Cruising, and Design,* Nautical Books, London, UK.

Saunders, A. E., (1987). *Small Craft Piloting and Coastal Navigation,* Alzarc Enterprises, Scarborough, Ontario, Canada.

Schlereth, H., (1982). *Commonsense Coastal Navigation,* W.W. Norton & Company, New York, NY.

Shufeldt, H. H., and Dunlap, G.D. as revised by Bauer, B.A., (1991). *Piloting and Dead Reckoning,* Third Edition, Naval Institute Press, Annapolis, MD.

Toghill, J., (1975). *The Yachtsman's Navigation Manual,* John de Graft, Clinton Corners, NY.

United States Power Squadrons, (1998). *Plotting & Labeling Standards,* The United States Power Squadrons®, Raleigh, NC.

Waters, D. W., (1958). *The Art of Navigation in England in Elizabethan and Early Stuart Times,* Yale University Press, New Haven, CT.

CHAPTER 6

PILOTING

"Piloting doesn't just imply plotting; it insists upon it. Those who mark their positions only in the cranial furrows of their memory, instead of recording them with pencil marks and log notations, may one day find themselves completely lost, pounding their bottom out on an unsuspected shallow place that "warn't supposed to be thar!"

–Frederick Graves

"It is established for a custom of the sea that if a ship is lost by default of the lodesman, the mariners may, if they please, bring the lodesman to the windlass and cut off his head without the mariners being bound to answer before any judge, because the lodesman had committed high treason against the undertaking of the pilotage, and this is the judgement."

–The Laws of Oleron, 1190 as quoted in Schofield

INTRODUCTION

This chapter follows directly the discussion of *dead reckoning* (DR) and amplifies and expands upon the material presented in Chapter 5. As noted, DR is used to project the position of the vessel at some future time using information on the course steered and speed maintained. If the helmsman steers a straight and accurate course and maintains constant speed, and water current and/or wind effects are minimal, the DR position will be quite accurate. However, these ideal conditions do not always prevail and DR positions need to be checked for accuracy and updated as necessary. In principle, these accuracy checks can be made by several means, such as visual reference to charted objects (termed *piloting*), electronic measurements (termed *electronic navigation*), and measurement of the elevation of celestial bodies (termed *celestial navigation*). In coastal (sometimes termed *pilot*) waters, visual reference to charted features (both natural and man-made) is convenient and commonly used. The principal tasks of piloting are: (1) to check, refine,

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and update DR positions, (2) to determine a sequence of fixes, (3) to calculate such revisions to the vessel's course or speed as are necessary to maintain the intended track, and (4) to monitor progress and select alternate tracks and/or ports as necessary to ensure a safe and efficient passage.

The objective of this chapter is to show how positions can be determined by visual reference to charted objects. However, material on position fixing by electronic means is also introduced in this chapter to familiarize the reader with the relevant nomenclature, notation, and procedures. Radionavigation is discussed in Chapter 9.

Because fixes are presumed to be more accurate than DR positions, students often ask why mariners take the trouble to maintain DR plots. This question is addressed implicitly in Chapter 5, but it is worthwhile to restate the answer here. There are at least three important reasons why a DR plot is necessary:

- ❏ First, a fix, no matter how accurate, is simply a determination of a vessel's position at an instant in time. By itself, a fix cannot be used to determine or estimate a vessel's future position—as is done by DR.
- ❏ Second, although it is recommended that a vessel's position be fixed frequently—particularly in pilot waters where it is necessary to ensure that the vessel does not stray into danger—opportunities for fixes may be limited. Fog or other weather phenomena that impair visibility may prevent frequent fixes, for example.
- ❏ Third, in certain parts of the country, the shoreline may be nearly featureless and *aids to navigation* (ATONs) few and far between. Unless the vessel has electronic navigation receivers, DR positions may be all that are available when operating in these areas.

Therefore, even though DR positions may be inaccurate and should be checked at suitable intervals, the preparation of DR plots is essential to prudent navigation.

For the most part, the material in this chapter is not difficult, either in principle or in practice. Nonetheless, statistics on *search and rescue* (SAR) cases from the *United States Coast Guard* (USCG) indicate that many distressed mariners do not know their positions with any accuracy. Inaccurate or incomplete position information not only contributes to accidents (e.g., groundings and fuel exhaustion) but also delays rescue, because *search and rescue units* (SRUs) waste time searching for the distressed vessel. Therefore, it is particularly important that this material be mastered.

Aside from the obvious safety element, there are many other benefits to being able to determine position rapidly and accurately. In general, these relate to the comfort and efficiency of the voyage. A captain who knows the vessel's position (at least approximately) at all times is a more confident captain, and so are any guests aboard. The determination that the vessel is not on the preplanned track means that corrective action can be initiated promptly.

For all these reasons, the information covered in Chapters 5 and 6 is essential for every mariner and, in a very real sense, constitutes the core of both the *Basic* and *Advanced Coastal Navigation* (BCN/ACN) courses. Take the time to read and reread these chapters thoroughly and to work out the problems in the *Study Guide* (SG).

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❏ ***Definitions of piloting, line of position, fix, running fix, estimated position and danger bearing***
- ❏ ***How to determine and plot a line of position***
- ❏ ***Utility of a line of position***
- ❏ ***How to determine and plot a visual fix***
- ❏ ***How to determine and plot an electronic fix***
- ❏ ***How to determine and plot a running fix***
- ❏ ***Danger bearings and their uses***

PILOTING

Piloting (also called pilotage) is navigation involving frequent reference to charted landmarks, ATONs, and depths. Piloting entails frequent comparison of the physical features of the earth's surface (including man-made features) and their relationships to those same features as depicted on the chart to reconstruct the same relationships of direction, angular differences, and distances to establish the position of the vessel.

The charted features include those of natural origin, such as promontories, hill and mountain tops, and fixed, man-made (sometimes termed cultural) objects such as towers of various types, buildings, smoke stacks, tanks, cooling towers, lighthouses, and other structures. Also included in these fixed features would be "invisible" ATONs such as radio beacons (RBn) and passive radar reflectors (Ra Ref). (The USCG has phased out radio beacons, although some aeronautical beacons are still in service.)

According to Bowditch, piloting "is practiced in the vicinity of land, dangers, etc., and requires good judgment and almost constant attention and alertness on the part of the navigator."

Buoys in Piloting

Buoys are also used in piloting, but the navigator should regard fixes determined solely from floating aids with caution because buoys are susceptible to accidental damage (sinking) or relocation (dragging) and cannot be guaranteed to be on station at all times (see sidebar). On this point, all prudent navigators agree. What is more controversial is whether or not buoys should be used for position fixing. This section highlights alternative viewpoints. In the introduction to the *Light List* (see Chapter 10), published by USCG, the following statements can be found:

> "Buoy positions represented on nautical charts are approximate positions only, due to the practical limitations of positioning and maintaining buoys and their sinkers in precise geographical locations. Buoy positions are normally verified during periodic maintenance visits. Between visits, atmospheric and sea conditions, seabed slope and composition, and collisions or other accidents may cause buoys to be sunk or capsized…*Prudent mariners will use bearings or angles from fixed aids to navigation and shore objects, soundings and various methods of electronic navigation to positively fix their position."* [Emphasis added.]

On many nautical charts, particularly small craft charts, the following warning is printed:

> "The prudent mariner will not rely solely on any single aid to navigation, particularly on floating aids. See U.S. Coast Guard List, and U.S. Coast Pilot for details."

The General Information chapter of the *U.S. Coast Pilot* (USCP) contains the following caution:

> "...A prudent mariner must not rely completely upon the charted position or operation of floating aids to navigation, but will also utilize bearings from fixed objects and aids to navigation on shore."

Bowditch offers the following guidance:

> "For these reasons, a mariner must not rely completely upon the position or operation of buoys, but should navigate using bearings of charted features, structures, and aids to navigation on shore."

The *Admiralty Manual of Navigation* states:

> *"The position of buoys and small-size floating structures must always be treated with caution even in narrow channels...* Remember in particular that buoys can quite easily drag or break adrift; that they are frequently moved as a shoal extends; and that they may not always display the correct characteristics…Buoys should not be treated as infallible aids to navigation, particularly when in an exposed position. Whenever possible, navigate by fixing from charted shore objects; use the echo sounder; check the DR/EP against the position; use but do not rely implicitly on buoys." (Emphasis in original.)

It also notes:

> "When shore marks are difficult to distinguish because of distance…or thick weather, buoys and light-vessels must often be used instead."

Many excellent texts on navigation provide cautionary statements regarding use of buoys for position-fixing, but don't rule this practice out completely. Brogden (1995), a former Captain in the USCG, offers the standard caution, but adds: "I don't hesitate to use buoys for bearings, but the bearings to them aren't as accurate or as reliable as bearings to lights."

The record of the USCG in maintaining buoys in U.S. waters is excellent. For example, the performance goal set by USCG (1999) is to maintain navigation availability on 99.7% of all days. The actual availability of short range ATONs over the years from 1994-1998 has been consistently over 98%—impressive performance, indeed. Readers should note, however, that this availability is measured against a standard of *where the buoy is supposed to be, not necessarily where it is shown on a particular edition of a chart*. Unless the mariner has updated the chart (see Chapter 10), the buoy (even if correctly positioned) may not be where it is shown on the chart.

Some texts (e.g., Pike, 1990) that argue that:

> "Passing a buoy gives an accurate fix in eyeball navigation and it can be worth diverting from the straight line course to obtain such a fix."

Markell (1984) is likewise sanguine about the use of buoys for position fixing. He notes:

> "The easy way to get an accurate fix is to come alongside a charted buoy and record the time."

Elsewhere he is more cautious and states:

> "The most reliable line of position is from a bearing taken on a range. Next in order of reliability is LOP from a bearing on a fixed object ashore, and third is a floating aid to navigation, such as a buoy. For our purposes...buoys are plenty accurate enough."

On balance, this ACN text takes the position that fixed ATONs and other shore-based objects are strongly preferred for position fixing. Mariners should treat any fix determined solely from bearings on buoys (or passing close to a buoy) with caution unless this position is checked and confirmed with other information. To use one term of art, mariners take a "position reference" from one or more buoys, not necessarily a fix. The prudent mariner uses several means of navigation in concert (see Chapter 12), rather than relying on any individual aid or system. As written, this is not intended to be an absolute prohibition on position fixing using buoys. This said, with the availability of low-cost electronic navigation receivers (such as *Global Positioning System* [GPS] or Loran-C) it is a simple matter to verify that a buoy is in its proper location.

THE LINE OF POSITION

A *line of position* (LOP) is a line established by observation or measurement on which a vessel can be expected to be located. A vessel can be at an infinite number of positions along any single LOP. In piloting, an LOP may be established by a measured bearing to a known and charted object, or by an alignment of two visible and charted objects, or by a measured distance from a charted object. In the case of bearings, LOPs are straight lines. In the case of distances, LOPs are circles, and sometimes referred to as *circles of position* (COP). LOPs are used in this text to refer to both. These methods for determination of LOPs are discussed below. LOPs can also be determined by electronic means, such as radar.

LOP BY BEARING FROM CHARTED OBJECT

One of the simplest and most common LOPs is developed from a single bearing on a charted object. The bearing can be taken using a pelorus (see Chapter 2), or a hand-bearing compass, or by orienting the boat so that the resulting relative bearing is dead ahead (000R), abeam (090R or 270R), or astern (180R). Bearings so determined could be compass bearings if the ship's compass is used, magnetic bearings if a hand-bearing compass is used in a location where it is free of deviation, or relative bearings if a pelorus is used. If a relative bearing is taken, it must be converted to a true bearing by first determining the compass heading at the instant of the relative bearing observation, correcting this compass heading to a magnetic heading by applying deviation, and then to a true heading by allowing for variation as discussed in Chapter 2. The relative bearing is then added to the vessel's true heading to determine the true bearing to the object. The true bearing is plotted on the chart to the object as a solid line. The *United States Coast Guard Auxiliary* (USCGAUX) encourages the use of standard plotting and labeling techniques adopted by the USCG, the U.S. Navy, as well as other authoritative sources such as the *United States Power Squadrons®* (USPS). These standards specify that LOPs should be drawn with solid lines over the range of possible positions of the vessel. "Impossible locations" along an LOP (e.g., on land, in the area between two range markers used to define the LOP) should be drawn as dashed lines.

GREAT BUOY VOYAGES, AN HISTORICAL ASIDE

The admonition not to rely solely on floating aids to fix your boat's position reflects the fact that buoys are not always where they are supposed to be. Wind, flooding, ice, and other environmental factors may cause a buoy to break its mooring and float away. Perhaps the most famous buoy "voyage" is reported in Amy Marshall's A History of Buoys and Tenders published as an insert in the Commandant's Bulletin of November 1995. The story reads in part: The whistle buoy, which marked Nantucket Shoals Light Vessel Station parted its mooring and headed southwest on Jan. 20, 1915. "Two months later, mariners sighted it 15 miles off Cape Hatteras, NC. On April 7, the crew of the Italian steamship Andrea intercepted the wandering buoy 400 miles east of Cape Hatteras, and towed it for more than 200 miles. For unknown reasons, the crew abandoned the buoy on April 16. On Aug. 7, reports of the errant buoy came in with a sighting 220 nautical miles NNE of San Salvador, Bahamas. By November, it was well on its way northward with confirmed sightings SSE of Cape Fear, NC (Nov. 9), ESE of Cape Hatteras (Dec. 12), 290 miles east of Bodie Island (Dec. 30), and finally 165 miles WSW of Bermuda (March 25, 1916).

In the meantime, the Lighthouse Service dispatched tenders to search for the buoy. Although its distinct shape, red paint, regulation markings, and blowing whistle made this buoy conspicuous, the tenders had no success in locating it.

On Aug. 16, 1916, after 19 months and 3,300 nautical miles, the buoy's voyage came to an end. The private vessel that finally recovered the buoy noted that its whistle still sounded and bits of its mooring chain were still attached."

Figure 6-1 shows the LOP construction and labeling. The vessel is somewhere on the solid portion of the LOP. This LOP is labeled on "top" with the time of the observation (using four digits in the 24-hour system) and on the "bottom" with the true bearing from the vessel to the object. Top and bottom are placed in quotation marks because it is not always obvious. However, there won't be any confusion if time is always written as four digits and bearing as three digits. Thus, for example, 1:20A.M. is written 0120.

An Example

The sailboat *Perdida* is steering a course of 264 true, speed 4.0 knots. The Point Judith Light is visible off to starboard. It is clearly visible from *Perdida* and is easily identified on the chart by its characteristics (magenta overlaying a dot within a circle, and the legend: Gp (0cc (1+2) 15 sec 65 ft 16 M). At 1015, the vessel is on a compass heading of 274C when the lighthouse is observed with a pelorus (see Chapter 2) bearing 073R (73° to starboard of the bow). The heading, relative bearing, and the time are recorded in the vessel's log: time, 1015; heading, 274C; relative bearing, 073R. The navigator corrects the compass heading to a *true heading* (TH) using the deviation for that compass heading observed from the deviation table or deviation curve (assume that the compass deviation is 5° E on a heading of 274C) and applies the local variation (assume that the variation is 15 W) using the method discussed in Chapter 2:

▲

FIG. 6-1–A Single LOP from a Visual Bearing

DIRECTION	HEADING	MEMORY AID
Compass	274C	Can
Deviation	+005E	Dead
Magnetic	279M	Men
Variation	-015W	Vote
True	264T	Twice
(Add East)		At Elections

The *true bearing* (TB) to the object from the boat is then determined by adding the *relative bearing* (RB) (073R) to the *true heading* (TH) (264):

TRUE BEARING OF OBJECT FROM VESSEL:
TH + RB = TB
264 + 073R = 337

The LOP is plotted to the lighthouse on a bearing of 337, and labeled with the time of observation (1015) on top and the true bearing from the vessel to the object (337) underneath the line. The vessel is assumed to be located somewhere on that line. The recommended practice is to plot a DR position whenever an LOP is determined. (The purpose of plotting a DR position is to determine the current set and drift as discussed in Chapter 7.) Therefore, the 1015-DR position should also be plotted in Figure 6-1.

ACCURACY OF LOPs

It is customary to regard visual LOPs as being highly accurate—that is, to assume that the vessel's position must be located exactly along an LOP. This convention is followed here. Keep in mind, however, that the possibility of error always exists in the determination of an LOP. An LOP determined by conversion of a relative bearing, for example, is subject to several errors. The error in the measurement of the relative bearing could easily be of the order of 1 or 2 degrees, even if a pelorus is used. The relative bearing is added to the ship's heading to determine a true

FACTOID: U.S. ATON SYSTEM

The United States has one of the best ATON systems in the world—in terms of both the quality and quantity of ATONs. From a purely quantitative perspective, the number of Federal ATONs (including, for example, buoys, beacons, sound signals) is nearly 50,000.

bearing (after conversion of the heading from compass to true). The ship's heading is not known with certainty, and errors of 2 degrees or so would not be regarded as uncommon. (All the more so if the navigator and the helmsman are the same person!) The conversion process from relative to true bearings, even though it is only a simple matter of addition and/or subtraction, introduces the possibility of additional errors. Leaving aside outright blunders, such as applying the deviation appropriate to the relative bearing rather than the ship's heading or errors in arithmetic, the vessel's compass is not perfectly accurate (particularly if the sea is other than flat calm) and the deviation table is only approximate. Thus, bearing errors of 2 or 3 degrees would not be thought of as unusual—even more if the seas are rough. Finally, the LOP needs to be plotted on a chart for position determination. Plotting errors of 1 degree or more can occur; so the maximum possible error in an LOP as plotted might easily be 3 or 4 degrees. Many of these errors are random, rather than systematic, and tend to average or "cancel out." Although the probable error is less than the maximum possible error, it is a mistake to believe that the overall error is negligible.

For these and other reasons, visual LOPs are only approximate, perhaps no more accurate than to within plus or minus 3 degrees on a small vessel. Electronic LOPs developed by radar are also subject to bearing error. To avoid chart clutter, it is generally appropriate to use the best estimate of the LOP and plot this alone, rather than attempt to calculate possible error limits (confidence intervals) and plot these on the chart. Nonetheless, it is important to keep these errors in mind and to take steps to minimize them by careful measurement and judicious selection of objects for observation. Additionally, it is important to recognize and allow for these errors in voyage planning. For example, courses should never be laid out so as to pass close to hazards to navigation unless otherwise unavoidable. Rather, an ample safety factor should be incorporated to ensure that the vessel remains in safe water.

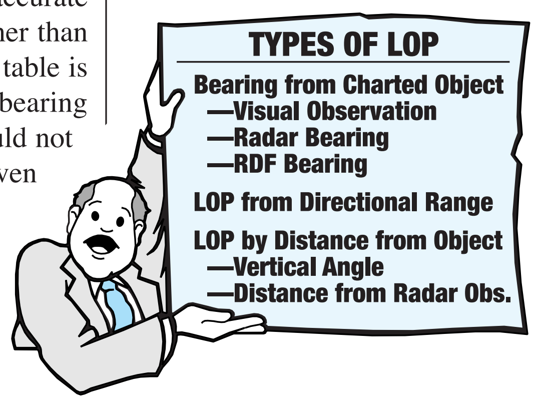


FIG. 6-2–A range LOP as determined by a charted tank and tower. Only the time is noted.

PHOTO COURTESY OF UNITED STATES COAST GUARD

Buoy being serviced by buoy tender. Prudent mariners should treat fixes determined by floating aids with great caution.

LOP BY DIRECTIONAL RANGE

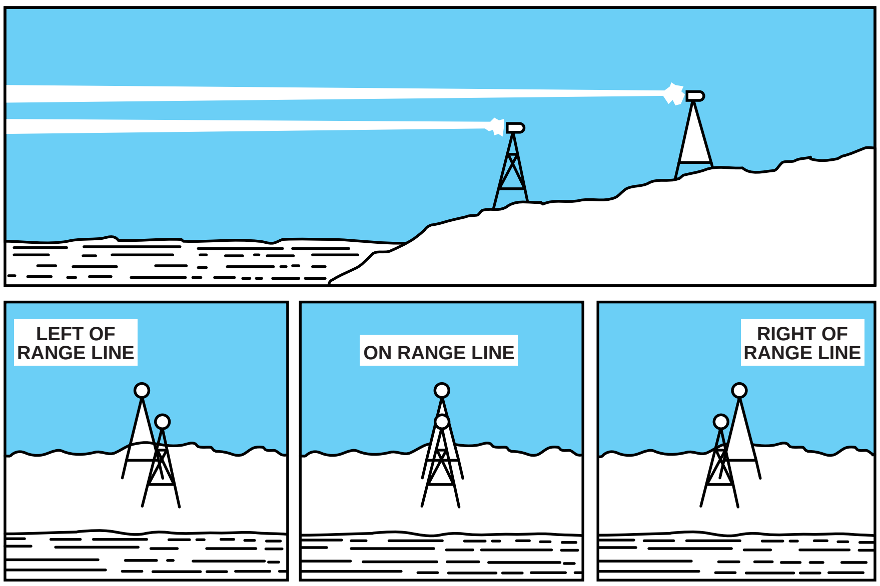
A directional range consists of two objects in line, one behind the other, and defines a unique direction and a range line (the line drawn through the two objects). (British nomenclature for a range is a *transit*.) Ranges can provide highly accurate visual LOPs and can be used in compass calibration as discussed in Chapter 2. They are also helpful in steering difficult channel approaches. The objects may be man-made, such as range markers for a channel, a steeple and a tank, or natural, such as two tangents of land (taken carefully to account for slope of land and curvature of earth's surface), a large rock and a waterfall, or a combination of both. In order to be used, objects in range must be charted.

Range markers place the taller of the markers behind the shorter marker viewed along the course line. The top object appears to be to the left of the lower object when the observer is left of the line determined by the range, and the top object appears to be to the right of the lower object when the observer is to the right of the range.

An LOP by range is the easiest LOP to determine and among the most accurate. Because no calculation is required, only the time needs to be noted and indicated on the chart. A range LOP is illustrated in Figure 6-2. Here, the navigator notes that a charted tank and a tower are in range at 1700. The range line is drawn as a solid line on the chart (except for the portion between the objects used to define the range and/or any portion over land) and labeled on top with the time. No direction label is required on the chart.

LOP BY DISTANCE FROM CHARTED OBJECT

Distance to an object can be determined by measurement using a radar observation, by measurement of vertical angle with a sextant, stadimeter, or range finder. In this case, however, the LOP is a circle rather than a straight line. The resulting COP (*or arc of position*) is drawn as the circumference of a circle with origin at the observed object and radius equal to the measured distance. The arc is drawn as a solid line and labeled with the time and the distance. The time is placed on the "top" of the arc (four digits) and the distance "below" (nautical miles and tenths preceded by the capital letter D). The entire COP is not shown, only the portion denoting the locus of possible positions of the vessel. Unless there is ambiguity, there is no need to draw a radius from the point of origin.



Range lights provide accurate directional information.

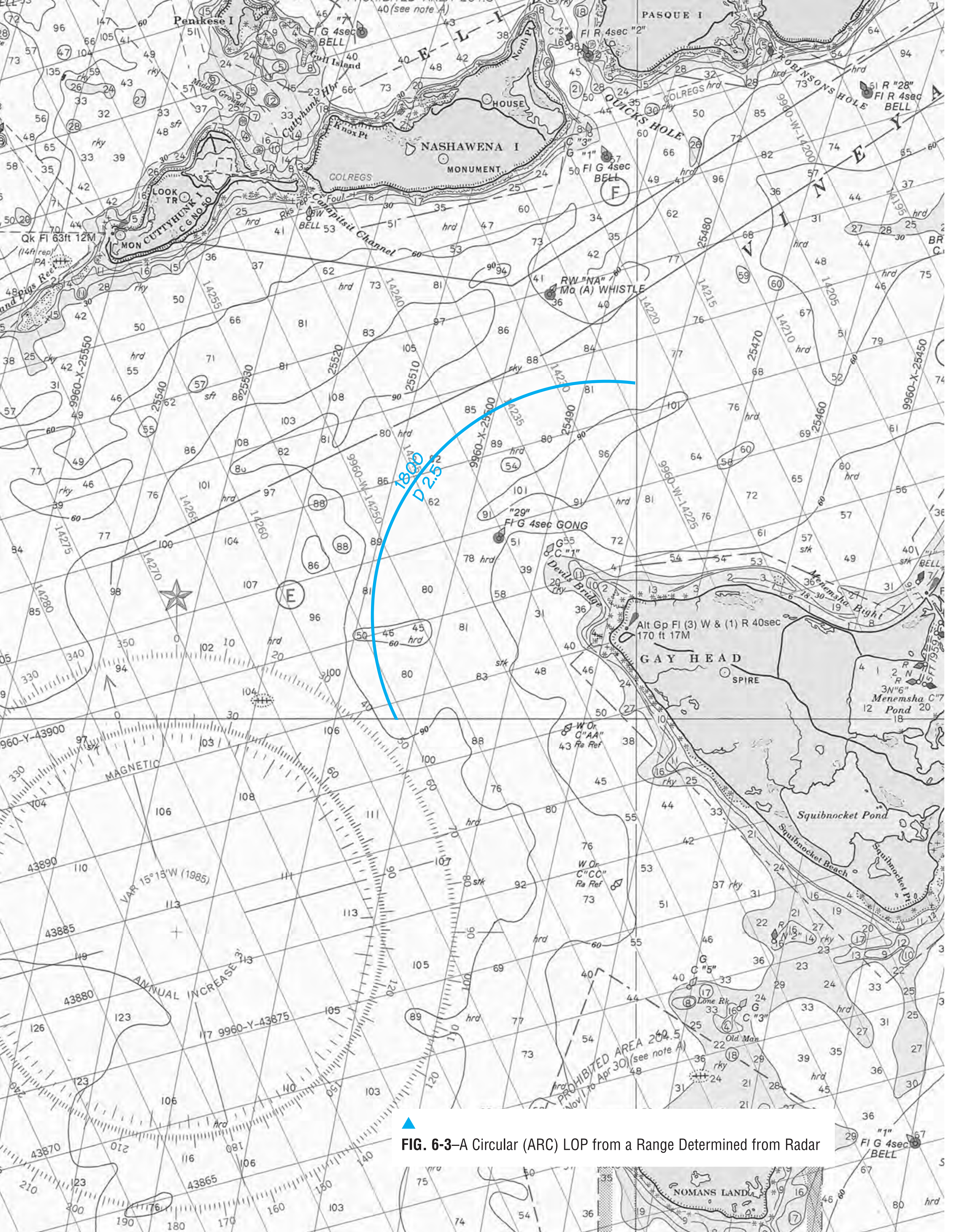


FIG. 6-3–A Circular (ARC) LOP from a Range Determined from Radar

DISTANCE BY VERTICAL ANGLE

(This section is more technical and can be omitted without loss of continuity.) A sextant can be used to measure the vertical angle of a charted object of known height. The distance in nautical miles to the object can be estimated by the height of the object (from the water level to the height of the light source—not the top of the structure—for a lighthouse) divided by the tangent (tan) of the angle measured (H), and divided by 6076 (to convert ft. to nautical miles), or:

$$d = h/[6076^* \tan H]$$

This calculation can be performed with an electronic calculator or by using special-purpose tables found in Bowditch. To illustrate the above equation, suppose a light of height 85 ft were observed to have a vertical angle of 0.53° (31.8 minutes, remember to convert to decimal degrees by dividing minutes by 60). For this angle, tan H = tan (0.53 degrees) = 0.00925, h = 85 ft (neglecting the difference between the chart datum for heights and the height of the tide) and d = 85/(6076) (0.00925) = 1.5 M.

After the range to the object is determined, a COP is drawn on the chart around the object (or an arc is swung from the object if it is clearly apparent as to which direction the vessel lies) using the drafting compass set on that range from the latitude scale on the chart. This circular LOP is labeled with the time and with the distance (D 1.5—the distance units are implicit and are not normally labeled). The vessel is assumed to be somewhere on the circle or the arc.

DISTANCE BY RADAR OBSERVATIONS

Using radar, the object is identified on the *plan position indicator* (PPI), the radarscope or screen. The *fixed range markers* (FRMs) or the *variable range marker* (VRM) can be used to determine the range of the object from the vessel. This is illustrated in Figure 6-3, where the light on the NW tip of Gay Head provides a "recognizable" radar target at range 2.5 M. (See Chapter 9 for a discussion of radar detection and identification of targets. The light structure, *per se,* may not be detected on radar, but the western end of the island at Gay Head is likely to have a characteristic radar signature.) A circular (or arc in this case) LOP is scribed around the object on the chart using a drafting compass set to the distance (here, 2.5 M) using the latitude or bar scale. The circle is labeled with the time (1800) above the line and the distance (D 2.5) below the line. The arc is drawn to cover the possible positions of the vessel. The vessel is somewhere on this circle (or arc). Although not specifically recommended by labeling conventions, the word RADAR might be added to the COP to denote the method used.

PRACTICAL POINTERS FOR DETERMINATION OF LOPs

Before discussing how fixes are determined, it is useful to provide some brief practical pointers on the selection of objects for determination of LOPs. In some cases, identifiable objects are few and far between and the navigator has little choice but to use any possible opportunity. In others, however, such as in the waters covered by the 1210-Tr chart, there is an abundance of charted objects suitable for LOP determination or position fixing, and some thought should be given to selecting those that are "best." As the mariner becomes familiar with the area, the identification of objects suitable for determination of LOPs or fixes becomes second nature. But, for unfamiliar waters, it is important to study the applicable nautical chart(s) and other relevant publications to plan for LOP opportunities.

- ❑ First, the object(s) selected for the LOP must be charted and readily identifiable. Land features, such as isolated and uncovered rocks or rocky bluffs can sometimes be used to advantage; but beware of gently sloping shorelines, because these are not distinct (particularly if radar is used) and may change apparent position with the height of the tide. Man-made structures, such as standpipes, water towers, radio towers, cupolas, or spires on buildings, as well as ATONs, can be readily used. Cartographers decide which objects to chart based on their possible navigational utility. However, examine the chart closely to ensure that the object selected cannot be mistaken for another. In this connection, isolated objects can sometimes be easier to see and identify than those in close proximity can. An object has to be both detected and identified in order to provide a valid LOP. In some cases, for example, with municipal water towers the object can be readily identified by writing (the town's name) or other distin-

TIP: USE THE USCP TO HELP SELECT PROMINENT OBJECTS

The USCP has a section titled “Prominent Features” that identifies features that might be used for position fixing. Here is an excerpt from the 30th Edition of the USCP that describes prominent features on the approaches to Newport Harbor:

“The following objects are prominent when approaching Newport Harbor either from the southward or northward: a hotel on Goat Island; a white building of the yacht club near Ida Lewis Rock in the southerly part of the harbor; church spires in the town; and the buildings of the Naval Education and Training Center and Naval War College on Coasters Harbor Island in the north part of the harbor. To the westward on Conanicut Island are several large hotels and a standpipe.”

These objects facilitate orientation and should be considered for determination of LOPs.

guishing marks on the side. In other cases, a unique color or color pattern may make some objects easy to recognize. (Local knowledge can be a great help.) The nautical chart or USCP often contains information that can determine the suitability of objects for position determination (see sidebar). For example, the 1210-Tr chart notes that the Gay Head Light shown in Figure 6-3 cannot be seen (and, therefore, would not be usable) in the area south of Nomans Land. Identification of objects using radar (discussed in Chapter 9), rather than visual means, requires some experience in interpretation of radar images. Remember, also, that different visual cues are important for recognition of objects at night compared to daylight viewing conditions. Lighted ATONs are often preferable because the color and characteristics of the light provide more positive identification during the hours of darkness.

❑ Second, choose objects that are as close as possible to the vessel’s position in preference to those that are located farther away. Remember a 1-degree error in determining an object’s bearing translates approximately to an error of 1 mile off in 60 (lateral error). Table 6-1 illustrates this point. It shows the lateral error in yards as a function of the distance off (in nautical miles or yards) and the error in determining an object’s bearing. Thus, for example, a bearing error of 3 degrees translates into a lateral error of only 13 yards if the object observed is 1/8th of a mile distant, but more than 2,000 yards if the object is 20 nautical miles away. Nearby objects are also easier to see and identify, particularly under conditions of restricted visibility.

❑ Third, choose objects that are taller in preference to those that are shorter. The ease with which an object can be detected and identified is a complex function of the prevailing visibility, shape of the object, color contrast compared to the surroundings, and other factors. But it is also a function of height of the object, a subject explored in more detail in Chapter 9. The distance to the visible horizon (arising from atmospheric refraction and the curvature of the earth) is a function of the observer’s height of eye and the height of the object, as shown in Table 6-2. Thus, for example, an observer on a vessel with a height of eye of 7.5 feet could, under ideal conditions, see an object of height 10 feet as many as 6.9 nautical miles away. If the object were 100 feet high, it might be seen at a distance of 14.9 nautical miles. (This is yet another reason why small buoys are difficult to see.) Actual distances of visibility could be smaller than shown in the table (which is based solely on average atmospheric refraction and the earth’s curvature) but in no event would be much larger than shown in this table. In any event, Table 6-2 shows the potential benefits of looking for taller objects. It is sometimes useful to draw an arc or circle of the distance to the visible hori-

DISTANCE TO OBJECT NAUTICAL MILES	YARDS	BEARING ERROR IN DEGREES 1	2	3	4	5	7.5	10
0.125	250	4	9	13	17	22	33	44
0.250	500	9	17	26	35	44	66	88
0.375	750	13	26	39	52	66	99	132
0.500	1,000	17	35	52	70	87	132	176
0.625	1,250	22	44	66	87	109	165	220
0.750	1,500	26	52	79	105	131	197	264
0.875	1,750	31	61	92	122	153	230	309
1.000	2,000	35	70	105	140	175	263	353
1.125	2,250	39	79	118	157	197	296	397
1.250	2,500	44	87	131	175	219	329	441
1.500	3,000	52	105	157	210	262	395	529
1.750	3,500	61	122	183	245	306	461	617
2.000	4,000	70	140	210	280	350	527	705
2.500	5,000	87	175	262	350	437	658	882
3.000	6,000	105	210	314	420	525	790	1,058
3.500	7,000	122	244	367	489	612	922	1,234
4.000	8,000	140	279	419	559	700	1,053	1,411
5.000	10,000	175	349	524	699	875	1,317	1,763
7.500	15,000	262	524	786	1,049	1,312	1,975	2,645
10.000	20,000	349	698	1,048	1,399	1,750	2,633	3,527
12.500	25,000	436	873	1,310	1,748	2,187	3,291	4,408
15.000	30,000	524	1,048	1,572	2,098	2,625	3,950	5,290
17.500	35,000	611	1,222	1,834	2,447	3,062	4,608	6,171
20.000	40,000	698	1,397	2,096	2,797	3,500	5,266	7,053

TABLE 6-1–Lateral errors as a function of bearing error and the distance to fix show importance of selecting nearby objects for fixes. Table entries show lateral error in yards.

zon on the chart to determine the maximum range at which key objects can be seen.

❑ Fourth, use fixed rather than floating structures for determination of LOPs. As noted above, this guidance is not intended to be an absolute prohibition against use of buoys for determining an LOP or position fixing. In some cases, buoys may be the only objects available, and their distinctive markings aid in identification. However, as soon as possible use other means to confirm (verify) any LOP or fix so determined.

❑ Fifth, ranges make for the most accurate LOPs, so these should be used whenever possible. This is partially a consequence of the precision with which small deviations can be seen on a range. But, it is also important to recall that no conversion of bearings from compass or magnetic are necessary before LOPs can be plotted from ranges. Thus, any errors due to compass deviation, local magnetic anomalies, or failure to apply properly the corrections for deviation or variation are eliminated. Look for "natural" as well as man-made ranges. (Remember, though, that many other vessels could also be using marked ranges, and keep a sharp lookout for traffic.)

❑ Sixth, it takes some practice before accurate compass bearings can be reliably obtained from the deck of a wave-tossed boat. If in doubt, take the average of several bearings rather than a single bearing. Learn to

HEIGHT OF OBJECT (FT.)	HEIGHT OF EYE IN FEET							
	0.0	2.5	5.0	7.5	10.0	15.0	20.0	30.0
0.0	0.0	1.8	2.6	3.2	3.7	4.5	5.2	6.4
2.5	1.8	3.7	4.5	5.1	5.5	6.4	7.1	8.3
5.0	2.6	4.5	5.2	5.8	6.3	7.1	7.8	9.0
7.5	3.2	5.1	5.8	6.4	6.9	7.7	8.4	9.6
10.0	3.7	5.5	6.3	6.9	7.4	8.2	8.9	10.1
12.5	4.1	6.0	6.8	7.3	7.8	8.7	9.4	10.5
15.0	4.5	6 4	7.1	7.7	8.2	9.1	9.8	10.9
17.5	4.9	6.7	7.5	8.1	8.6	9.4	10.1	11.3
20 0	52	7.1	7 8	&4	8 9	9 8	10.5	11.6
22.5	5.5	7.4	8.2	8.8	9.2	10.1	10.8	12.0
25.0	5.8	7.7	8 5	9.1	9.5	10.4	11.1	12.3
27.5	6.1	8.0	8.8	9.3	9.8	10.7	11.4	12.5
30.0	6.4	8.3	9.0	9.6	10.1	10.9	11.6	12.8
35.0	6.9	8.8	9.5	10.1	10.6	11.5	12.2	13.3
40.0	7.4	9.2	10.0	10.6	11.1	11.9	12.6	13.8
45.0	7.8	9.7	10.5	11.1	11.5	12.4	13.1	14.3
50.0	8.3	10.1	10.9	11.5	12.0	12.8	13.5	14.7
55.0	8.7	10.5	11.3	11.9	12.4	13.2	13.9	15.1
60.0	9.1	10.9	11.7	12.3	12.8	13.6	14.3	15.5
65.0	9.4	11.3	12.0	12.6	13.1	14.0	14.7	15.8
70.0	9.8	11.6	12.4	13.0	13.5	14.3	15.0	16.2
75.0	10.1	12.0	12.7	13.3	13.8	14.7	15.4	16.5
80.0	10.5	12.3	13.1	13.7	14.2	15.0	15.7	16.9
85.0	10.8	12.6	13.4	14.0	14.5	15.3	16.0	17.2
90.0	11.1	12.9	13.7	14.3	14.8	15.6	16.3	17.5
95.0	11.4	13.3	14.0	14.6	15.1	15.9	16.6	17.8
100.0	11.7	13.5	14.3	14.9	15.4	16.2	16.9	18.1
110.0	12.3	14.1	14.9	15.5	16.0	16.8	17.5	18.7
120.0	12.8	14.7	15.4	16.0	16.5	17.3	18.0	19.2
130.0	13.3	15.2	16.0	16.5	17.0	17.9	18.6	19.7
140.0	13.8	15.7	16.5	17.0	17.5	18.4	19.1	20.3
150.0	14.3	16.2	16.9	17.5	18.0	18.9	19.6	20.7
175.0	15.5	17.3	18.1	18.7	19.2	20.0	20.7	21.9
200.0	16.5	18.4	19.2	19.8	20.2	21.1	21.8	23.0

TABLE 6-2–The distance to the visible horizon in nautical miles as a function of the observer's height of eye in feet and object height in feet shows the importance of selecting tall objects for LOP determination.

hold a hand-bearing compass as level as possible to minimize observation errors.

- ❏ Finally, take the time to plot LOPs carefully. Parallel rules or paraline plotters can slip when transferring lines–particularly on a crowded and pitching navigator's desk aboard a vessel. Check plotted bearings (including the conversion from compass to true) at least twice.

WHAT IS THE WORTH OF A SINGLE LOP?

It is often (but not universally) accepted that two LOPs determine a fix and that three or more LOPs can determine the possible accuracy of a fix. It is also important to note that even a single LOP can be useful.

One LOP may not enable you to determine exactly "where you are," but it can be useful to determine

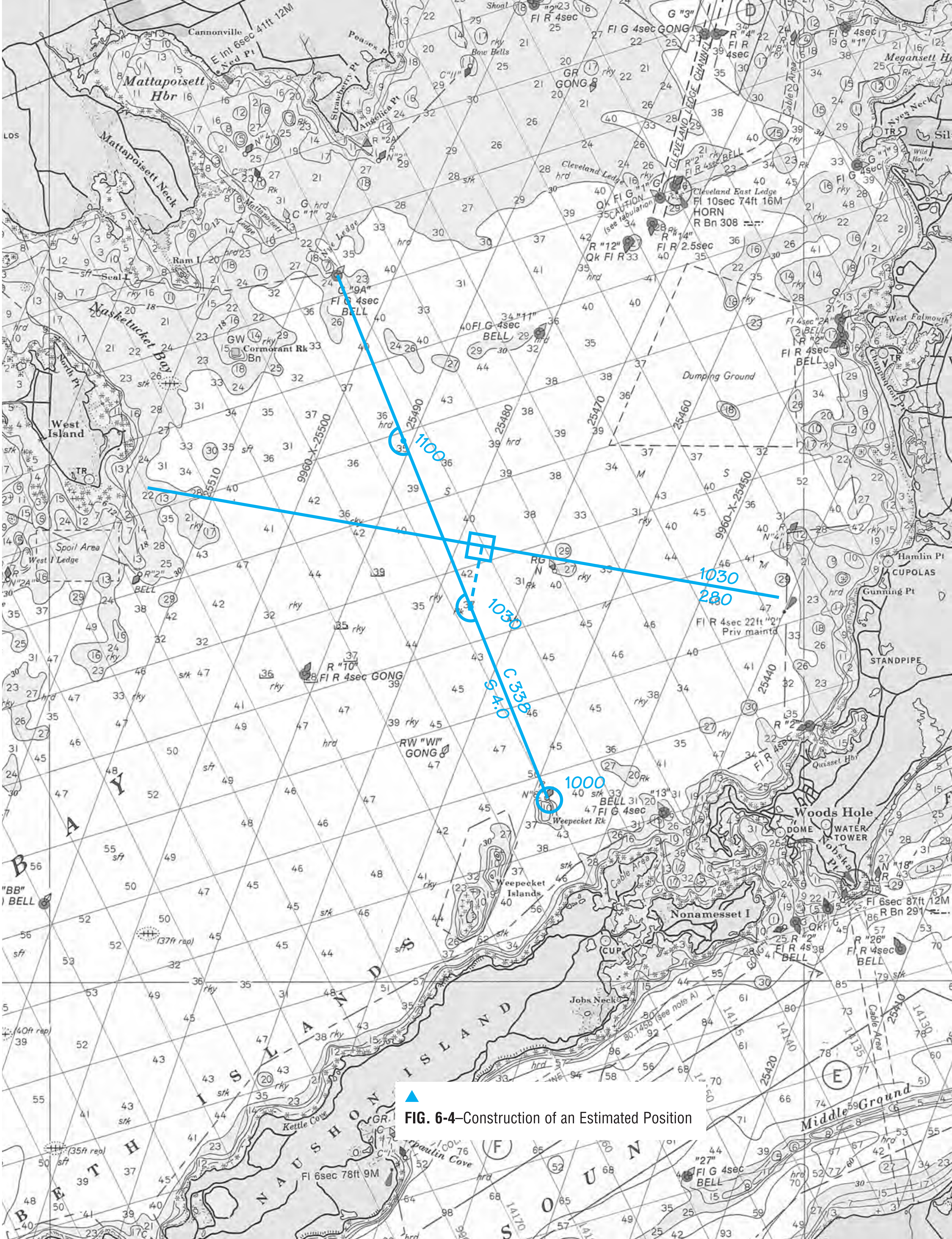


FIG. 6-4–Construction of an Estimated Position

"where you are not." In other words, a single LOP can enable the mariner to rule out possible locations. And, as shown below, a single LOP has many other uses.

In certain situations, objects can be selected for a visual (or electronic) LOP that are more or less directly in line with the vessel's course, either ahead or astern. A single LOP from such an object can be used to determine whether or not the vessel is making good the intended course, even if a fix is not obtained. Such an LOP is sometimes said to be a *course or track line LOP*. Such opportunities occasionally happen by chance, but should be a deliberate part of the voyage plan itself. In other words, a course can be laid out in such a way that several objects can be used for trackline LOPs along the intended course. Tracking toward a specific object (albeit with reference to the compass) can simplify the job of the helmsman.

Course turn points can often be conveniently identified and specified by means of a single LOP. That is, the vessel proceeds along one course until the bearing of a preidentified (preferably fixed rather than floating) object reaches a predetermined bearing. For example, a portion of the voyage plan might be to proceed on a course of 090 degrees until a particular lighthouse bears 045 degrees, then come left to 045 and track inbound. Because large ships do not respond instantly, it is necessary to locate the "wheel over" point before reaching the turn point. For most recreational boats the radius of turn can be disregarded.

Objects can also be selected for determination of LOPs that are (more or less) directly abeam of the vessel. In this case, the LOP can be used to compare the vessel's *speed made good* (SMG) with the vessel's *speed through the water* (STW) and compute the fair or foul current (see Chapter 7). These LOPs are termed *speed LOPs*. Speed LOPs are particularly useful if the vessel is operating in a narrow channel or river where the margin for lateral error is small. In fact, many river mariners do not go to the trouble of determining fixes in the conventional sense at all; they simply use buoys to stay in the channel and speed LOPs to monitor progress and revise estimates.

HINT: AVOID THIS PLOTTING ERROR

One of the common plotting errors made by students is to draw the EP at the intersection of the DR course and the LOP. Except for the fortuitous case where the course line is exactly perpendicular to the LOP to begin with, this incorrect procedure will result in a position that is farther away from the DR position than if a perpendicular had been drawn.

Single LOPs can be used to determine an *estimated position* (EP) when used in conjunction with a DR position. (EPs allowing for current are considered in Chapter 7.) Figure 6-4 illustrates the idea. This figure shows a conventional DR plot for a voyage in the waters covered by the 1210-Tr chart. At 1000, sailing vessel *Vagaroso* takes departure from buoy N "8" and heads towards Mattapoisett Harbor at 4.0 knots. At 1030, an LOP from the tower on West Island is determined, and (following the instructions given in Chapter 5) a 1030 DR position is immediately plotted. Now consider the problem posed by this information. By hypothesis, the vessel is somewhere along the 1030 LOP (subject, of course, to the above provisos on the accuracy of an LOP). But, absent the LOP, the best estimate of the *Vagaroso's* position is the 1030 DR position. The recommended solution to this dilemma (see some of the references for an alternative procedure) is to *locate the vessel's EP along the LOP, but as close to the DR position as possible*. It is easy to show from the principles of plane geometry that the shortest distance between a point and a line is formed by a perpendicular drawn from the point to that line. In other words, the EP is that point along the LOP where a line drawn from the DR position intersects the LOP at a right angle. Figure 6-4 illustrates this construction. The EP is denoted with a square around the intersection of the single LOP and the dashed line perpendicular to the LOP drawn from the comparable time DR position. If the time of the EP is clear from the construction, it may be omitted to reduce chart clutter.

Although some argue otherwise (see some of the references at the end of this chapter), conventional practice is *not* to renew the DR plot at an EP—only at a fix, or running fix (see below). This is because the

EP so determined lacks the precision of a fix. The only circumstance where it is recommended that a new DR track should be started from an EP (rather than continued from the DR position) is if the EP were closer to hazards to navigation and prospects for a prompt fix are poor. The reason for this suggestion is that, if the vessel's position is uncertain, it would be prudent to assume that the vessel is located at the more hazardous of the two locations (DR and EP) and a course be set to remain well clear of the hazards. This situation arises more commonly in areas that do not have the abundance of ATONs shown on the 1210-Tr chart. In the exercises given in the SG, therefore, assume that a new DR track is started only from a fix or running fix.

To distinguish the construction line used to determine the EP from the ship's course, it is recommended that the perpendicular construction line be dashed rather than solid. The true direction of the construction line is easily seen to be the true bearing of the LOP plus or minus 90 degrees, or 010 degrees in the example shown in Figure 6-4. (As with all directions, 360 degrees may have to be added to, or subtracted from, the result.) It is preferable to calculate the direction and plot this exactly with parallel rules or a paraline plotter rather than attempt to estimate the perpendicular by eye alone. (It is not necessary to label the bearing of the dashed line.) Any discrepancy between the EP and the DR position is a result of the factors discussed in Chapter 7 on currents and whatever lack of precision is entailed in the determination of the LOP.

To summarize, a single LOP does not determine a fix but is very useful nonetheless. If reference objects are selected so as to be along the course line, a single LOP enables the navigator to determine whether or not the vessel is making good the intended course. If reference objects are selected so as to pass abeam, the single LOP can be used to check the vessel's SMG. Additionally, the single LOP can be used to determine an EP, which incorporates both the DR position and the LOP. Absent an allowance for current, the EP is determined by drawing a dashed perpendicular line from the DR position to the LOP. The EP is denoted by a square surrounding the point. Finally, a single LOP can later be advanced (or retired) to determine a running fix, as discussed below.

ATONs FOR POSITION FIXING

ATONs are designed precisely for the purpose of helping the mariner determine the position of the vessel. These are able to be identified by appearance, sound, markings, light patterns (if lighted) etc. Take special pains to positively identify ATONs before plotting positions. Remember Alton Moody's famous statement, "An incorrectly identified mark is a hazard, not an aid, to navigation."

Navigation Without a Fix

In many cases it may be possible to navigate efficiently and safely without an explicit fix. For example, the navigator can maintain a constant bearing towards an identifiable charted object without explicit determination of a fix, provided that the direct course to the object passes through safe water (consult a chart to make this determination). Perhaps even more convenient, a range (either a specific navigational range or a simple alignment of charted objects) can be used for this purpose. Many ranges can only be used over a fixed area and it is important that the navigator does not continue to follow the range into hazardous waters. To ensure safe passage, use appropriate measures (e.g., reference to a depth sounder or channel marker).

Depending upon the bottom contour and presence of hazards to navigation, following a depth contour may provide safe passage without having to determine an explicit fix. In order to use this method, there must be a reasonable depth gradient in the vicinity of the intended route. Therefore, this method cannot be used in an area of uniform depth (no position reference) or where there is abrupt shoaling (may not be able to take evasive action in time). To use this method, the navigator monitors the depth gauge; if the depth appears to increase, the vessel's heading is shifted in a direction towards shallower water, and the converse. At some point in the voyage, it may be necessary to abandon the track

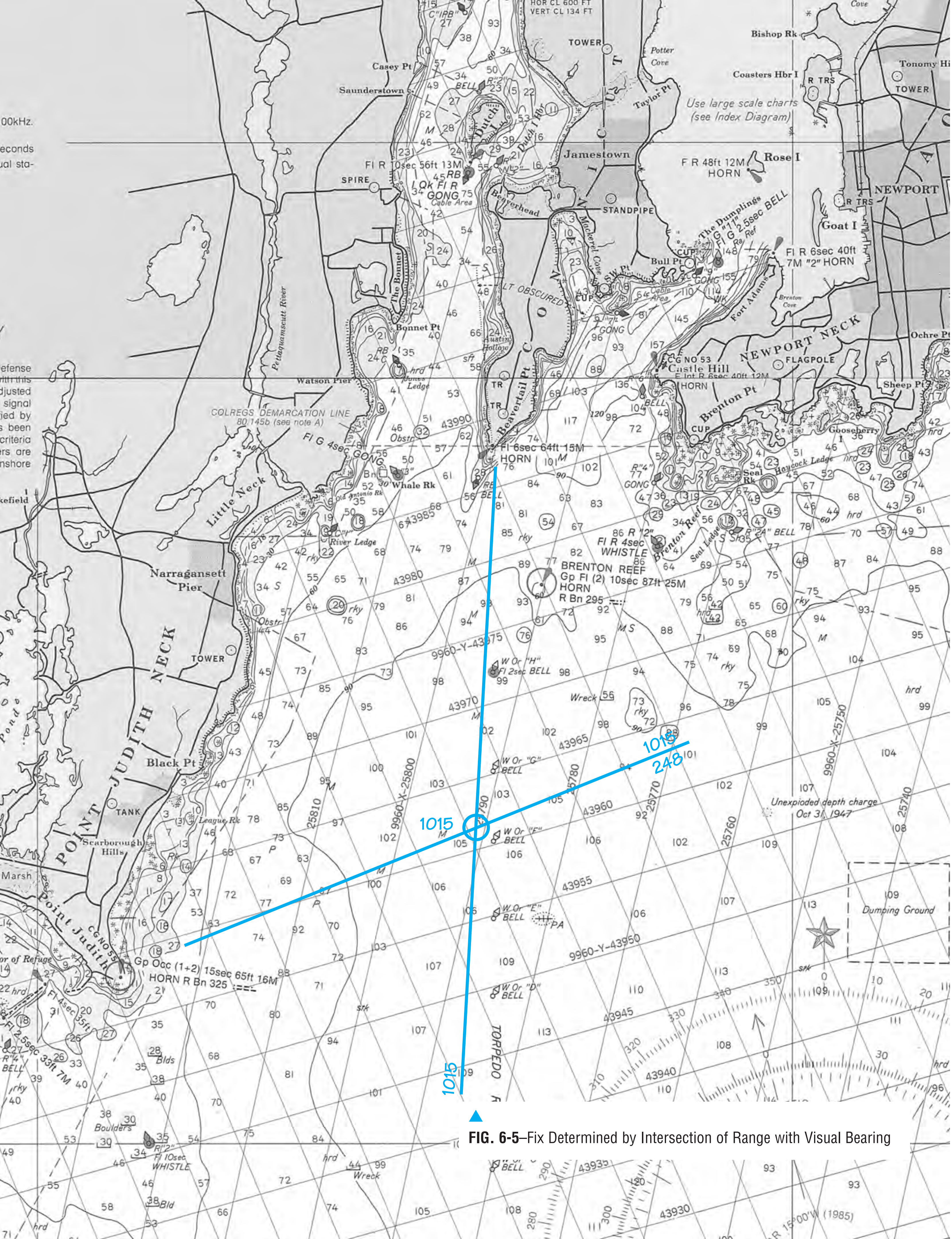


FIG. 6-5–Fix Determined by Intersection of Range with Visual Bearing

defined by the depth contour. For example, a depth contour might be followed until an inlet is identified at which point the vessel would shift direction to enter the inlet.

Although this topic is referred to as "navigating without a fix," it does not mean navigating without position information. In the examples given above, the navigator must have knowledge of the approximate position of the vessel and appropriate charts to ensure that following a range or depth contour can be done safely.

THE FIX

The fix is an accurate position established by the simultaneous, or nearly simultaneous, intersection (crossing) of two or more LOPs, passing close aboard to a fixed ATON, or read directly from a navigation receiver (GPS or Loran-C). Some cautious navigators would argue that at least three LOPs are required to determine a fix. The intersection of two LOPs would be treated as an estimated position.

In addition to direct readout of position from a navigation receiver, fix possibilities include:

- ❑ **Cross bearing:** The intersection of two or more LOPs determined from visual or electronic bearings.
- ❑ **Range and bearing:** The intersection of a range LOP with a bearing on another object.
- ❑ **Two ranges:** The intersection of the LOPs formed by two visual ranges.
- ❑ **Two distances:** The intersection of two (or more) COPs determined from visual or electronic means.

FIX OPTIONS EXPLAINED IN THIS CHAPTER

The following fix options are explained in this chapter:

- ❑ **Cross bearings,**
- ❑ **Range and bearing,**
- ❑ **Intersection of two ranges,**
- ❑ **Two distances,**
- ❑ **Distance and bearing to object,**
- ❑ **Bearing and line of soundings,**
- ❑ **Passing close to a fixed charted object,**
- ❑ **Electronic fix,**
- ❑ **Running fix, and**
- ❑ **Two bearings on the bow.**

- ❑ **Distance and bearing:** Intersection of a distance COP with a bearing to one or more objects.
- ❑ **Known reference:** Passing close to a fixed ATON or other charted object.

To assure maximum accuracy of the fix, it is important that the intersection angle of any two LOPs be as close to 90° as possible. If three LOPs are used, these should intersect at angles as close to 60°-120° as possible. Following these criteria minimizes fix errors, but reasonable deviations of a few degrees (10° - 20°) from the optimum will provide an acceptable fix (and as such, should not be discarded), but the accuracy will be less than optimal. Intersection angles of less than 40° should be avoided for fixes unless they are all that are available. Then, the rule of using all available information would prevail. *Remember that a dead reckoning plot is always started over at a fix.*

The coordinates of a fix (e.g.. latitude and longitude, *time differences* [TDs]) can also be read from a navigation receiver. Electronic navigation is covered in Chapter 9, but the plotting conventions for electronic fixes are noted below.

CROSS BEARINGS

Crossing two or more LOPs based on bearings is a common means of establishing a fix. Figure 6-5 illustrates crossing two bearing LOPs, one from a range consisting of the two towers on Beavertail Pt and the other a visual LOP on the Point Judith Light sighted on a true bearing of 248 degrees from the vessel. The resulting fix is plotted with a circle around the point of intersection and the time (1015) written horizontally. Should the navigator be running a DR plot at this time (not shown in Figure 6-5), as is recommended, a new plot would be initiated using the fix as its beginning.

RANGE AND BEARING

Establishing a fix by the intersection of a range and a bearing LOP is a convenient way to determine a turning point while following the range down a channel at night. While the two objects (lights) are in range, the boat is known to be on this LOP. By taking frequent bearings on another object (light) to one side, a series of fixes are determined and the progress of the vessel can be tracked. When the bearing reaches that marking the turning point, the navigator notes the location and recommends a change to the new course. It is essential that some other object (or method of fixing position) is used in conjunction with the range, else the vessel runs the risk of running into dangerous waters. Well-marked rivers where range lights are used, such as the Delaware, employ a sequence of ranges to aid navigation. One range is followed until the next in sequence is aligned (ranges are distinguished by the colors and flashing characteristics of the lights), whereupon the vessel turns and comes to the new course. Of course, it is important to maintain a sharp look-out for other vessels using the same range!

This process is illustrated in Figure 6-6, where the range of 090 is followed, with successive bearings taken first on the light on the point at 2000 (036), and 2015 (342), and then shifted to the flashing green light at 2030 (037), and finally, to the turning bearing (000) at 2042, at which time the boat changes to its new course of 158 to stay in the next channel. Fixes obtained at 2000, 2015, 2030, and 2042 are labeled accordingly with a circle around the point of intersection and the time horizontally with the base of the chart.

TWO RANGES

Perhaps the easiest fix to plot is that obtained by the intersection of two ranges. The only label required for this fix is a circle around the point of intersection of the ranges and the time. Each range is an LOP, and the intersection constitutes a fix.

TWO DISTANCES

The intersection of two circular LOPs also establishes a fix, although there is a possibility of ambiguity since circles can intersect at two points. Unless the correct intersection is known, say by an approximate bearing on some other reference, two “fixes” are possible, but only one is correct.

Circular LOPs are often developed by radar observations. This fix is indicated in Figure 6-7 with radar range determinations of 3.0 M from Buzzards Bay Light and 2.5 M from

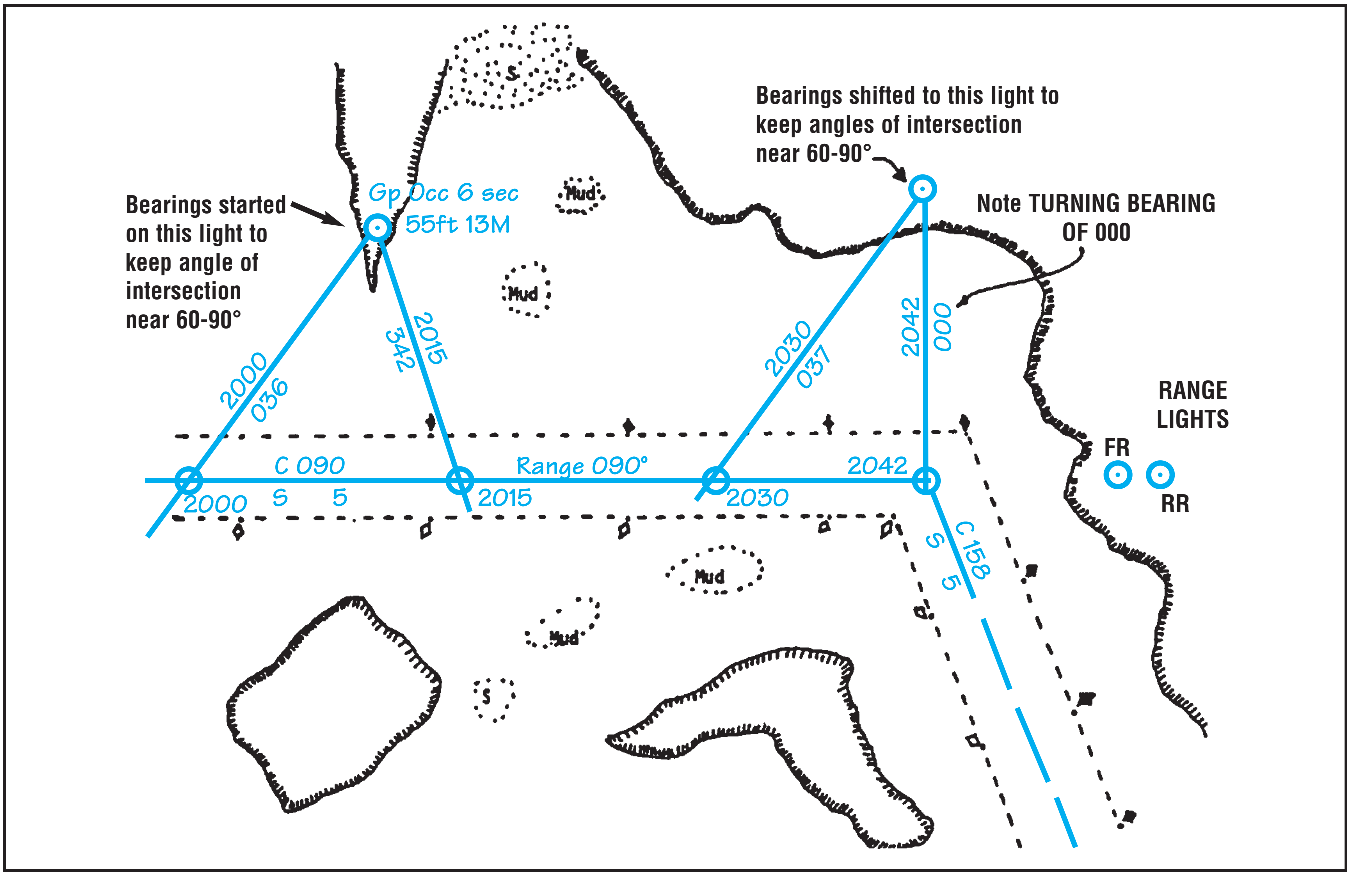


FIG. 6-6–Fixes determined by intersection of bearings with range and illustration of turning bearing of 000 for course change to C 158. All directions indicated are true.

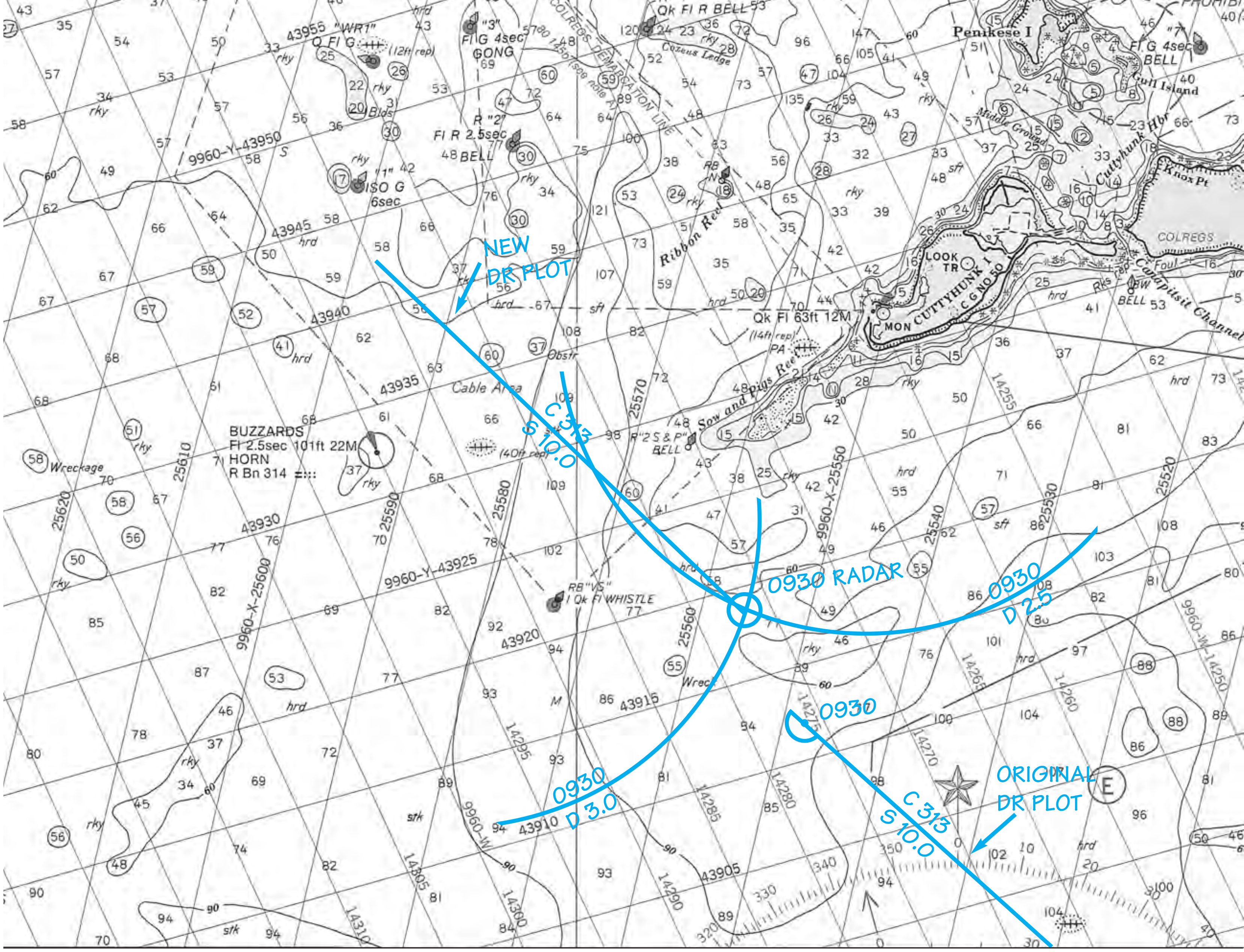


FIG. 6-7–Circular LOP's determine radar fix; DR track is restarted.

the SW tip on Cuttyhunk Island. The point of intersection is labeled with a circle (dot in center). The word RADAR may also be added after the time if the LOP was determined by radar. As with any other fix, a new DR track is initiated after the fix as shown in Figure 6-7. (Note also in Figure 6-7 that the time is written above, and distance written below, the LOP regardless of whether these are within or outside the arc. This is easier to read.)

Figure 6-7 shows both the DR position and the fix. This provides a useful opportunity for a brief digression to cover some practical aspects of the navigator's job. Perhaps most important, the navigator should not be content with simply following rote procedures, such as immediately starting a new DR plot from the fix, without attempting to interpret the available data. For example, the navigator should determine whether the apparent discrepancy between the DR position and the fix is plausible.

In this illustration, the two positions are quite close, so there is probably no reason to look further, except to note that there appears to be a current (or wind/current combination) setting the vessel north and slightly west of the DR position. File this information away and see if this trend is continued at the next fix. Perhaps this current should be compensated for in planning the next course using the methods discussed in Chapter 7 on current sailing.

Suppose, however, that the DR position and the fix were further apart. Rather than simply accepting this conclusion as fact, the navigator should use the opportunity to check the accuracy of the DR plot, the fix, or both. The fix might be checked, for example, by taking another range, bearing, or by measuring the depth of water and consulting the chart to see if this information is consistent with the apparent fix. This example illustrates another important point. Information should be plotted and analyzed as soon as possible after it is gathered. Merely recording data for later analysis forecloses the opportunity to check the fix by additional measurements. A good navigator should never "get behind" the vessel; new information should be analyzed when developed. If this cannot be done, the navigator may wish to slow or stop the vessel (see Chapter 12).

Navigators should always be alert to the possibility that their vessels are "standing into danger." In this example, the vessel is likely to pass closer to the Sow and Pigs Reef than originally planned. A glance at this portion of the chart (see Figure 6-7) indicates that the buoy R "2 S & P" bell marks the western edge of this reef. Perhaps the lookouts should be alerted to watch for this buoy, or the radar should be adjusted to a smaller range setting to help ensure safe passage. Alternatively, perhaps the vessel's course should be altered more towards the Buzzards Bay entrance light to ensure that the reef is left a safe distance to starboard. Which choice is best depends upon numerous factors, such as the prevailing visibility, draft of the vessel, and the navigator's familiarity with the local waters. Plotting and fix taking should not be "clerical" activities done according to rote. Instead, position fixes provide the basis for considered action.

DISTANCE AND BEARING TO OBJECT

This fix can be determined visually by a range finder and handheld compass. This method can also be used if radar is available. The object is first identified on the PPI. Next, the VRM is set to measure the distance and an *electronic bearing line* (EBL) is used to measure the bearing to the object. (Caution should be used, however, with radar bearings, the precision of which are about 1° – 2° in azimuth at best (see Chapter 9) and could be worse, depending upon the amount of yaw, pitch, and roll of the vessel. The precision of the distance measurement is usually greater. In this case, the intersection of the circular distance LOP and the straight-line bearing LOP determines the fix.

The same type of fix results if a navigation receiver is being used. For any defined waypoint (specific location stored in the receiver's memory), the receiver can display the bearing and distance to the waypoint. The bearing and distance to the waypoint can be plotted to establish the fix—although the latitude and longitude can be read directly. Many mariners believe that plotting distances and bearings is quicker and less prone to error than plotting latitude and longitude readings on the chart. Waypoints should be chosen (see Chapter 9) to define the various "legs" of the planned voyage. Waypoints are entered (and checked!) dockside, which removes some of the en route work, another benefit of this procedure.

BEARING AND LINE OF SOUNDINGS

A vessel coasting (running off shore, essentially parallel with the coast) may use this method by taking soundings and a bearing when the opportunity presents itself. As the course is run, the soundings are plotted at intervals, according to the speed and course of the vessel, on a piece of drafting parchment or vellum (a smooth heavy tracing paper) using the same scale as on the chart. When the bearing is taken, the distance from the object is determined by aligning the soundings along the course and the bearing, and moving the sounding trace toward or away from the object (on the bearing line) until close agreement with the charted soundings is obtained. This determines a fix. However, this fix is not very precise unless the soundings change abruptly or offer some other unique feature which distinguishes the specific area from oth-

PHOTO COURTESY OF UNITED STATES COAST GUARD

Fixed markers are preferable for position fixing.

ers. A navigator may be more comfortable terming this an estimated position and labeling this position with a square to denote an EP.

In circumstances of reduced visibility (e.g., in fog), it is sometimes convenient to navigate by following a depth contour, rather than laying out straight-line courses—particularly if the vessel is not equipped with GPS or Loran-C. Although the computation of DR positions along a curved course are more tedious, the actual course can be approximated by a series of straight lines and, with practice, quite accurate DR plots can be made. If the sea bottom is well shaped, it is surprisingly easy to follow a depth contour.

PASSING CLOSE TO A FIXED CHARTED AID TO NAVIGATION

Every time the vessel passes a fixed charted ATON (such as a light), or other charted object, a fix is obtained. As noted above, it is a matter of judgment whether or not to label it a fix if a floating aid is passed close aboard. In Figure 6-4, for example, passing close to buoy N 8 was judged equivalent to a fix and so denoted with a circle. The factors contributing to this judgment included depth soundings indicating a shoal and the close proximity to identifiable objects on the shore.

ELECTRONIC FIX

Navigation receivers for GPS, *Differential* GPS (DGPS), or Loran-C can provide fix data in terms of latitude and longitude or (in the case of Loran-C) time differences (see Chapter 9). These coordinates define a fix. The fix is denoted with a circle (dot in center), the time, and the means used to determine the fix. Examples include 1225 GPS, 0745 DGPS, 1130 LORAN, etc.

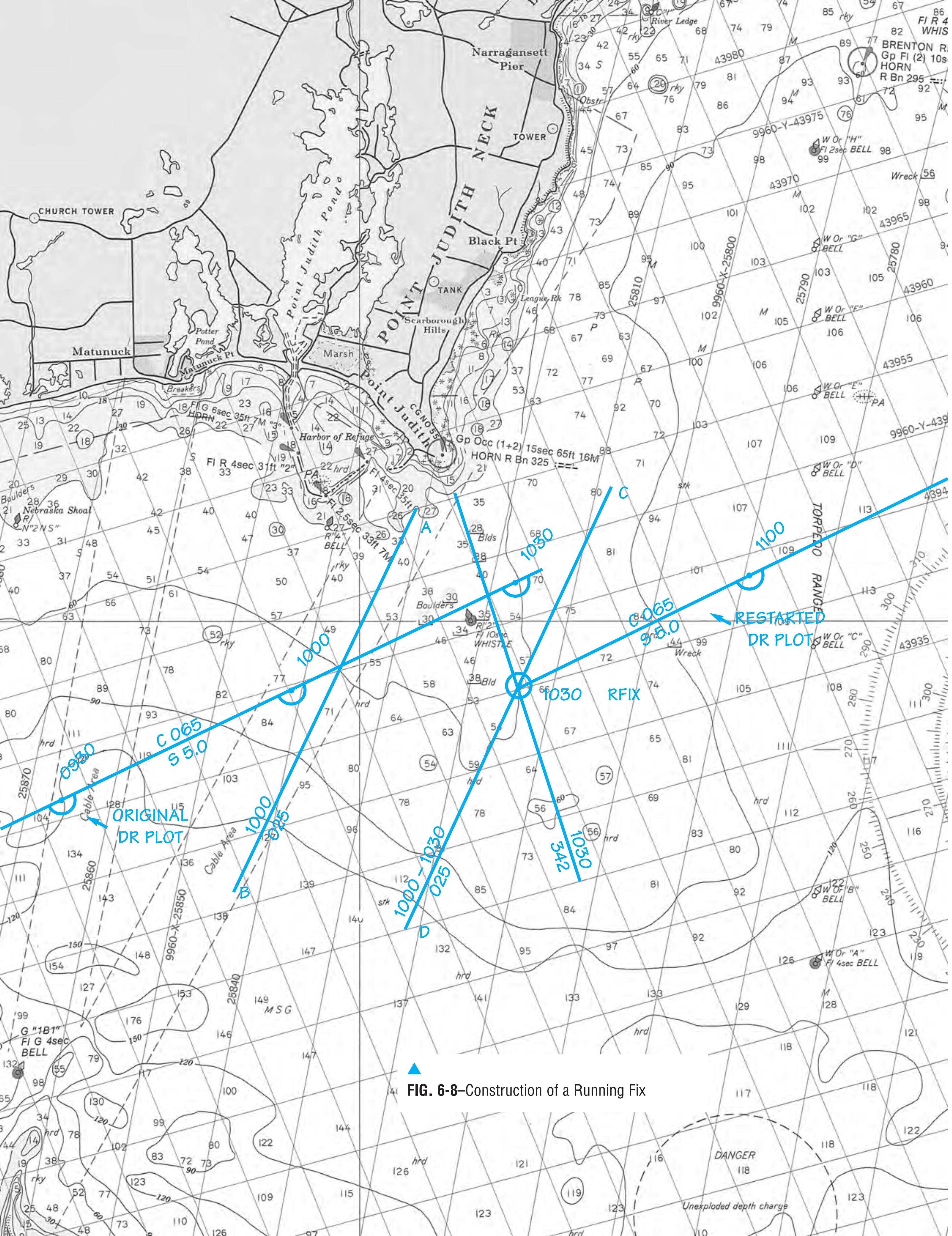
RUNNING FIX (R FIX)

It is not always possible to obtain two LOPs at nearly the same time. For example, poor visibility may limit the number of objects that can be seen. In this case, a *running fix* may be used. A running fix uses an LOP on one object, with a previous (or subsequent) LOP on the same or another object, which is "time corrected" (*advanced or retired*) by dead reckoning calculation of the vessel's direction and distance traveled during the interval between observations of the LOPs. This section considers the running fix without any allowance for current. The running fix with current is discussed in several of the references. To plot a running fix, follow the steps below, which are also illustrated in Figure 6-8:

- ❑ Allow for the time lapse between the first and second bearing. This is done by advancing (or retiring) the first LOP along the vessel's dead reckoning course as if it were advancing (or retiring) at the same speed and in the same direction as the vessel's course and speed.
- ❑ The first LOP is advanced (retired) by moving it parallel to itself, forward (backward) along the course line a distance equal to the distance covered by the vessel in the interval between the two LOPs. The intersection of the advanced (or retired) LOP at the time of taking the second bearing represents the best estimate of position and is called a running fix (abbreviated R Fix).
- ❑ A new dead reckoning plot is started at the position of the running fix.
- ❑ Avoid advancing (or retiring) an LOP for more than 30 minutes if you are in near-shore waters where currents are variable, unpredictable, and/or uncertain. However, in open waters (free of navigational hazards) it is common practice to advance (or retire) LOPs for longer periods, providing you have good course and speed records.

Example of a Running Fix

Vessel *Perdida* is southwest of Point Judith on a course of C065 maintaining 5.0 knots in intermittent showers and 4-ft. seas. A portion of the DR plot for this segment (labeled "original DR plot") is shown in Figure 6-8, along with DR positions at 0930, 1000, and 1030. At 1000, a visual bearing (converted to 025 degrees true) is taken on the light at the tip of Point Judith, and the LOP is plotted and correctly labeled with the time and the bearing (it is denoted "AB" in Figure 6-8). The 1000 LOP crosses ahead of the 1000 DR position, suggesting that the SMG is greater than 5 knots and/or that *Perdida* is farther south than the DR position would indicate. *Perdida's* navigator monitors the depth sounder and alerts the lookout to watch for buoy R "2" as a check on the vessel's position. But, R "2" cannot be seen (possibly because of the seas) or heard. In any event, at 1030 Point Judith Light is again seen, bearing 342 degrees true. This second LOP is drawn and the navigator decides to plot a running fix.



▲ **FIG. 6-8**–Construction of a Running Fix

The steps are detailed below:

- ❑ Obtain the time interval and distance that the vessel traveled since the 1000 LOP.

  10 hr 30 min
  -10 hr 00 min

  0 hr 30 min time interval

- ❑ Calculate the distance that the vessel would move in the interval between the LOPs.

  D = ST/60
  D = 5 x 30/60
  D = 150/60 = 2.5 nautical miles

- ❑ Using a pair of dividers, measure the distance (2.5 M) off the latitude or nautical mile scale along the 065-course line in the direction traveled from the point where the 1000 LOP crosses the course line.
- ❑ Advance the first LOP, ensuring it is moved parallel to itself forward along the true course line an amount equal to the distance traveled (2.5 M). Draw the advanced LOP. Label the advanced LOP with the time interval (1000-1030) written above the line to indicate that it is an advanced LOP over the period from 1000 to 1030. The bearing (025) is written beneath the line. This advanced LOP is denoted "CD" in Figure 6-8.
- ❑ Plot and label the LOP resulting from the second bearing. The running fix is located at the point of intersection with the advanced LOP. Label this point with a circle, and horizontally with 1030 R Fix, clear of the course line. A new DR plot is started at this running fix.

The above example focuses on the mechanics of determining and plotting a running fix. In practice, the navigator should actively explore other means to determine *Perdida's* position. The crossing angle of the advanced LOP and the 1030 LOP (43° in this illustration) is much smaller than the ideal 90 degrees and the failure to observe or hear buoy R "2" are factors that would be of concern. Depth information could rule out the possibility that *Perdida* is too close to Point Judith but is not of much help in deciding between the 1030 DR position and the running fix (both lie nearly along the 60-ft. depth contour). This might be a good time to stop imitating Christopher Columbus and look at the GPS receiver!

In the illustration in Figure 6-8, the running fix was determined using nonsimultaneous observations of the same object. A running fix can also be determined from two non-simultaneous observations of two different objects. In this case, the procedure is identical to that described above, except that the second LOP is plotted from another object.

The running fix assumes that the vessel's SMG and CMG are equal to the STW and course, respectively. In other words, the procedure assumes that the DR plot over the time interval between the two observations is without error. To the extent that this assumption is valid, the running fix is likewise error free. However, current and wind conspire to undermine the validity of this assumption. Other things being equal, therefore, a conventional fix is superior to a running fix.

In the illustration in Figure 6-8, the vessel is assumed to maintain a constant course and speed. A running fix can also be determined if

AVOID THESE COMMON ERRORS IN PILOTING

According to Bowditch, the more common errors in piloting include:

- ❑ **Failure to obtain or evaluate soundings**
- ❑ **Misidentification of ATONs**
- ❑ **Failure to use navigational aids effectively**
- ❑ **Failure to adjust a magnetic compass or keep a table of corrections**
- ❑ **Failure to apply deviation or variation**
- ❑ **Failures to check compass readings regularly**
- ❑ **Failure to maintain a DR plot**
- ❑ **Failure to plot new information**
- ❑ **Failure to properly evaluate new information**
- ❑ **Poor judgement**
- ❑ **Failure to use information in charts and navigation publications**
- ❑ **Failure to "keep ahead of the vessel"**
- ❑ **Failure to have backup navigation methods in place**

the vessel changes course and/or speed. All that is necessary is to find the resultant course and speed over the interval. The resultant course and speed can be determined by drawing a single line between the DR positions at the time that the original bearing is taken and the time that the second LOP is taken and treating this as the overall course and speed line. Consult the references given in the bibliography for details.

ANGLE ON THE BOW

(This section is more technical and can be omitted without any loss of continuity.) Running fixes on the same object can also be treated mathematically, without reference to the charts. Figure 6-9 provides an illustration of the running fix and symbols used in this discussion. Here the vessel takes a first bearing on an object (e.g., a lighthouse) and converts this to an angle on the bow. (Also referred to as an angle off the bow.) This angle, shown as angle Y in Figure 6-9, is measured from 0 through 180 degrees. (For this purpose, it is not necessary to distinguish right from left, as it is assumed that the object remains on one or the other side of the vessel.)

After taking the first bearing, the vessel maintains course and speed until a second bearing is taken. The second bearing is likewise converted to an angle on the bow, and is shown as angle H in Figure 6-9. The distance run between the bearings, denoted x, can be calculated from the usual TSD formula discussed in Chapter 5 as x = ST/60. Now if angle H is exactly twice angle Y–for example, if Y = 20 and H = 40, or Y = 45 and H = 90–then it follows that the triangle formed by the distance run and the two bearings is an isosceles triangle, with the "distance off" at the second bearing, denoted y in Figure 6-9, exactly equal to the distance run between the fixes. Because no mathematics is involved in figuring this out, it is a common method of figuring distance off. Choosing such a pair of angles and calculating distance off is termed "doubling the angle on the bow."

Although the computations are particularly simple if the angle on the bow is doubled, the method can be employed for any pair of angles (ideally, not too closely spaced for maximum accuracy) on the bow, Y and H. In particular, it can be shown (using the law of sine's from elementary trigonometry) that the distance off at the second bearing, y, is given by the equation, y = (ST/60) sin Y/sin (H-Y), and that the distance off when directly abeam, denoted by the symbol h in Figure 6-9, is h = (ST/60) (sin Y) (cos [90-H]) divided by sin (H-Y). (This distance, h, is sometimes called the distance at the *closest point of approach* (CPA) and is discussed at greater length in Chapter 9.) An electronic calculator equipped with trigonometric functions is most convenient for calculating the distances y and h.

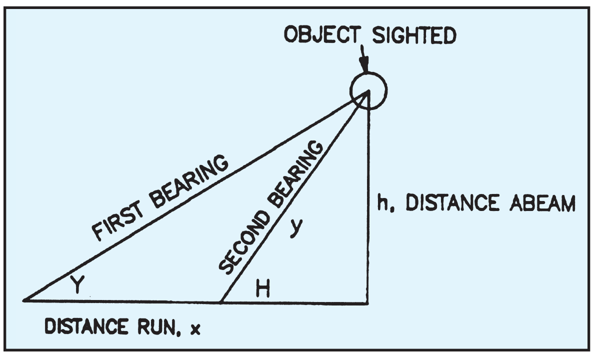


FIG. 6-9–Two-bearing problem illustrated

Alternatively, special purpose tables can be used to find the multiplying coefficients in the above equations. To illustrate, let F1 be equal to sin Y/sin (H - Y). Table 6-3 gives values for F1 as a function of the angles Y and H. Simply enter the table at the row corresponding to the angle on the bow at the first bearing and the column corresponding to the angle on the bow at the second bearing. The value read from the table, Fl, is then multiplied by the distance traveled, ST/60, to calculate y.

Likewise, let F2 be defined as (sinY) (cos [90-H])/sin (H-Y). Table 6-4 shows F2 as a function of the angles Y and H. F2 is read from the table and multiplied by the distance between bearings, ST/60, to determine the distance off when abeam, or the CPA. (A more comprehensive set of tables can be found in Bowditch.)

The calculations go faster if a worksheet, such as that shown in Table 6-5, is used to organize the calculations. As a specific numerical illustration, suppose that the sportfish *Esplendido* is maintaining a true course of 090, and speed of 6 knots, in an area where the magnetic variation is 015W. At 1200, a magnetic bearing of 090 is taken on a lighthouse using a hand-bearing compass, assumed here to be free of deviation. The true bearing is, therefore, 090 - 015W = 075. The angle on the bow is the absolute difference (difference without regard to sign) between the true bearing 075 and the vessel's course (090), or 015 degrees in this example.

F1 FIRST ANGLE, Y (DEGREES)	SECOND ANGLE, H, (DEGREES) 10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	1.000	0.502	0.337	0.255	0.206	0.174	0.152	0.136	0.123	0.114	0.106	0.101	0.096	0.093	0.090	0.089	0.087
10		1.992	1.000	0.671	0.508	0.411	0.347	0.303	0.270	0.246	0.227	0.212	0.201	0.192	0.185	0.180	0.176
15			2.970	1.490	1.000	0.757	0.612	0.518	0.451	0.403	0.366	0.338	0.316	0.299	0.286	0.275	0.268
20				3.924	1.970	1.321	1.000	0.809	0.684	0.596	0.532	0.484	0.446	0.418	0.395	0.377	0.364
25					4.849	2.434	1.633	1.236	1.000	0.845	0.737	0.657	0.598	0.552	0.516	0.488	0.466
30						5.737	2.879	1.932	1.462	1.183	1.000	0.872	0.778	0.707	0.653	0.610	0.577
35							6.581	3.303	2.216	1.677	1.357	1.147	1.000	0.892	0.811	0.749	0.700
40								7.375	3.702	2.484	1.879	1.521	1.286	1.121	1.000	0.909	0.839
45									8.113	4.072	2.732	2.067	1.673	1.414	1.233	1.100	1.000
50										8.789	4.411	2.960	2.240	1.813	1.532	1.336	1.192
55											9.399	4.717	3.165	2.395	1.938	1.638	1.428
60												9.937	4.987	3.346	2.532	2.049	1.732
65													10.399	5.219	3.502	2.650	2.145
70														10.782	5.411	3.631	2.747
75															11.083	5.563	3.732
80																11.299	5.671
85																	11.430

Note: A more complete table can be found in Bowditch.

TABLE 6-3–Abbreviated Table of Values of Factor F1 for "Angle on the Bow" Computations

F2 FIRST ANGLE, Y (DEGREES)	SECOND ANGLE, H, (DEGREES) 10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	1.174	0.130	0.115	0.108	0.103	0.100	0.098	0.096	0.094	0.093	0.092	0.091	0.090	0.090	0.089	0.088	0.087
10		0.516	0.342	0.284	0.254	0.236	0.223	0.214	0.207	0.201	0.196	0.192	0.188	0.185	0.182	0.179	0.176
15			1.016	0.630	0.500	0.434	0.394	0.366	0.346	0.330	0.317	0.306	0.297	0.289	0.281	0.274	0.268
20				1.658	0.985	0.758	0.643	0.572	0.524	0.488	0.461	0.438	0.420	0.403	0.389	0.376	0.364
25					2.425	1.396	1.050	0.874	0.766	0.692	0.638	0.596	0.562	0.533	0.508	0.486	0.466
30						3.291	1.851	1.366	1.120	0.969	0.866	0.790	0.731	0.683	0.643	0.608	0.577
35							4.230	2.336	1.698	1.374	1.175	1.040	0.940	0.862	0.799	0.746	0.700
40								5.215	2.836	2.034	1.628	1.378	1.208	1.082	0.985	0.906	0.839
45									6.215	3.336	2.366	1.874	1.572	1.366	1.214	1.096	1.000
50										7.200	3.820	2.682	2.105	1.751	1509	1.330	1.192
55											8.140	4.275	2.974	2.313	1.909	1.632	1.428
60												9.006	4.686	3.232	2.494	2.04	11.732
65													9.772	5.041	3.449	2.640	2.145
70														10.414	5.329	3.617	2.747
75															10.914	5.541	3.732
80																11.256	5.671
85																	11.430

Note: A more complete table can be found in Bowditch.

TABLE 6-4–Abbreviated Table of Values of Factor F2 for "Angle on the Bow" Computations

Now suppose that at 1230, *Esplendido* again takes a bearing on the light, 060M or 045 true. The second angle on the bow is, using the absolute value, equal to 045 degrees. In the time interval between the bearings, the vessel moved a distance, x, of (6) (30)/60, or 3.0 nautical miles. From Table 6-3, factor Fl is 0.518, and, from Table 6-4, F2 is 0.366. The vessel's distance off at the second bearing is 0.518 (3.0) = 1.6 nautical miles (rounded to one decimal place), and the distance of the CPA is 0.366 (3.0) = 1.1 nautical miles. Table 6-6 shows the completed worksheet for this example.

This procedure is exactly equivalent to plotting the running fix. As discussed here, no allowance for current is included. Although the computations may appear tedious, with practice these can be done rapidly and reliably, particularly if a worksheet is employed. Bear in mind, also, that no calculations are required in the event that the angle on the bow is doubled.

DANGER BEARINGS

Before summarizing the material presented in this chapter, one last topic, danger bearings (called *clearing bearings* in British texts), is included. To make the discussion concrete, refer to Figure 6-10. This figure provides an extract from a vessel's DR plot. The vessel is steering a course generally east, and intends to round a point of land with a lighthouse before turning southeast en route to its destination. Suppose, however, that there is an unmarked danger area (e.g., fish traps, shoals, or coral) that is located just west of the light, denoted by the shaded area in Figure 6-10. A prudent mariner would ensure that a wide berth was given to this area. One simple procedure is to lay off a line (shown in Figure 6-10) well north of the area, and to note the bearing of this line (here 090 true). Provided that the actual true bearing to the light was never less than 090 true, the mariner could be sure that the vessel would not enter the danger area. The bearing, 090 in this example, is termed a *danger bearing* and labeled NLT (denoting *Not Less Than*) above the danger bearing. As a practical matter, this is one of the areas where it would also be prudent to write the magnetic bearing on the chart as well, since a hand-bearing compass is likely to be used as a check. If the hazard to navigation were on the other side, NMT (denoting Not More Than) would be used. Conventional practice would be to draw "whiskers" or hash marks, not shown in Figure 6-10, on the side of the danger bearing facing the hazard.

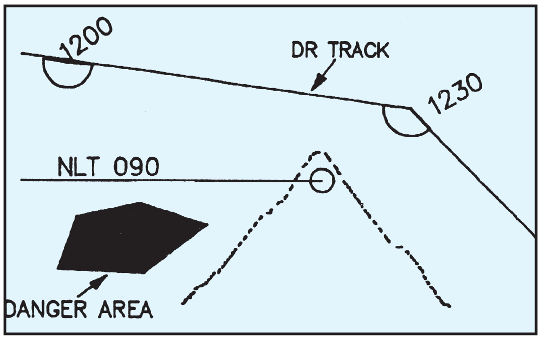


FIG. 6-10–Danger Bearing Illustrated

In order to use danger bearings to advantage it is necessary that there be a charted object (here the lighthouse) on which bearings can be taken. Obviously, danger bearings only make sense if the hazard is not otherwise well marked. However, even if a buoy were shown on the chart, it might be worthwhile to lay off a danger bearing as a precaution in the event that the buoy were off station. (This advice is particularly helpful in areas of the world and seasons where buoys are less frequently on station.) Readers interested in additional detail on danger bearings should consult the references provided at the end of this chapter.

SUMMARY OF SYMBOLS

Figure 6-11 presents a summary and brief description of the drafting symbols used for DR and piloting. These plotting conventions differ from those employed in other parts of the world (Europe, principally). Aside from some additional notation introduced in Chapter 7, this comprises the entire set of symbols used.

THE MOST PROBABLE POSITION (MPP)

Because there are always errors associated with all measurements, it is almost impossible to establish the exact position of the vessel on the chart relative to the earth. However, when the information is adequate, such as three reliable LOPs crossing at a point (or, more typically, within a very small triangle), little judgment is necessary to establish a satisfactory estimate of the vessel's position.

But, there are also circumstances when the navigator has uncertain or conflicting information regarding the vessel's position. Three LOPs, for example, may not cross at a single point or be located within a small triangle, or the apparent fix may be located an implausibly large distance away from the vessel's DR position. Situations such as these require a careful weighing of the information at hand and intelligent and cautious rejection of suspicious information. The resulting position, adjusted for such discrepancies, is termed the *most probable position* (MPP).

Many mariners equate an MPP with an EP. Although an MPP could be an EP in certain circumstances, the MPP is a more general concept than an EP. In principle, an MPP could be a fix, running fix, EP, DR position, or some combination of these. In the example given in Figure 6-8, many navigators might

Item No.	Item	Value	Units	Remarks
1.	Course	______	degrees	Entered in degrees true.
2.	Speed	______	knots	From speedometer or speed curve.
3.	Variation	______	degrees (E, W)	From nautical chart.
4.	Time of first bearing	______	HH:MM	Read from watch.
5.	First bearing to object	______	degrees	From hand-bearing compass.
6.	First bearing of object (true)	______	degrees	Line 5 + Line 3 (if east) or -Line 3 (if west).
7.	Angle off bow at first bearing	______	degrees	Absolute value of [Line 6 -Line 1].
8.	Time of second bearing	______	HH:MM	Read from watch.
9.	Second bearing to object	______	degrees	From hand-bearing compass.
10.	Second bearing of object (true)	______	degrees	Line 9 + Line 3 (if east) or -Line 3 (if west).
11.	Angle off bow at second bearing	______	degrees	Absolute value of [Line 10 -Line 1].
12.	Time between bearings	______	minutes	Line 8 -Line 4 converted to minutes.
13.	Distance run between bearings	______	M	D = (Line 2)(Line 12)/60.
14.	Factor 1	______	NA	From Table 6-3, or sin (Line 7)/sin(Line 11 -Line 7).
15.	Factor 2	______	NA	From Table 6-4, or (Line 14) x Cos (90 -Line 1).
16.	Distance off at second bearing	______	M	(Line 13) x (Line 14).
17.	Distance off abeam (CPA)	______	M	(Line 13) x (Line 15).

TABLE 6-5 (TOP) & TABLE 6-6 (BELOW)–Worksheets for Angle on the Bow Computations

Item No.	Item	Value	Units	Remarks
1.	Course	090	degrees	Entered in degrees true.
2.	Speed	6	knots	From speedometer or speed curve.
3.	Variation	015 W	degrees (E, W)	From nautical chart.
4.	Time of first bearing	1200	HH:MM	Read from watch.
5.	First bearing to object	090	degrees	From hand-bearing compass.
6.	First bearing of object (true)	075	degrees	Line 5 + Line 3 (if east) or -Line 3 (if west).
7.	Angle off bow at first bearing	015	degrees	Absolute value of [Line 6 -Line 1].
8.	Time of second bearing	1230	HH:MM	Read from watch.
9.	Second bearing to object	060	degrees	From hand-bearing compass.
10.	Second bearing of object (true)	045	degrees	Line 9 + Line 3 (if east) or -Line 3 (if west).
11.	Angle off bow at second bearing	045	degrees	Absolute value of [Line 10 -Line 1].
12.	Time between bearings	30	minutes	Line 8 -Line 4 converted to minutes.
13.	Distance run between bearings	3.0	M	D = (Line 2)(Line 12)/60.
14.	Factor 1	0.518	NA	From Table 6-3, or sin (Line 7)/sin(Line 11 -Line 7).
15.	Factor 2	0.366	NA	From Table 6-4, or (Line 14) x Cos (90 -Line 1).
16.	Distance off at second bearing	1.6	M	(Line 13) x (Line 14).
17.	Distance off abeam (CPA)	1.1	M	(Line 13) x (Line 15).

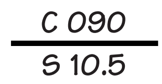
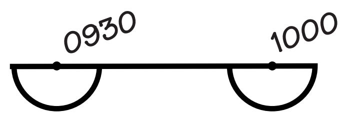
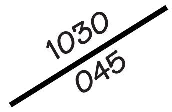
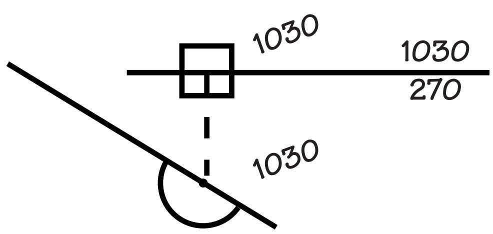
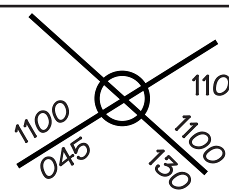
ITEM	DIAGRAM	DESCRIPTION
DR plot		Course (090 true) written above line, speed (10.5 knots) written below line.
DR position		Time (24 hour) written at angle to semicircle denoting DR position.
LOP		Lightly drawn line with time (24 hour) above LOP and true bearing beneath.
Estimated Position		Square located where dashed perpendicular line from DR position touches LOP.
Visual Fix		Circle where two or more LOPs cross. Time written parallel to chart axis.
Electronic Fix		Time and method (if relevant).
Running Fix		Circle containing the intersection of a given LOP and another LOP advanced (or retired) in time, with RFIX and the time specified.

FIG. 6-11–A Concise Summary of Navigation Drafting Symbols

decide that the running fix determined was an MPP or EP rather than a fix. There is no generally agreed upon symbol or label to denote an MPP; however, the letters MPP written next to the position would be clear enough. Likewise, there is no clear consensus among navigators on whether or not to start a new DR plot at an MPP. The more "conservative" navigators would certainly not renew a DR plot at an

MPP, waiting instead until a "proper" fix was determined. Other equally competent practitioners would have a more flexible attitude on this question.

Many of the "judgment" issues, such as whether or not to use floating aids for fixes, how much faith to put in a running fix, whether or not to start a new DR plot from an MPP or EP, serve to remind us that navigation is both an art and a science.

PERSPECTIVES AND PRACTICAL IDEAS FOR SMALL BOATS

The techniques described in Chapters 4 and 5 are ideally suited to vessels that have sufficient space aboard to plot courses and fixes. Ships, yachts, larger sportfishing vessels, trawlers, and many sailboats offer sufficient space and stability to permit use of most or all of these techniques. Aboard a center-console boat or a runabout, it is difficult to use the piloting methods discussed in this chapter. Having said this, the extent to which these techniques can be used when the navigator is convinced that accuracy is important is amazing. (As observed by William Thomas Cummings (1903-1944) in a field sermon on Bataan in 1942, "There are no atheists in the foxholes.")

Here are some additional ideas and perspectives for you to consider:

- ❑ To a large degree, preplanning can substitute for on-the-water plotting. Even operators of small (and/or fast) boats can lay out and plot the track of the intended voyage, including courses and DR positions. In many cases, courses can be selected so as to minimize the necessary precision of navigational fixes. For example, the course can be positioned on the chart "one or two depth contours greater than the vessel's draft," where less precision is required. Fix opportunities can be identified and preplanned. Danger bearings can be determined and plotted on the chart.
- ❑ Annotate the nautical chart extensively to highlight dangers and fix opportunities. For example, if there are buoys and fixed ATONs near the planned route, circle these with a pencil and write the identifying letters, numbers, and light characteristics in large characters.
- ❑ For many trips, it is not necessary that every fix be of high accuracy. An approximate position will do. The preplanned route can be followed and principles described in this chapter can be used to fix the vessel's position periodically. For example, you can use a hand-bearing compass to take a bearing on a suitable object. Rather than plot this LOP exactly, the navigator's hand can be used as a surrogate for the parallel rulers. With practice, you can estimate LOPs to within 5 degrees or so. Certain fixes, such as those in the vicinity of hazards to navigation, may have to be quite accurate and conventional plotting used for these critical fixes.
- ❑ You can preplot (RYA 1990) possible fixes by drawing a *bearing lattice*. Suppose, for example, that two objects are to be used for fixing the vessel's position. A series of light dashed lines can be drawn from each of the objects with various possible bearings noted. When underway, simply measure and record the bearings, then observe the preplotted position where these measured bearings cross on the chart.
- ❑ After plotting the intended track and annotating the nautical chart, cut and/or fold the chart into a strip that covers the area of this track line and necessary surrounding detail. Underway, the strip can be unrolled to match the vessel's progress without taking up a great deal of room—a poor man's electronic chart display.
- ❑ If your boat is equipped with electronic navigation receivers (given the low cost, size, and weight of these receivers, there is little excuse not to have at least one aboard), waypoints marking the checkpoints to be used along the track can be preprogrammed. The *cross-track error* (XTE) displayed by the receiver can be monitored and used to correct courses from those determined from the chart. If more electronic equipment is carried, additional methods can be used. For example, if radar is carried, the vessel can navigate a fixed distance off the shoreline by maintaining one of the FRMs or a preset VRM tangent to the apparent shoreline. In areas with a regular depth gradient, the depth sounder can be used for the same purpose.
- ❑ If you plan to cruise in a well-defined inshore channel, such as

portions of the Intracoastal Waterway where buoys and other markers are closely spaced, it is not really necessary to maintain a tactical DR plot. Just lay out the track line (with courses), steer these courses, look for (and note the passage of) various ATONs, and keep a sharp eye on the depth sounder. However, when planning trips out of sight of land, or where fix opportunities are less frequent, ensure that you follow the methods presented in this chapter.

Nowadays, most coastal navigation is accomplished by a judicious combination of DR plots, seaman's eye, and electronic navigation.

SELECTED REFERENCES

Anon, "Celestial Navigation, the Basics (Part VII) This Segment Offshore Plotting," *Ocean Navigator,* No. 13. May/June 1987, pp. 49 et seq.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA), Marine Navigation Department web site (http://www.nima.mil/).

Bright, C., (1989). Celestial Navigation, The Basics: Celestial Draftsmanship, *Ocean Navigator,* Jan/Feb, pp. 53 et seq.

Brogdon, W., (1995). *Boat Navigation for the Rest of Us—Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Campbell, S., (1985). *The Yachting Book of Practical Navigation,* Dodd, Mead & Company, NY, especially pp. 81 - 101.

Eyges, L, (1989). *The Practical Pilot: Coastal Navigation by Eye, Intuition, and Common Sense,* International Marine Publishing Co., Camden, ME.

Fraser, B., (1981). *Weekend Navigator,* John de Graff, Inc., Clinton Corners, NY.

Graves, F., (1981). *Piloting,* International Marine Publishing Co., Camden, ME.

Groth, L., (1988). Sticking With the DR Position, *Ocean Navigator,* Nov/Dec, pp. 15 et seq.

Kielhorn, W. V., (1988). *A Piloting Primer,* privately published, Naples, FL.

Ministry of Defense (Navy), (1987). *Admiralty Manual of Navigation,* BR 45 (1), Volume 1, Her Majesty's Stationary Office, London, UK.

Markell, J., (1984). *Coastal Navigation for the Small Boat Sailor,* Tab Books Inc., Blue Ridge Summit, PA.

Moody, A. B., (1980). *Navigation Afloat, A Manual for the Seaman,* Van Nostrand Reinhold Co., New York, NY.

Pike, D., (1990). *Fast Boat Navigation,* Adlard Coles Nautical, London, UK.

Royal Yachting Association, (1990). *Navigation, An RYA Manual,* David & Charles, Newton Abbot, UK.

Sexton, J., (1987). Interpreting the Single LOP, What to Do When Your DR Position is Several Miles From a New LOP?, *Ocean Navigator,* No. 11, Jan/Feb, pp. 48 et seq.

Schofield, B.B. (1977). *Navigation and Direction, The Story of HMS Dryad,* Kenneth Mason, Hampshire, UK.

United States Power Squadrons® (USPS), (1998). *Plotting & Labeling Standards,* The United States Power Squadrons, Raleigh, NC.

Commandant USCG, (1999). *United States Coast Guard, Fiscal Year 2000 Budget in Brief,* Washington, DC.

Vesey, T., (1989). Dead Reckoning in Fog, *Cruising World,* Vol. 15, No. 10, October, pp. 33 et seq.

Walsh, G., (1988). Coastal Navigation, The Basics, Building on DR: The Line of Position, *Ocean Navigator,* No. 19, May/June, pp. 55 et seq.

Williams, J. R., (1988). Starting a Fresh DR Track, A Navigator Makes the Case for Using EPs and Running Fixes, *Ocean Navigator,* No. 20, July/August, pp. 68 et seq.

CHAPTER 7

CURRENT SAILING

So, we beat on, boats against the current,
borne back ceaselessly into the past.

–Francis Scott Fitzgerald, *The Great Gatsby*

We must take the current when it serves,
or lose our ventures.

–William Shakespeare, *Julius Caesar*

INTRODUCTION

This chapter covers the important topic of current sailing for the mariner. It builds upon the material presented in Chapters 5 and 6 to include allowance for the effects of current in voyage planning and en route navigation. Although sailing vessels are affected to a greater degree than most powerboats, this chapter is important reading for sailors and powerboat skippers alike.

Sailors are long accustomed to dealing with wind and current in voyage planning. Winds affect the vessel's *speed through the water* (STW) and create the necessity to tack rather than run direct courses to a destination. Current affects the speed made good (SMG) and the required course to achieve a desired track. These truths are obvious to sailors.

Powerboat operators, in contrast, often regard wind and current as minor annoyances except when either assumes extreme proportions. Currents are thought to present more of a challenge for powerboat seamanship than powerboat navigation. This view is overly simplistic and misleading. As shown in this chapter and later in Chapter 11, the effects of current can be very important for powerboats—particularly in terms of fuel efficiency and range. Operators of commercial vessels routinely select advantageous times to enter a harbor or navigate a river so as to minimize fuel consumption. Powerboats are also affected by current in less subtle ways; ask any navigator why DR positions are not exact!

This chapter covers three principal topics:

- ❏ First, it illustrates the additional notation necessary for plotting current problems.

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- ❑ Second, it explains the calculations necessary to determine the actual current set and drift.
- ❑ Third, it shows how to determine the course necessary to compensate for estimated currents and to calculate the resulting SMG/SOA.

To master these topics requires some elementary knowledge of vectors. These are introduced early in this chapter from a mechanical, rather than a mathematical, perspective. Steps to calculate a solution are clearly described and illustrated with numerical examples. Additionally, the *Maneuvering Board* (M Board) is introduced in this chapter as a tool for rapid and accurate analysis of current sailing problems. Use of M boards for other applications (e.g., radar plotting) is deferred until Chapter 9.

Finally, a more complete voyage planning form is introduced to simplify and organize current sailing calculations.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❑ ***Definitions of terms used in current sailing.***
- ❑ ***How to determine current set and drift.***
- ❑ ***How to determine the vessel's estimated position.***
- ❑ ***How to figure the course to steer to compensate for set and drift.***

This chapter is slightly shorter than Chapters 5 or 6. But, teaching experience suggests that the material in this chapter requires fully as much time to master as the earlier chapters on dead reckoning (DR) and piloting. Reread both of these chapters, particularly the definitions contained therein, before studying this chapter.

CURRENT

The process of allowing for current in determining the predicted course made good, or in determining the effect of a current on the direction of motion of a vessel, is termed *current sailing*. For the purposes of this chapter, the term current as used in current sailing includes:

- ❑ The horizontal motion of water over the ground, including ocean current, tidal, and river currents,
- ❑ The effect of wind and seas, and
- ❑ The effects of steering errors made by the helmsman, compass error, speed curve error, tachometer or other engine error, log or speedometer error, and fouled bottom or unusual trim.

APPLICATIONS

Current sailing calculations may also be used to correct course and speed for the effects of known (measured or calculated) or suspected current in order to arrive at the intended destination at the intended time. Current sailing calculations may be applied directly to a DR plot to convert a DR position into an *estimated position* (EP).

CURRENT SAILING TERMS

The following terms are used in current sailing:

- ❑ ***Estimated Current:*** This is the current developed from evaluation of known or predicted forces using calculations, current tables, diagrams, and/or charts. These methods are presented in Chapter 8.
- ❑ ***Actual Current:*** This is the current measured as the difference between the vessel's actual position (fix) and that predicted without taking into account the effects of current (i.e., the DR position). The actual current incorporates all of the effects of current described above. (Purists may challenge the use of the word actual, arguing that even a fix has uncertainty so that even this actual current is an estimate. To avoid confusion with the estimated current as determined above this objection is put aside and the term remains actual current.)
- ❑ ***Set:*** Set is the direction toward which a current flows, or the direction toward which the vessel has been moved as a result of the current. Set is expressed in degrees, true. (This convention is exactly opposite to that for wind. The wind direction is the direction from which the wind is blowing.)
- ❑ ***Drift:*** Drift is the magnitude or speed of the current. Drift can be expressed in knots, statute miles per hour, or kilometers per hour. The choice of units depends upon the cruising area. It is convenient to use speed units to match the distance units given on the chart of the area.

THE CURRENT TRIANGLE

Graphical calculation of the effects of current involves the use of the current triangle, which is a simple vector diagram. The components of the current triangle have both magnitude and direction. The current triangle can be constructed on a separate piece of blank paper, or directly on the chart, using the compass rose as a convenient means of measuring direction and the latitude scale as a means of determining magnitude in units of speed (knots or mph). Additionally, current problems can be solved on an M board, the approach recommended here.

MANEUVERING BOARD (M Board)

The M board is a special-purpose plotting aid that is published by the *National Imagery & Mapping Agency* (NIMA), formerly the *Defense Mapping Agency* (DMA). It is sold in pads of 50 sheets and comes in two sizes, a 10-inch diameter (DMA number 5090), and a 20-inch diameter (DMA number 5091). The smaller diameter pad (5090) is more convenient aboard small vessels and can be purchased at authorized agents for NIMA publications and many dealers in navigation supplies. It is reproduced in Figure 7-1. The M board is a so-called polar diagram, consisting of ten equally spaced concentric rings, termed distance circles, around an origin (denoted by the symbol "e," drawn by hand in Figure 7-1) graduated with the numbers 2 through 10 (1 is not shown but is implicit). These distance circles can be used to represent either distance (e.g., in yards, statute, or nautical miles) or speed (e.g., in knots or statute miles per hour). The M board also contains 36 equally spaced bearing lines, one for every 10 degrees in azimuth (written on the outermost ring), originating at the center and radiating towards the outer rings. Along the outermost ring are smaller degree gradations, enabling azimuths to be drawn every 1 degree from 0 through 359 degrees. Just beneath the outer bearing scale is an inner bearing scale, shown in smaller print, that presents the reciprocals of the principal bearings (e.g., the reciprocal of 10 degrees is 190 degrees, and this is shown beneath the 10-degree mark). At the bottom (not shown in Figure 7-1 because of space limitations) is a self-explanatory nomograph that can be used to solve *time-speed-distance* (TSD) problems. On each side of the sheet are two auxiliary scales, four in total (representing alternative scales of 2:1, 3:1, 4:1, and 5:1), that can be used in lieu of the principal distance scale. There are also inset tables for recording time, bearing, and range, a feature that is useful for radar plotting (see Chapter 9) but is not relevant here. The use of the M board is explained below.

VECTORS TO DETERMINE THE EFFECTS OF A KNOWN OR ESTIMATED CURRENT

The effects of current on a vessel are easily determined with an M board. As a first example, assume that a vessel is steering a course of 090 degrees and maintaining a speed of 7.0 knots. The course or velocity vector for the ship is diagrammed in Figure 7-1 and denoted "ec." It is drawn outward from the origin (e) a distance of 7.0 units along a bearing of 090 degrees. In vector terminology, the "tail" of the vector is at the origin, and the "head" of the vector is located at the point (090 degrees, 7.0 knots). For this example, a distance scale of 1:1 is used, so the "range rings" can be read in knots directly. If a different scale were used, it would be necessary to set the dividers using the auxiliary scales to the right or left and mark off the vector length. (It is good practice to record the scale used somewhere on the diagram for later reference.) To draw the ec vector, simply use a paraline plotter or parallel rules, align the origin and the 090 mark on the outer bearing ring, and draw a solid line of length 7.0 units. (If a bearing were intermediate between the outer graduations, it would be convenient to use a divider preset to a 7-unit length to locate the head of the vector.) Label this first vector with the course and speed in the same manner as for a DR plot, course above the line and speed beneath the line.

Now suppose that an estimated current with a set of 180 degrees and drift of 4 knots affects the progress of the vessel. Obviously, the overall effect of this current will be to shift (set) the vessel to the right (south) of its course. In other words, the estimated *course of advance* (COA) or *course made good* (CMG) will be greater than 090. Likewise, the SOA or *speed made good* (SMG) may differ from the speed through the water (STW, or more simply, speed, S). (SOA and SMG are virtually—but not exactly—interchangeable terms. The distinction is discussed later.)

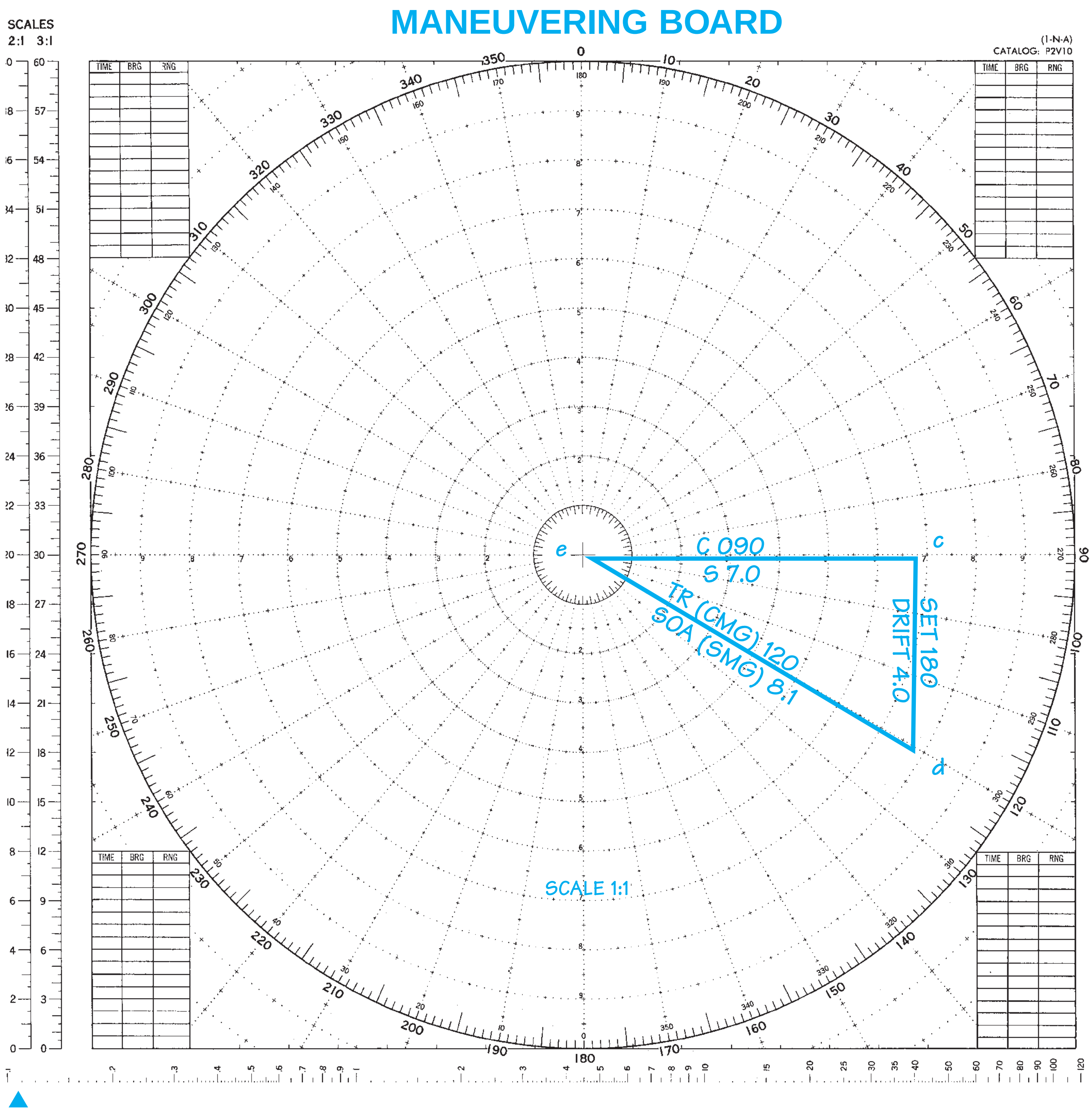

FIG. 7-1–Maneuvering Board with Example Problem

The operative question is, by how much?

To answer this question, it is first necessary to draw another vector, the current or drift vector, to represent the effect of the current. In this case, the current vector is drawn from the head of the course vector, c, in the direction of the set of 180 degrees, a length of 4.0 units, and labeled SET 180, DRIFT 4.0, as is also shown in Figure 7-1. DRIFT is sometimes written Dft or simply “D” to save space. (Since navigators also use the symbol “D” for distance, it is preferable not to use “D” for drift to avoid ambiguity.) To draw this vector, the parallel rule, or paraline plotter, is first aligned with the origin along a bearing of 180 degrees and then walked or rolled until aligned with the head of the course vector. A pair of dividers preset to length 4.0 (the drift in this example) is used to determine the length of the current vector. The tail or the drift vector is at point c, and the head is labeled d.

Finally, the resultant vector, ed, which denotes either the track (TR)/SOA or CMG/SMG, can be determined. It is drawn from the origin (e), to the head of the current vector (d). The TR or CMG can be read from the outer bearing ring and is approximately equal to 120 degrees, some 30 degrees to the right of the course steered in this example. The SOA or SMG can be measured from the length of the vector just drawn in, approximately 8.1 knots in this example, 16% more than the STW. (Any current for which the SMG is greater than the STW is termed a fair current. If the SOA/SMG is less than the STW, the current is termed foul.) This vector is labeled with the TR or CMG above the line and SOA or SMG beneath the line. This completes the analysis of the problem. The effect of the current is easily seen and determined quantitatively by use of the M board.

In this example, the difference between the course steered and estimated track, which might be termed the *current drift angle* (CDA), is quite substantial. In general, the CDA is a function of the relative orientation of the course and drift vectors and of the vessel's STW compared to the drift. CDAs are largest when the current is abeam (90 degrees to the vessel's course) and when the drift is large compared to the vessel's speed, as shown in Table 7-1, for a "beam" current. Inspection of Table 7-1 (produced by computer) shows why fast powerboats are less likely to be affected by the current than slower sailboats. But, it also shows that CDAs are significant, nonetheless, and should not be disregarded. Assuming a 4-knot drift, for example, the CDA would be nearly 6 degrees, even if the vessel's STW were 40 knots, hardly a negligible effect.

The effect of current on the vessel's progress in the original example can also be shown in a more familiar manner, by use of the DR plot, shown in Figure 7-2. The DR course and DR positions are now shown beginning with a fix or departure assumed to take place at 1000. Remember that the DR positions do not include the effect of current, so the DR course line is plotted in a conventional manner. Instead, the effects of the estimated current are shown in a series of *estimated positions* (EPs), or DR positions, corrected for drift. The vector diagram on the M board described a time period of one hour, so the drift vector, cd, is drawn from the 1100 DR position to determine the 1100 EP. The drift vector is drawn with a dashed line and appropriately labeled as shown. EPs for times other than 1100 are easily drawn from the corresponding DR positions parallel to the drift vector a length sufficient to touch the line drawn from departure to the 1100 EP.

Arguably, the line connecting the EPs is a more realistic estimate of the vessel's actual path with respect to the ground, so the student may wonder again why the DR plot is not abandoned in favor of the EP plot. Although there is some merit to this idea, remember that the drift vector is merely an estimate and may be proven wrong with subsequent fixes. All that is known with (near) certainty is that the vessel steered 090 and maintained 7.0 knots. Thus, it is recommended in situations where there is a predictable current that both DR positions and EPs be drawn.

The above method for estimating the effects of a known current on the vessel's position is also used in correcting a running fix for current. In the conventional running fix calculation, the first LOP is advanced along the course steered a distance equal to the DR distance over the time period that the first LOP is advanced. In the presence of a known current, the above procedure is used to determine the resultant CMG/SMG, and the *line of position* (LOP) is advanced along the CMG (rather than the course) a distance calculated using the SMG (rather than the speed) over the time interval that the first LOP is being advanced. The position so determined might be termed a running

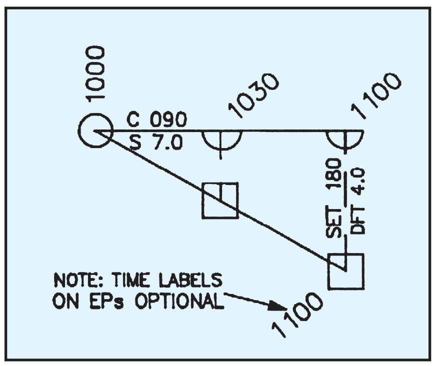

FIG. 7-2–Current problem in Figure 7-1 as it might appear on a nautical chart.

VESSEL STW (KNOTS)	DRIFT OF BEAM CURRENT (KNOTS) 1.00	1.50	2.00	2.50	3.00	4.00	4.50	5.00
1.0	45.0	56.3	63.4	68.2	71.6	76.0	77.5	78.7
2.0	26.6	36.9	45.0	51.3	56.3	63.4	66.0	68.2
3.0	18.4	26.6	33.7	39.8	45.0	53.1	56.3	59.0
4.0	14.0	20.6	26.6	32.0	36.9	45.0	48.4	51.3
5.0	11.3	16.7	21.8	26.6	31.0	38.7	42.0	45.0
6.0	9.5	14.0	18.4	22.6	26.6	33.7	36.9	39.8
7.0	8.1	12.1	15.9	19.7	23.2	29.7	32.7	35.5
8.0	7.1	10.6	14.0	17.4	20.6	26.6	29.4	32.0
9.0	6.3	9.5	12.5	15.5	18.4	24.0	26.6	29.1
10.0	5.7	8.5	11.3	14.0	16.7	21.8	24.2	26.6
14.0	4.1	6.1	8.1	10.1	12.1	15.9	17.8	19.7
16.0	3.6	5.4	7.1	8.9	10.6	14.0	15.7	17.4
18.0	3.2	4.8	6.3	7.9	9.5	12.5	14.0	15.5
20.0	2.9	4.3	5.7	7.1	8.5	11.3	12.7	14.0
25.0	2.3	3.4	4.6	5.7	6.8	9.1	10.2	11.3
30.0	1.9	2.9	3.8	4.8	5.7	7.6	8.5	9.5
35.0	1.6	2.5	3.3	4.1	4.9	6.5	7.3	8.1
40.0	1.4	2.1	2.9	3.6	4.3	5.7	6.4	7.1

TABLE 7-1–Current Drift Angles (Degrees off Course) as a Function of Vessel STW and Current Drift for Beam Current

fix corrected for drift, or an estimated position, depending upon the likely accuracy of the drift estimate. In following this procedure, make sure that you properly take into account the time between LOPs and do not, for example, arbitrarily assume that the current is affecting the progress of the vessel for 1 hour, when the interval between LOPs is only 20 minutes.

CHART PLOTTING CONVENTIONS

As noted in Chapters 5 and 6, the *United States Coast Guard Auxiliary* (USCGAUX) encourages the use of standard plotting and labeling techniques adopted by the USCG and the U.S. Navy, as well as other authoritative sources such as the *United States Power Squadrons*® (USPS). This section reviews these plotting conventions for EPs, with and without current or LOPs, when plotting on a nautical chart.

- Figure 7-3 illustrates the plotting convention for an EP assuming that only an LOP is available (no current information). The procedure is to determine and plot a DR position at the time corresponding to the LOP and to draw a dashed construction line from the DR perpendicular to the LOP. (This is a review of material covered in Chapter 6.)
- Figure 7-4 illustrates the plotting convention if there is an actual or estimated current but no LOP. Here a dashed construction line is drawn from the DR position at an angle equal to the current set. The length of this construction line is equal to the distance that the vessel would move in the time interval since the last fix. For example, if the time since the last fix were 2 hours and the current drift 1.1 knots, the length of the drift vector would be 2.2 nautical miles. It is unnecessary to draw a head on this arrow because lines are always drawn from a DR position.
- Figure 7-5 illustrates the case where both current information and an LOP are available. First, a DR position is plotted. Next, a

dashed construction line is drawn from the DR position (in the direction of the set) a length equal to the distance that the vessel would drift since the last fix. Finally, another dashed construction line is drawn from the end of the drift vector perpendicular to the LOP.

Some of this formalism is omitted if current problems are being solved on a maneuvering board.

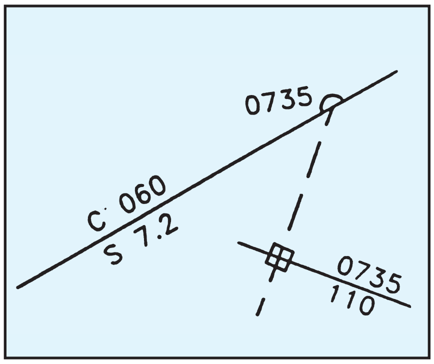

ILLUSTRATION COURTESY OF USPS

FIG. 7-3–Plotting convention for estimated position without current but with LOP.

DISTINCTIONS BETWEEN TR/CMG AND SOA/SMG

It is noted above that the terms TR and CMG (likewise, SOA and SMG) are virtually, but not exactly, interchangeable. The distinctions are not central to the first example but become more important for discussion of the other current sailing problems. As used in current sailing, the *track* (TR) refers to an intended or expected direction of travel with respect to the ground (*course of advance* (COA)), whereas *course made good* (CMG) refers to the actual direction of travel with respect to the ground. Likewise, SOA refers to an intended or expected average ground speed, whereas *speed made good* (SMG) refers to an actual average ground speed.

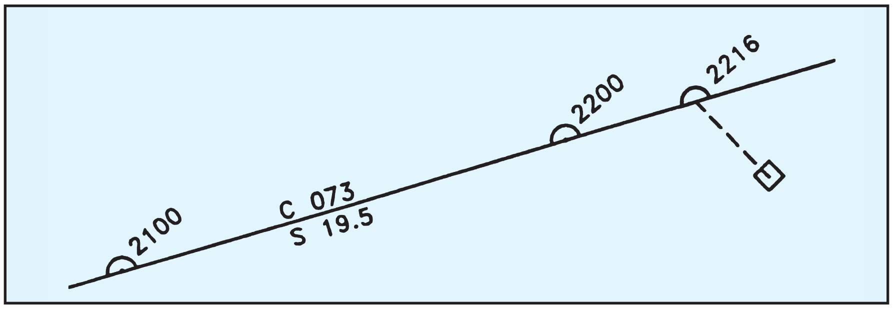

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FIG. 7-4–Plotting convention for estimated position with current but no LOP.

The next current problem, discussed below, refers to the determination of the actual current, from knowledge of the course steered and speed maintained, as compared to the actual average ground speed and direction. In other words, for determination of the actual current, the vessel's course and speed vector are compared to the CMG/SMG. (Whatever the skipper's intentions or expectations were is beside the point.) Alternatively, for planning purposes, it is necessary to decide what course and speed to run in order to maintain an intended track (TR) and, possibly, intended average ground speed as well. Solutions to this problem are also discussed in this chapter. But here the TR and SOA are relevant. Put somewhat differently, TR and SOA refer to before-the-fact estimates, whereas CMG and SMG refer to actual, rather than planned, courses and speeds.

These differences are subtle and are often ignored by mariners. Indeed, if the before-the-fact estimates of current are accurate, then the TR is almost exactly equal to the CMG, and the SOA is, likewise, equal to the SMG.

DETERMINATION OF SET AND DRIFT

Set and drift are usually determined from an analysis of the DR plot when a fix is obtained, by sim-

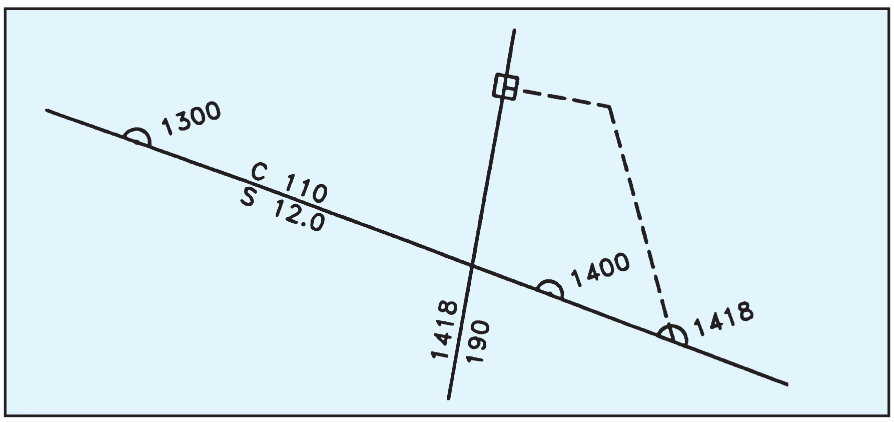


ILLUSTRATION COURTESY OF USPS

FIG. 7-5–Plotting convention for estimated position with LOP and current.

ply reversing the procedure described above. Briefly stated, current set and drift account for the difference between a fix and a DR position. If there is no current, then the fix and the DR position should coincide.

The procedure for determination of current set and drift is carried out in the following four steps and is illustrated with a numerical example from a portion of a cruise in the waters covered by the 1210-Tr chart. Although an M board could be used for estimation of the current vector, it is more common to solve this problem directly on a chart, so this technique will be illustrated.

- ❑ First, prepare a DR plot in the conventional manner, noting either departure or the vessel's earlier fix, together with course(s) steered and speed(s) maintained. (Note that it is not necessary that the vessel steer only one course and/or maintain only one speed for the procedure to produce correct answers! This point is made clear in a later example.) An illustrative DR plot is provided in Figure 7-6. This plot shows that the vessel takes departure from the green lighted buoy near Quick's Hole on the east side of Nashawena Island at time 1330 and maintains a course (213 degrees true) and speed (5.0 knots). Figure 7-6 also shows the appropriate DR positions plotted every 30 minutes on the hour and half hour.
- ❑ Second, plot a fix whenever it is obtained. In this example, a cross-bearing fix is obtained (355 degrees true to the light on the SW tip of Cuttyhunk Island and 301 degrees true to the Buzzards Bay entrance light) at 1450. (If desired, a CMG/SMG vector can be drawn in by connecting the initial fix and the newly acquired fix with a straight line, measuring the CMG, and calculating the SMG by the TSD formula.) Immediately plot the DR position corresponding to the fix time (1450), as is illustrated in Figure 7-6.
- ❑ Third, draw a dashed line, the drift vector, *from the DR position* just plotted to the fix taken at the same time. Measure the bearing of this drift vector (from the DR position to the fix) using a paraline plotter or parallel rule. This bearing (320 degrees true in the example) is the set of the current. Label the drift vector appropriately with the set written above the dashed line representing the drift vector.
- ❑ Finally, measure the length of the drift vector—1.6 nautical miles in this example. This is the distance that the vessel drifted *over the time period between the two fixes*. Remember that drift is the distance covered in one hour (it is measured in knots or statute miles per hour), and, therefore, it is necessary to divide by the time period (either in decimal hours or, using S = 60D/T, in minutes) to calculate the rate. In this example, the time period between fixes was 1 hour and 20 minutes (1450 minus 1330 = 80 minutes), so the drift = 60 (1.6)/80, or 1.2 knots. (A common error is to forget this step.) Add the label to the drift vector directly beneath the set notation.

The drift vector just determined is termed the actual current, because it is based on actual data rather than an estimate derived from current tables, charts, or diagrams (see Chapter 8).

COMMON ERRORS IN CURRENT PROBLEMS

Experience (both in the classroom and on the water) shows that students often make the following errors. Avoid these errors!

- ❑ ***Drawing the drift vector from the fix to the DR position rather than from the DR position to the fix and, therefore, calculating the reciprocal of the drift vector***
- ❑ ***Failing to take in to account the actual time between fixes (which may differ from 30 minutes or 1 hour) and, therefore, figuring the drift incorrectly***
- ❑ ***Failing to plot a DR position corresponding to the exact time a fix is taken***
- ❑ ***Failing to renew the DR plot at every fix***

As noted above, there is no requirement that the vessel maintain a constant course or speed for these calculations to be accurate. Any combination of course and speed changes can be accommodated, provided that these are recorded

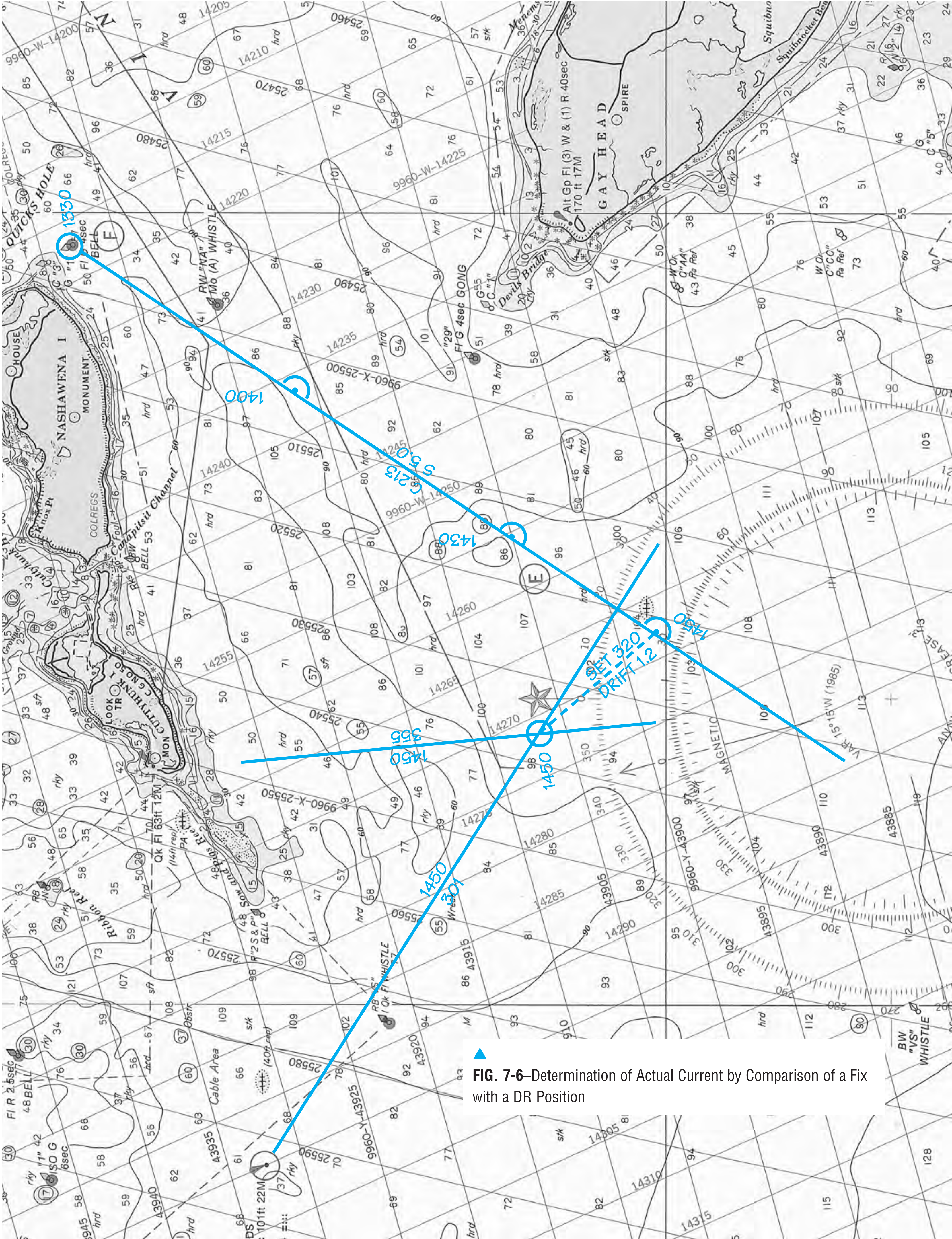
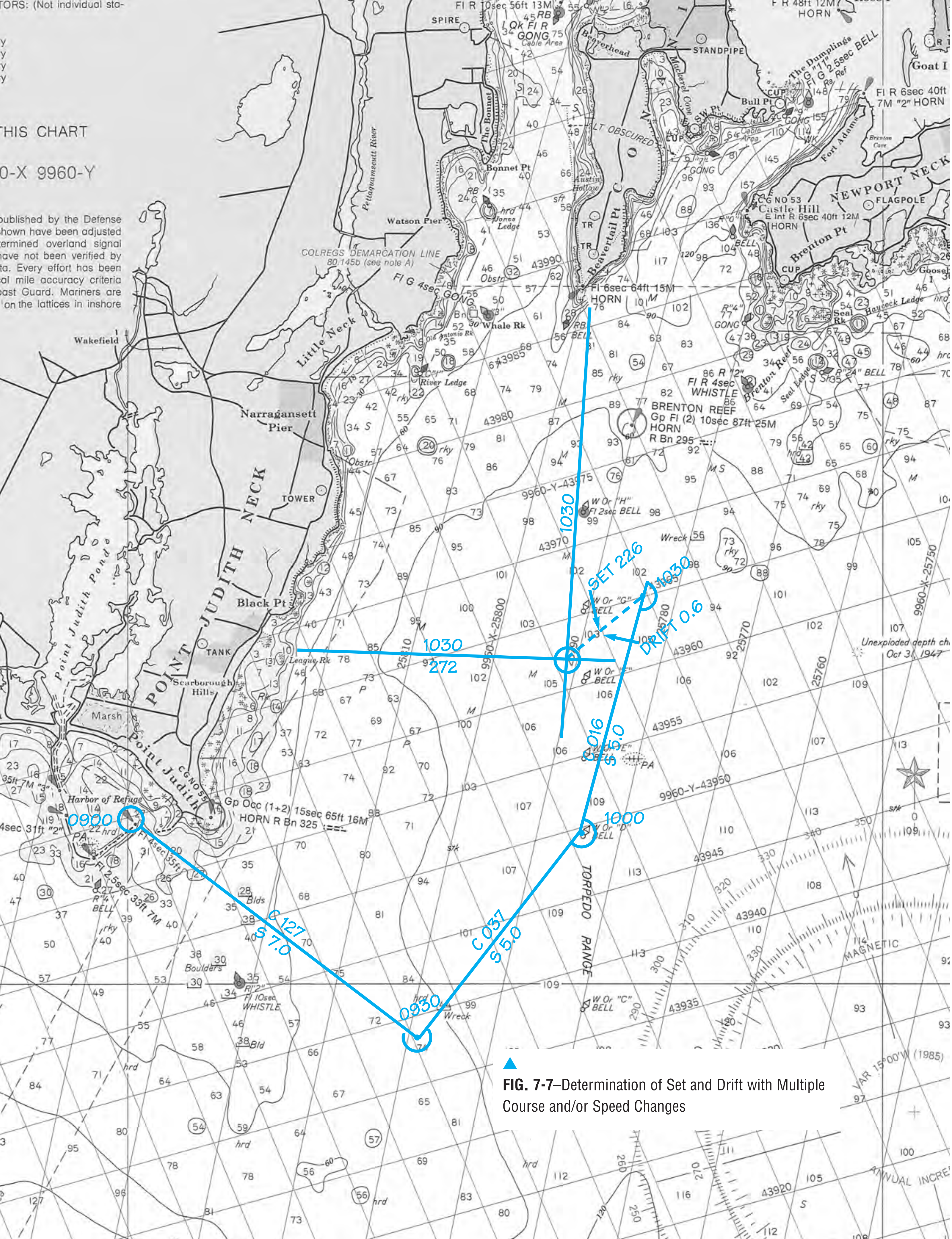


FIG. 7-6–Determination of Actual Current by Comparison of a Fix with a DR Position



▲ **FIG. 7-7**–Determination of Set and Drift with Multiple Course and/or Speed Changes and reflected in the DR plot. Figure 7-7 illustrates this slightly more complex case. Here the vessel takes departure from the Harbor of Refuge near Point Judith at 0900 and makes several course and/or speed changes, as shown on the DR plot. At 1030, a fix is obtained from a range line consisting of the two towers located on Beavertail Point and the tank (bearing 272 degrees true) located on Point Judith Neck. (Note from Figure 7-7 that the bearing on the range is omitted, in accordance with the plotting conventions discussed in Chapters 5 and 6.) This 1030 fix is plotted, together with the 1030 DR position. The drift vector is drawn in and the bearing (set = 226 degrees) and length (0.9 nautical miles) determined. The time between departure and the first fix was 1.5 hours (1030 – 0900), so the estimated drift is 0.9/1.5 or 0.6 knots. The set and drift are labeled appropriately. As can be seen, the procedure required to incorporate course and/or speed changes is only slightly more complicated (because the DR plot is more complex) but is otherwise identical to the simpler case. Incidentally, this example is a nice illustration of the fact that the CMG and SMG vector is, to some degree, an abstraction. The CMG/SMG vector is determined by connecting the two fixes with a straight line. In this case, the straight line would carry the vessel over a portion of Point Judith! Do not think of this as an error; it follows directly from the definition of the CMG/SMG vector as the resultant vector.

These two examples show that the procedure for calculation of the actual current is quick and easy to follow. That said, common errors include drawing the drift vector from the fix to the DR position rather than from the DR to the fix (thus obtaining the reciprocal of the set), failing to take into account the elapsed time between fixes, and failing to plot a DR position corresponding to the time that the fix was taken. Remember, also, to renew the DR plot at the fix.

As noted above, an M board can be used as well as the chart. For cases where a constant course and speed have been maintained, the problem is particularly simple and amounts to reversing the logic used in constructing Figure 7-1. That is, the course and speed vector, ec, is first drawn. Next, the CMG/SMG vector, ed, is drawn based on the vessel's actual positions at the times of the two fixes. Finally, the current vector, cd, is drawn from the course/speed vector to the CMG/SMG vector. The orientation and length of this vector give the set and drift, respectively. (Remember to draw the vector from c to d, and not from d to c; else the set will be off by 180 degrees!)

USE OF THE M BOARD

Current problems can be solved (plotted) on either an M board or a chart. Experience shows that the M board usually provides more precise answers and is easier to grasp for many students. Solving the current problem off the chart results in less chart clutter. However, every marina or marine retailer does not sell M boards. Moreover, doing the work "off the chart" may make it more difficult for your relief to check (if you have the luxury of multiple navigators).

ADDITIONAL REMARKS ON DETERMINATION OF CURRENT

The above examples show how to estimate the actual current by comparing the DR position with a fix. It is also possible to estimate the current by comparing a DR position with an EP derived from a single LOP neglecting any allowance for current. Just substitute the word EP for the word fix in the above discussion and follow the same procedure. However, because the EP derived from a single LOP is likely to be less accurate (perhaps substantially less accurate) than a fix, the "actual" current so determined is, likewise, less accurate.

Even if a fix, rather than an EP, is used for estimation of actual current, it is important to realize the limitations of this estimate. First, the "actual" current includes all of the factors listed under the definition of current, e.g., helmsman's errors, errors in the speed curve, wind effects, and other factors besides the horizontal movement of water. Even without this consideration, the actual current should be termed an "historical estimate" relevant to a particular time and expanse of water. Conventional practice is to apply this historical estimate to future legs. However, what is needed is a forecast of future current in the area where the vessel will be cruising, rather than estimates of past currents for areas already traveled. Judgment is required to decide whether or not to use the actual current determined on one leg of a trip as a surrogate for those applicable to subsequent voyage legs. Current diagrams and related material, discussed in Chapter 8, provide an indication of the spatial distribution of current and, hence, the possible differences between the current in one area and that in another. If these differences are small, the mariner may use the historical estimate with more confidence. Local knowledge is also useful in forming sound judgments.

To return to the topic of the accuracy of the actual current, it is important to note that the overall accuracy is a function of the fix accuracy and the time period over which the estimate was developed. If the time period is "short," the fix will be "close" to the DR position, and any errors in the fix or the DR plot will have a substantial effect on the error in the resulting current estimate. However, if too long a time period is used, the calculated actual current is less proximate and, therefore, less relevant. As a practical matter, a time period of at least 30 minutes, and as much as 1 hour or more, is often used for current determination.

DETERMINATION OF A COURSE TO STEER (CURRENT GIVEN)

A common problem in current sailing is to determine the appropriate course to steer (C) in order to make good an intended track (TR), assuming that the current set and drift are known (either because these are estimated in advance using the methods of Chapter 8 or determined by a comparison of the vessel's DR position with a fix as discussed above), as well as the vessel's speed (S). This problem is easily solved on an M board in the following five steps.

To make the discussion concrete, assume that the skipper wishes to make good a track of 050 degrees, and that the current set and drift are 130 degrees and 2.0 knots, respectively. The vessel's speed is 8.0 knots. The M board solution is shown on Figure 7-8 and is discussed below.

❑ First, lightly draw a line of arbitrary length in the direction of the intended track (050 degrees). When completed, this line will represent the vessel's TR and SOA. However, the length (SOA) cannot yet be determined. The vector begins at the origin, e, of the M board.

❑ Second, draw the current vector from the origin, e, and label the set and drift. The head of the current vector, located in this example at the point (130 degrees, 2.0 knots), is designated with the letter "g" in Figure 7-8. As in the earlier M board example, a scale of 1:1 is convenient and is also noted.

❑ Third, set the drafting compass to a length equal to the speed, S, of the vessel using the distance or auxiliary scales as appropriate. Place the metal point of the compass on the head of the current vector (at g), and "swing"

CURRENT SAILING IN AN ELECTRONIC WORLD

The availability of modern navigation systems, such as the Global Positioning System (GPS) or Loran-C, can simplify current sailing. As noted in Chapter 9, the navigator can specify the intended voyage track as a series of waypoints that define the ends of route segments.

Once started along this route, the helmsman steers the vessel in accordance with the navigation receiver's display to keep the cross-track error (XTE) at or close to zero. Most navigation receivers have a display with a heading arrow directing the helmsman to steer right or to steer left. The average heading necessary to keep the XTE at or close to zero is the correct course to compensate for the current.

The navigation receiver can also display the SMG or velocity along route (VAR) from which an estimated time of arrival can be calculated. Navigating in this way, there is no need for explicit current calculations of the type presented in this chapter. However, not all vessels are equipped with navigation receivers, any piece of equipment can fail (especially on a boat), and "hand calculations" can serve as a useful check on navigation receivers (see Chapter 9).

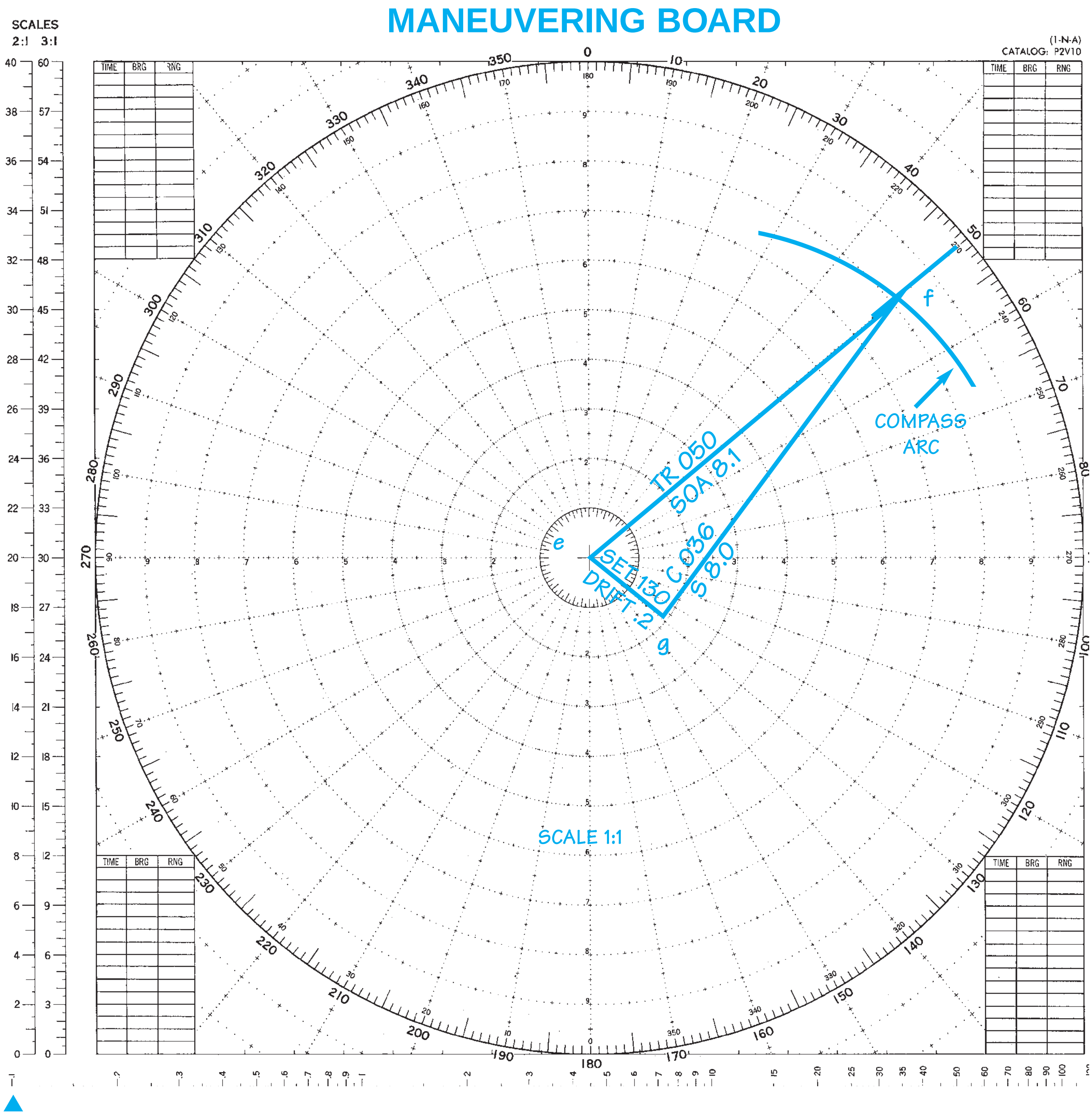


FIG. 7-8–Determination of Course to Make Intended Track with Current Given

an arc of length S (8.0 units in this example) until it intersects the track line lightly drawn in the first step. Note and darken this intersection point, labeled "f" in Figure 7-8.

❑ Fourth, draw a solid line from point g to point f. This line is the course/speed vector for the vessel. Using a parallel rule or paraline plotter, measure the bearing of this line. This angle, 036 degrees in this example, is the course that needs to be steered at 8.0 knots to make good the intended track. Label the course (C 036) and speed (S 8.0) as on a DR plot.

- Fifth, darken and measure the length of the TR/SOA vector ef. This length (approximately 8.1 units in the example) is the estimated SOA along the track. Label the track (TR 050) and SOA (SOA 8.1) on the vector ef as shown.

This completes the procedure. The answer is interpreted as follows. To make good an intended track of 050 degrees in a current with drift 2.0 knots and set 130 degrees, it is necessary to steer a course of 036 degrees if the vessel's speed is 8.0 knots. The estimated SOA is approximately 8.1 knots. It is good practice to check the plausibility of the results before setting off on the calculated course. In this example, the current set is to the right of the intended track. That is, the current is tending to push the vessel to the right of the intended track. It makes sense, therefore, that the course to compensate for this current should be to the left of track. And, indeed, 036 degrees (the course) is to the left of 050 degrees (the intended track). The difference between the course steered and track (036-050 = 014 degrees) is termed the *current correction angle* (CCA). This result is plausible.

Next, consider the SOA estimate. Because the current set is forward of the beam, albeit only slightly, the SOA should be (slightly) greater than the vessel's speed. In other words, the current in this example is (slightly) fair. This, too, checks, as the calculated SOA (8.1 knots) is slightly greater than S (8.0 knots).

The current correction angle can be determined mathematically and is a function of the relative bearing of the set compared to the vessel's course and the ratio of the drift to the vessel's speed. Current correction angles are largest when the current is abeam the intended track and when the drift is large in relation to the vessel's speed. This point is illustrated in Table 7-2, which shows computer calculated values of the current correction angle in degrees as a function of the relative bearing of the set in relation to the track (the rows in the table) and the ratio of the drift to speed (the columns). In this example, the relative bearing of the set is 80 degrees, and the ratio of drift to speed (2/8) is 0.25. Reading along the row corresponding to the relative bearing (080) and down the column corresponding to the speed ratio (0.25), the table entry, -14 degrees, is shown. Thus, to maintain a track of 050 the vessel would need to steer 050-014, or 036 degrees—exactly the value determined by use of the M board.

CURRENT COMPENSATION WHEN THE SOA IS PRESPECIFIED

The technique described above is applicable to determination of the course to steer to compensate for known or estimated currents in the conventional case where the vessel's speed is specified. This is the usual situation in current sailing. The speed is either estimated (in the case of sailing vessels) or "known" as in the case of powerboats maintaining a specified engine revolutions per minute (RPM). In either case, the vessel's speed is assumed to be fixed in advance rather than a decision variable to be determined.

It is also of interest to solve cur-

USE OF ELECTRONIC CALCULATORS

Graphical methods are developed in this chapter. These calculations can also be made mathematically, using trigonometric formulas (see Rogoff, 1979; Shufeldt and Dunlap, 1991). Electronic calculators are convenient for these calculations. Additionally, several manufacturers make special-purpose calculators (typically for aviators) that are designed for these calculations. Mariners using one of these special-purpose calculators made for aircraft pilots should remember that the convention for wind direction differs by 180° from that used for current set. Therefore, it is necessary to add (or subtract) 180° to the set in order to make these calculations correctly.

RELATIVE BEARING OF SET (DEGREES)	RATIO OF CURRENT DRIFT TO VESSEL'S SPEED THROUGH THE WATER (STW)															
	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70	0.80	0.90	1.00
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	-1	-1	-2	-2	-3	-3	-4	-4	-5	-6	-7	-8	-8	-10
20	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-12	-14	-16	-18	-20
30	0	-1	-3	-4	-6	-7	-9	-10	-12	-13	-14	-17	-20	-24	-27	-30
40	0	-2	-4	-6	-7	-9	-11	-13	-15	-17	-19	-23	-27	-31	-35	-40
50	0	-2	-4	-7	-9	-11	-13	-16	-18	-20	-23	-27	-32	-38	-44	-50
60	0	-2	-5	-7	-10	-13	-15	-18	-20	-23	-26	-31	-37	-44	-51	-60
70	0	-3	-5	-8	-11	-14	-19	-19	-22	-25	-28	-34	-41	-49	-58	-70
80	0	-3	-6	-8	-11	-14	-17	-20	-23	-26	-29	-36	-44	-52	-62	-80
90	0	-3	-6	-9	-12	-14	-17	-20	-24	-27	-30	-37	-44	-53	-64	-90
100	0	-3	-6	-8	-11	-14	-17	-20	-23	-26	-29	-36	-44	-52	-62	-80
110	0	-3	-5	-8	-11	-14	-16	-19	-22	-25	-28	-34	-41	-49	-58	-70
120	0	-2	-5	-7	-10	-13	-15	-18	-20	-23	-26	-31	-37	-44	-51	-60
130	0	-2	-4	-7	-9	-11	-13	-16	-18	-20	-23	-27	-32	-38	-44	-50
140	0	-2	-4	-6	-7	-9	-11	-13	-15	-17	-19	-23	-27	-31	-35	-40
150	0	-1	-3	-4	-6	-7	-9	-10	-12	-13	-14	-17	-20	-24	-27	-30
160	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-12	-14	-16	-18	-20
170	0	0	-1	-1	-2	-2	-3	-3	-4	-4	-5	-6	-7	-8	-8	-10
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
190	0	0	1	1	2	2	3	3	-4	4	5	6	7	8	8	10
200	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
210	0	1	3	4	6	7	9	10	12	13	14	17	20	24	27	30
220	0	2	4	6	7	9	11	13	15	17	19	23	27	31	35	40
230	0	2	4	7	9	11	13	16	18	20	23	27	32	38	44	50
240	0	2	5	7	10	13	15	18	20	23	26	31	37	44	51	60
250	0	3	5	8	11	14	19	19	22	25	28	34	41	49	58	70
260	0	3	6	8	11	14	17	20	23	26	29	36	44	52	62	80
270	0	3	6	9	12	14	17	20	24	27	30	37	44	53	64	90
280	0	3	6	8	11	14	17	20	23	26	29	36	44	52	62	80
290	0	3	5	8	11	14	16	19	22	25	28	34	41	49	58	70
300	0	2	5	7	10	13	15	18	20	23	26	31	37	44	51	60
310	0	2	4	7	9	11	13	16	18	20	23	27	32	38	44	50
320	0	2	4	6	7	9	11	13	15	17	19	23	27	31	35	40
330	0	1	3	4	6	7	9	10	12	13	14	17	20	24	27	30
340	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
350	0	0	1	1	2	2	3	3	4	4	5	6	7	8	8	10

TABLE 7-2–Current Correction Angle as a Function of Relative Bearing of Set and Ratio of Drift to STW

rent problems where the SOA, rather than the vessel's speed, is specified. For example, you may wish to arrive at a drawbridge at a time of scheduled opening or arrive at an inlet at a time of slack water. Other examples include attempts to rendezvous at a specified place and time, cross a shoal at or near high tide, pass under a fixed bridge at low tide, etc. For these problems, the vessel's speed is assumed to be a decision variable, rather than fixed in advance. It is also assumed that the current is known (or able to be estimated) as are the intended track and SOA. The problem is to determine the course to steer and speed to maintain in order to make good the intended track and SOA.

Solution of this problem is a minor variant—a simplification, in fact—of the technique discussed above. It, too, is solved on an M board, using the sequence of three steps explained below. As an example, assume that the *estimated time of departure* (ETD) is 1015 and an *estimated time of arrival* (ETA) of 1045 at a location bearing 280 degrees true

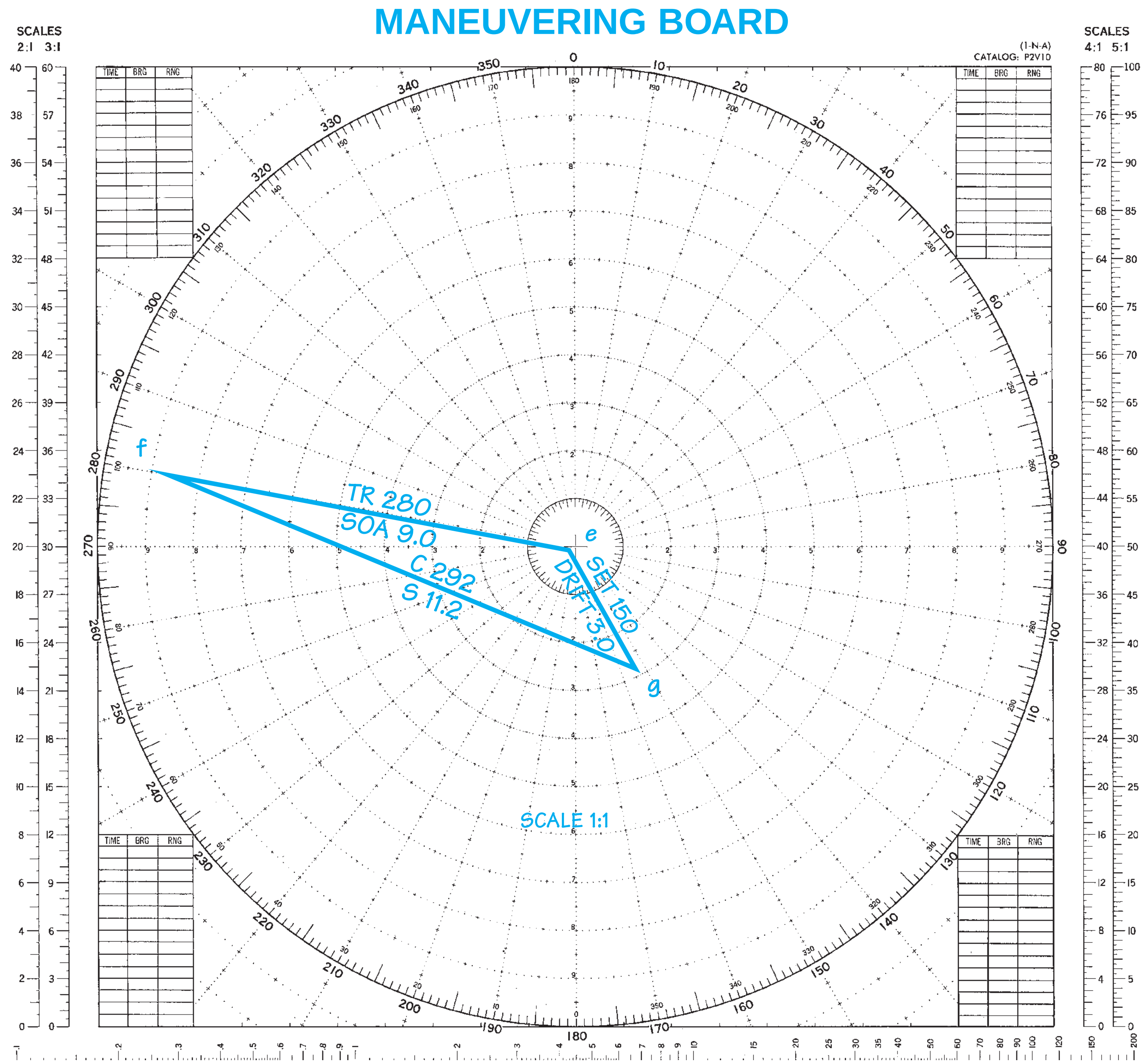


FIG. 7-9–Determination of the Course and Speed to Achieve a Specified Track and SOA, with Known Current

and 4.5 miles distant is desired. The estimated current sets 150 degrees at 3.0 knots. What is the course to steer and speed to maintain? A TSD calculation readily shows that the SOA must be 9.0 knots to attain the ETA, so the problem givens are: SOA 9.0 knots, set 150 degrees, drift 3.0 knots, and intended track 280 degrees. The M board solution is shown in Figure 7-9.

Here are the steps to follow to solve this type of problem:

- ❑ First, draw the TR/SOA vector from the origin, e, out along the intended track (280 degrees) a length equal to the SOA (9.0 knots) to the point f. (Unlike the case where the speed, rather than the SOA is specified, this vector can be drawn completely in the first step.) A scale of 1:1 is used here.
- ❑ Second, draw the current vector from the origin, e, to point g, as

in the earlier case, and label the set (150 degrees) and drift (3.0 knots).

- ❏ Third, draw the course/speed vector from the head of the current vector (point g) to the head of the TR/SOA vector (point f). Measure the length of this vector (11.2 units); this is the required speed (11.2 knots) to make good the SOA. Next, measure the bearing (using a parallel rule or paraline plotter), 292 degrees in this example. This is the course required to compensate for the current.

The answer is interpreted as follows. To make good an intended track of 280 degrees and SOA of 9.0 knots in a current with set of 150 degrees and drift 3.0 knots, it is necessary to steer 292 degrees and maintain 11.2 knots. The answer is plausible; the current is setting the ship to the left of track, so the CCA should be to the right. Additionally, the current is foul, so the speed will have to exceed the intended SOA.

All current problems are subdivided into one of four categories: (i) determination of the EP from course steered and speed maintained, (ii) determination of the actual current from knowledge of the course steered and maintained compared to the CMG/SMG, (iii) determination of the course to steer to compensate for known currents in order to make good an intended track given the speed, and (iv) determination of the course to steer and speed to maintain, given actual current, in order to make good an intended track and attain a specified SOA. Review the steps for solution of each of these problem types and practice plotting these on both a chart and an M board. Pay particular attention to what is being plotted as well as to the steps. For example, suppose you estimate a current and use this estimate to calculate a course to compensate so as to make good an intended track. Later, you determine a fix and wish to calculate the actual current. Remember to compare the DR track with the CMG/SMG—neither the TR nor the SOA enter into this calculation. Practice alone prevents these blunders.

VOYAGE PLANNING: PUTTING IT ALL TOGETHER

As discussed above, current sailing techniques are useful for two purposes. First, these are used for prevoyage planning to estimate the requisite courses and SOAs based on forecasted currents (see Chapter 8 for details), and second, in a more or less “real time” mode, where a comparison of the vessel’s DR plot with positions enables calculation of actual currents and necessary course adjustments.

Normally, current problems are solved sequentially. For example, a preliminary estimate of set and drift is used to calculate a course and estimate an SOA. This course is steered until a subsequent fix is obtained. The fix is compared to the DR position, and a revised estimate of current set and drift is made. This revised set and drift is compared to known information (see Chapter 8) and adjusted (if necessary) based upon the vessel’s future intended track. The revised set and drift are used to determine a new course and SOA, and so forth in an iterative manner.

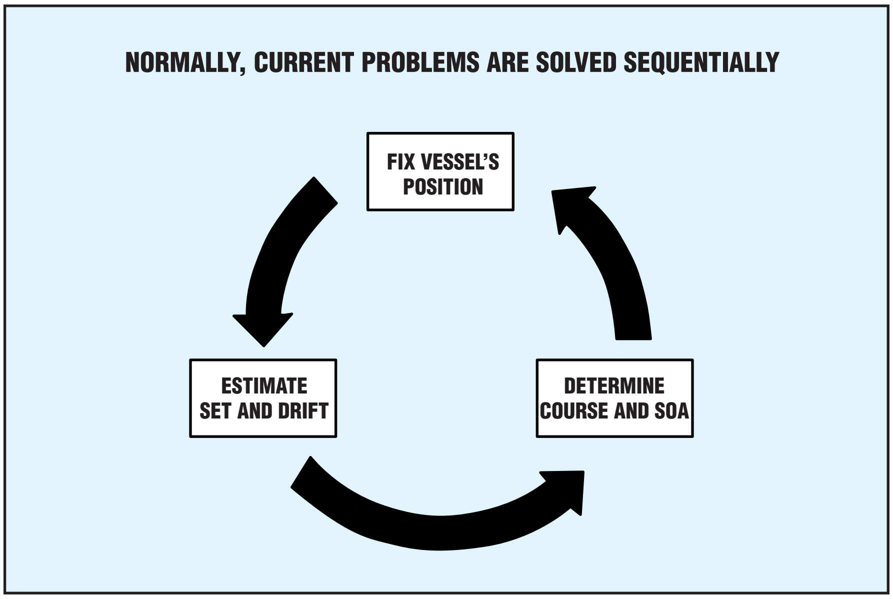
Prevoyage planning is an important activity in itself. From the point

WHEN TO USE THESE TECHNIQUES

The competent navigator should be able to solve current sailing problems quickly, accurately, and with confidence. To maintain this (or any other skill), it is necessary to stay in practice. Therefore, it is necessary (at a minimum) to make these calculations at least occasionally.

For many voyages, currents can be substantial, and formal use of these techniques is necessary. For example, in crossing the Gulf Stream from Florida to the Bahamas, it is essential to correct for currents (these have a northward set). Even on voyages where the current correction angles are less, say in navigating a tidal river, current can have a substantial effect on SMG and fuel requirements. As noted, electronic navigation systems can do much of the work. But, valuable as these systems are, these do not substitute for the human brain.

There are also voyages that do not require formal use of these techniques. Trips in local waters, areas where currents are modest, and areas with well-marked channels may not require use of these techniques.



of view of the ACN course, it provides an opportunity to integrate the various topics covered thus far, e.g., charts, the ship's compass, DR, piloting, and current sailing. The essence of prevoyage planning is to select the appropriate route and timing of the voyage (from inspection of relevant charts and other reference materials), lay out the voyage legs (including the identification of suitable objects for fixes, turnpoints, etc.), precalculate courses, SOAs, fuel consumption, and other tasks.

There is no single "best" approach to this planning process, but it is helpful to have a worksheet, or checklist, to structure the process. One trip planning worksheet is shown in Figure 7-10. It contains checklist information and entries for such items as track, leg distance, engine RPM, STW, current set and drift, course to steer (true), the TVMDC calculations, estimated SOA, *estimated time en route* (ETE), ETA, and fuel planning data (discussed in Chapter 11). These entries are arranged in the order in which they would normally be calculated for planning purposes.

The first (handwritten) line describes one leg of a voyage from Block Island to Wood's Hole on the 1210-Tr Chart. Follow through the calculations and ensure that you are able to understand how these are developed.

USE OF ELECTRONIC CALCULATORS

Electronic calculators can be used for many of the problems solved by graphical methods in this chapter. Programmable calculators or laptop computers with spreadsheet programs can also be used. The necessary equations are given in many texts (e.g., Schufeldt and Newcomer, 1980). A calculator or computer provides rapid and accurate answers to current problems and is particularly handy when evaluating several voyage plan options (route and timing).

Several manufacturers make electronic calculators used by aircraft pilots for solving "wind problems," the aeronautical equivalent of current problems. If you elect to use one of these, remember that wind directions are always given as the direction ***from which*** the wind is blowing, not ***towards which*** the wind is blowing. When entering the inputs to the calculator, it is necessary to add (or subtract) 180° to the current in order to use this as a "wind." Drawing even an approximate vector diagram provides a rough "reality check" on plausibility of the answers determined by calculator.

DEALING WITH CURRENTS USING ELECTRONIC NAVIGATION RECEIVERS

Full function navigation receivers (whether Loran-C or GPS) simplify dealing with currents when underway. These receivers enable the navigator to set up a series of course legs (a *route*) by defining the *waypoints* (points of specified latitude and longitude) that mark the ends of each of the legs. The receiver displays the bearing and distance to the next waypoint in the route sequence as well as the vessel's ground speed. Navigation receivers also display the *cross-track error* (XTE)—the amount by which the vessel is off course and the direction to turn to put the vessel back on course. XTEs are typically shown in fractions of a mile. Initially, the helmsman steers a course to match the intended track—or the track +/- the CCA if an estimate of current is available. If there is any appreciable "sideways" component to the current, the vessel will gradually develop an XTE error. You must turn back towards the intended

REMARKS ON VOYAGE PLAN:

BLOCK ISLAND TO WOOD'S HOLE

GENERAL INFORMATION:

CHECK ITEMS

DATE: 6-9-99
NAVIGATOR: LDM
VESSEL: PERDIDA

CHARTS REQD: ✓
COAST PILOT ✓
LIGHT LIST: ✓
TIDE CHARTS: ✓

CURRENT TABLES: ✓
DEVIATION TABLE: ✓
FUEL/RPM TABLE: ✓
PILOT CHARTS: ✓

NAV. GEAR: ✓
TIMEPIECE: ✓

TIME START: 1030 FOB (GAL): ________

DETAILED LEG PLAN:

LEG	FROM	TO	INTENDED TRACK (TRUE)	LEG DISTANCE (N.M.)	POWER SETTING (RPM)	ESTIMATED STW (KNOTS)	CURRENT SET	CURRENT DRIFT	TRUE COURSE	VARIATION	MAGNETIC COURSE	DEVIATION	COMPASS COURSE	ESTIMATED SOA (KNOTS)	ETE HH:MM	ETA HH:MM	EST. FUEL CONSUMPTION (GAL)	EST. FUEL REMAINING (GAL)
1	"1A"	WOR "A"	050	9.2	1250	5.3	130	2	028	15W	043	3E	040	5.2	1:46	1216		

FIG. 7-10–Illustrative Voyage Planning Worksheet with First Leg of Voyage entered.

track to compensate for the effect of the current. By trial and error, a course can readily be determined that keeps the vessel close to the intended track.

These navigation receivers simplify navigation and reduce underway workload. However, the navigator should not rely exclusively on any one source of data. Waypoints can be entered incorrectly, the receiver may lose signal, and other errors can occur. Therefore, it is prudent to check the accuracy of bearings, distances, and other quantities provided by the receiver.

The simple expedient of turning towards the intended track to correct for cross-track error works well if the cross-track error is modest. However, if a large XTE is allowed to develop, it is necessary to verify by reference to the nautical chart that turning back to the intended track, or resetting the origin waypoint, will not place the vessel in dangerous waters. Additional details are provided in Chapter 9.

In dealing with a foul current—which results in a SMG that is slower than the STW—ensure that you will have adequate fuel reserves to complete the voyage. Otherwise, use of the navigation receiver will ensure that you stay on track to the point of fuel exhaustion! Unanticipated fair or foul currents may also mean that you have to adjust power settings in order to arrive on schedule (e.g., to reach drawbridges before scheduled openings or to run inlets at slack current).

SELECTED REFERENCES

For additional material on current sailing, please refer to the same references as given at the end of Chapters 5 and 6. Note that books published in Great Britain use a different set of plotting symbols than are employed here.

Coolen, E., (1987). *Nicholls's Concise Guide to Navigation,* Volume 1, Brown, Son & Ferguson Ltd, Glasgow, Scotland, pp 314 et seq.

Ministry of Defense, (Navy) BR45 (1) (1987). *Admiralty Manual of Navigation,* Volume 1, D/DNW/ 102/3/14/2, Her Majesty's Stationary Office (HMSO), London, UK, pp 204 et seq.

Rogoff, M., (1979). *Calculator Navigation,* W.W. Norton & Company, New York, NY.

Schufeldt, H. H., Dunlop, G.D., and A. Bauer, (1991). *Piloting and Dead Reckoning,* 3rd Edition, Naval Institute Press, Annapolis, MD.

Schufeldt, H.H., and K. E. Newcomer, (1980). *The Calculator Afloat: A Mariner's Guide to the Electronic Calculator,* Naval Institute Press, Annapolis, MD.

United States Power Squadrons, (1998). *Plotting & Labeling Standards,* The United States Power Squadrons®, Raleigh, NC.

CHAPTER 8

TIDES AND TIDAL CURRENTS

"As they say on my own Cape Cod,
a rising tide lifts all the boats."

(President John F. Kennedy, address in the Assembly Hall at the Paulskirche, Frankfurt, Germany, June 25, 1963.)

"The tides are the heartbeat of the ocean,
a pulse that can be felt all over the world."

(Albert Defant, *Ebb and Flow: The Tides of Earth, Air, and Water)*

INTRODUCTION

This chapter provides a discussion of two important phenomenas to the mariner: tides and tidal currents. Tides and tidal currents are of great interest to the oceanographer as well, but the focus of this chapter is on items of interest to the mariner. Experience in teaching the *Advanced Coastal Navigation* (ACN) course indicates that students typically find the material in this chapter straightforward. The exposition is clear and the calculations are not difficult. However, the computations are tedious and numerical errors are easily made. To minimize errors and simplify computations, several worksheets (containing directions) are included. This said, some perseverance is required. Read the chapter through once to get an overview of the key concepts, then again more carefully to study the details and work through the problems.

Estimating the height of tides is necessary in order to identify safe water, know how much anchor line to deploy when anchoring, and estimate the vertical clearance under bridges. Estimating tidal currents is equally important, but for different reasons. Tidal current information is essential for voyage planning. It is used, for example, to select a time to enter inlets, rivers, or bays to maximize safety and/or minimize travel time, and to estimate the *speed made good* (SMG) and fuel consumption for voyages in areas affected by tidal currents.

Prediction and estimation of tides or tidal currents is facilitated by use of the *Tide Tables,* or *Tidal Current Tables*. Formerly published and sold to the general public annually by the *National Ocean Service* (NOS), these are now reproduced by commercial publishers based upon NOS data. The bulk of this chapter is devoted to a discussion of how to use and interpret these tables.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❑ *The relevance of tide and tidal current information*
- ❑ *How to read and interpret Tide Tables*
- ❑ *How to use Tide Tables to make tide height predictions*
- ❑ *How to read and interpret Tidal Current Tables*
- ❑ *How to use Tidal Current Tables to make current predictions*
- ❑ *Uses of tidal current information in voyage planning*
- ❑ *Calculation of the time of sunrise and sunset*

TIDES AND TIDAL PATTERNS

At the outset, it is important to distinguish between two related but distinct terms. *Tide* refers to the *vertical motion* of the water, *tidal current* (called tidal stream by the British) to the *horizontal motion* of the water. Both tides and tidal currents have the same origin and vary with the same factors, including the gravitational effects of the moon and sun, and runoff from rain or snowfall. Although tides and tidal currents are related, these are logically distinct concepts.

As noted, tides result from the gravitational effects of the moon and sun, and experience (and theory) indicates that tides are periodic. There are predictable variations in tidal heights, hour-by-hour, day-by-day, season-by-season, and year-by-year. Tide and tidal current predictions can be made years in advance—though periodic recalibration of the mathematical models based on actual observations enable more accurate predictions to be made.

All tidal heights are measured from a *vertical datum* or reference plane. In the United States, and certain other parts of the world, this reference plane is what is termed *mean lower low water* (MLLW). The term high water denotes the

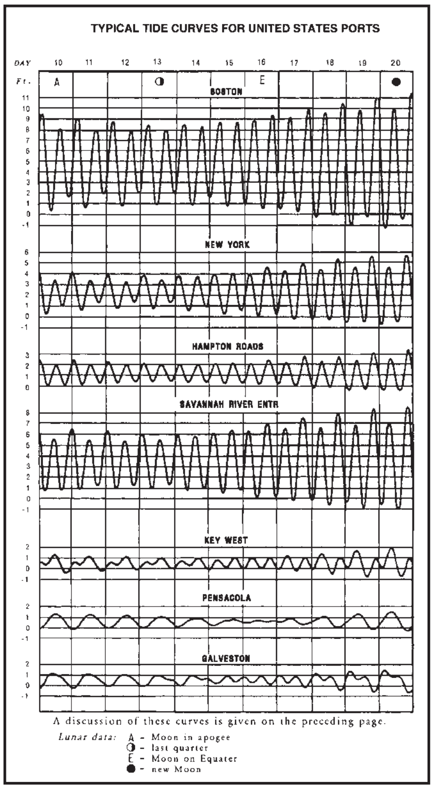


FIG. 8-1–Typical Tide Curves for United States East Coast Ports

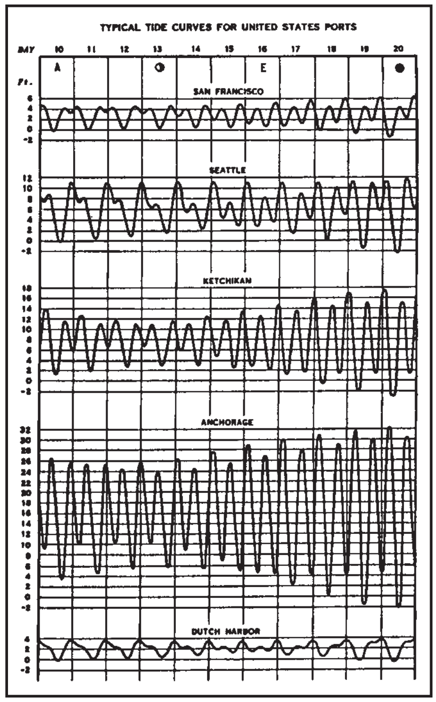


FIG. 8-2–Typical Tide Curves for United States West Coast Ports

maximum height reached by each rising tide, and low water the minimum height reached by each falling tide. The tidal range is the height difference between consecutive high and low waters.

Figure 8-1 and Figure 8-2 show the hourly and daily patterns of tide heights (measured relative to datum) for several locations on the East, Gulf, and West Coasts of the United States. This small sample is sufficient to indicate the most important patterns (discussed below) and some typical tidal heights and ranges.

As can be seen from the patterns in Figure 8-1 and Figure 8-2, there are often two high and two low waters in a day, but other patterns occur (see below). Tides follow the moon more closely than the sun. Although the sun is much larger, the moon is very much closer to the earth, more than compensating for the mass difference in the gravitation equation. Thus, the period evident in Figures 8-1 and 8-2 tends to match that of the lunar day—approximately 24 hours and 50 minutes—rather than the solar day. Because the lunar day is slightly longer than the solar day, the times for high and low tides occur later on each succeeding calendar day.

There are three principal daily patterns observed for tides: diurnal, semidiurnal, and mixed.

- **Diurnal:** A diurnal tide has a period or cycle of approximately one tidal (lunar) day—that is, a diurnal tide will have one high and one low tide each day.
- **Semidiurnal:** A semidiurnal tide has a period of approximately one-half of a tidal day (see, for example, the patterns for Boston, Massachusetts, and New York, New York, in Figure 8-1); that is, there are typically two times of high water and two times of low water in each day.
- **Mixed:** A mixed pattern (see, for example, Seattle, Washington, or San Francisco, California, as shown in Figure 8-2) is a type of tide with a large inequality in the high and/or low water heights, with two high waters and two low waters usually occurring each tidal day.

In addition to the daily patterns evident in the illustrations in Figure 8-1 and Figure 8-2, there are more subtle patterns with a longer period. Tides have a smaller range when the moon is in *apogee* (farthest from the earth, denoted with the symbol "A" in Figure 8-1 and Figure 8-2), and a larger range when the moon is in *perigee* (closest to the earth).

When the moon and the sun are in conjunction and "pulling together" (i.e., at a new or full moon a phenomenon termed syzygy and pronounced sizz-a-gee), larger tidal ranges, termed *spring tides,* occur. (The term spring has nothing to do with the season.) Alternatively, when the gravitational forces of the sun and the moon are in quadrature (i.e., at right angles), tides with smaller range, termed *neap tides,* occur.

Tidal range varies with location on the earth, as well as with the positions of the sun and moon. Examination of the patterns shown in Figure 8-1 and Figure 8-2, shows that there are substantial differences in the tidal ranges among U.S. ports. At Anchorage, Alaska, for example, the tidal range is 30 feet or more, whereas at Key West or Pensacola, Florida, the tidal range is considerably smaller (only 2 or 3 feet). Other locations with large tidal ranges include the Bay of Fundy (adjoining the provinces of Nova Scotia and New Brunswick in Canada) where mean tidal ranges of 40 feet or more are observed, some locations on the coast of Maine (20 feet or more), and near the southern tip of South America. Locations with relatively small tidal ranges include Barnegat Bay, New Jersey, (less than 1 foot), and portions of the Chesapeake Bay. The area covered by the 1210-Tr chart includes some locations with small ranges (e.g., Little Harbor near Woods Hole, with a range of 1.4 feet) and others (e.g., several locations in Buzzards Bay) where the tidal range is greater (4 to 5 feet). Mariners using inland lakes and many rivers are not affected by tides.

This brief sample of tidal data indicates that the practical importance of tidal phenomena varies from region-to-region and even location-to-location within regions. Mariners from some locations in New Jersey, for example, may worry little about tides, while tides are a central fact of life for boaters in Maine, Alaska, or other areas with large tidal range.

PRACTICAL REASONS WHY TIDES ARE IMPORTANT

Before discussing how tidal heights are estimated, it is useful to review briefly why knowledge of tides is important to the mariner. Anyone who has run aground, had to replace or straighten a bent prop or shaft, had their anchor drag, or trimmed the top few feet off the mast of their sailboat by crossing under a bridge with insufficient clearance can skip this section—such experience provides more than ample motivation for careful study of this chapter!

PHOTO COURTESY OF BOAT/US MARINE INSURANCE

▲ Tide height calculations are not difficult, but care must be taken to avoid numerical errors.

HISTORICAL FOOTNOTE

Mariners in days gone by were taught to enter an unfamiliar harbor cautiously at "half tide and rising." Half tide ensured that there would be water under the vessel, and a rising tide meant that the vessel could be promptly refloated—assuming a soft bottom—in the event of miscalculation. This advice is still sound. Modern prediction methods, however, are more accurate.

In Chapter 3, it is noted that the charted depth of water is based on a vertical datum of *mean lower low water* (MLLW, the average of the lower of the low tides each day). The actual water depth varies with the height of the tide, so in order to calculate this depth—and, thus, whether or not safe water exists—it is necessary to calculate tidal heights. Knowledge of water depth is obviously important to the safety of the voyage—after all, who wants to run aground or have to wait days until high tides are sufficient to clear a harbor? Vessels imprisoned in harbors with shallow entrances awaiting favorable tides to depart were often said to be "neaped."

Knowledge of water depth can also be important to the *efficiency* of a voyage as well as its *safety*. It sometimes happens, for example, that you have a choice of alternate routes to your final destination—a deep but indirect channel or a shorter, more direct route that takes you over the shallows. Knowledge of the height of the tide may enable you to take a shortcut—in perfect safety—that will save substantial distance and (therefore) time. Plan the voyage at a time when the tides are relatively high.

Knowledge of the height of the tide is also very important when anchoring or mooring. Suppose, for example, that you anchor in 3 feet of water and the distance from the bow to the waterline for your vessel is 2 feet. Following recommended procedures, you elect to deploy 40 feet of anchor line, figuring that this will give you a "safe" scope of 8 to 1 (40/(3 + 2) = 8). But suppose it was low tide when you anchored, and that the tidal range is 5 feet. At high tide the water depth would be 8 feet (5 + 3) and the effective scope would be reduced to only 4 to 1 (40/(3 + 5 + 2) = 4), not nearly enough. (Table 8-1 shows how the actual scope of anchor line at high tide varies with the scope at low tide and the tidal range, assuming that the distance from the bow to the waterline is 2 feet) The point of these simple calculations is that you should plan to put out enough line to ensure a sufficient scope at high tide. This means that you need to know the state of the tide at anchoring and the depth of water at high tide. These calculations can be really dramatic for areas such as Anchorage (a misnomer, to be sure) or the Bay of Fundy, where (as discussed above) the tidal range can be 30 or 40 feet! At some of these locations it may not even be possible to deploy sufficient anchor line to ensure a safe scope at high tide. The only alternative is to maintain a constant anchor watch.

Anchoring at low tide risks deploying an insufficient scope if the tidal range is not considered. But, anchoring at high tide also has risks if tidal heights are ignored. This is because the radius of the swing circle (the distance from the anchor to the stern of the vessel) increases for a fixed anchor line length as the tide height decreases. If this effect is not considered, you run the risk of being on intimate terms with other vessels in a crowded anchorage!

Finally, knowledge of tidal heights is important to determine whether or not there is sufficient clearance between the vessel's mast(s) or outriggers and overhead obstructions, such as bridges or power lines. In some critical cases, it may be necessary to pass under a bridge only at low tide to ensure that sufficient clearance exists.

For these and other reasons it is important for the mariner to know how to estimate tide heights.

SOURCES OF TIDAL INFORMATION

There are several sources of tidal information. Many newspapers, for example, routinely publish information on the time and height of tides at several locations. Television weather broadcasts, particularly those oriented towards mariners, often give tidal information, as do scheduled government weather broadcasts. Several private companies publish almanacs or other guides that contain tidal information. Increasingly, computer

Intended Scope	Water Depth When Anchoring (Ft.)	Tidal Range(Feet) 1	2	3	4	5	7	10
6	3	5.0	4.3	3.8	3.3	3.0	2.5	2.0
6	4	5.1	4.5	4.0	3.6	3.3	2.8	2.3
6	5	5.3	4.7	4.2	3.8	3.5	3.0	2.5
6	6	5.3	4.8	4.4	4.0	3.7	3.2	2.7
6	7	5.4	4.9	4.5	4.2	3.9	3.4	2.8
6	8	5.5	5.0	4.6	4.3	4.0	3.5	3.0
6	9	5.5	5.1	4.7	4.4	4.1	3.7	3.1
6	10	5.5	5.1	4.8	4.5	4.2	3.8	3.3
6	12	5.6	5.3	4.9	4.7	4.4	4.0	3.5
7	3	5.8	5.0	4.4	3.9	3.5	2.9	2.3
7	4	6.0	5.3	4.7	4.2	3.8	3.2	2.6
7	5	6.1	5.4	4.9	4.5	4.1	3.5	2.9
7	6	6.2	5.6	5.1	4.7	4.3	3.1	3.1
7	7	6.3	5.7	5.3	4.8	4.5	3.9	3.3
7	8	6.4	5.8	5.4	5.0	4.7	4.1	3.5
7	9	6.4	5.9	5.5	5.1	4.8	4.3	3.7
7	10	6.5	6.0	5.6	5.3	4.9	4.4	3.8
7	12	6.5	6.1	5.8	5.4	5.2	4.7	4.1
8	3	6.7	5.7	5.0	4.4	4.0	3.3	2.7
8	4	6.9	6.0	5.3	4.8	4.4	3.7	3.0
8	5	7.0	6.2	5.6	5.1	4.7	4.0	3.3
8	6	7.1	6.4	5.8	5.3	4.9	4.3	3.6
8	7	7.2	6.5	6.0	5.5	5.1	4.5	3.8
8	8	7.3	6.7	6.2	5.7	5.3	4.7	4.0
8	9	7.3	6.8	6.3	5.9	5.5	4.9	4.2
8	10	7.4	6.9	6.4	6.0	5.6	5.1	4.4
8	12	7.5	7.0	6.6	6.2	5.9	5.3	4.7

TABLE 8-1–Actual Scope of Anchor Line at High Tide as a Function of Low Water Depth and Intended Scope for Various Values of Tidal Range, Assuming that Vessel is Anchored at Low Tide

software is coming on the market that automates the calculation of tidal heights. Tide height calculations can be done in advance as part of the voyage planning process or when underway—particularly if a laptop computer is available.

The most authoritative source of tidal information (and, indeed, the source of the reference data republished by other firms) is found in the *Tide Tables*. These tables were formerly published annually by the U.S. Department of Commerce, *National Oceanic and Atmospheric Administration* (NOAA), *National Ocean Service* (NOS). Now, the *National Imagery and Mapping Agency* (NIMA) publishes these for internal government use only. NOS still provides the same information to commercial publishers. Some elect to reproduce these in the exact NOS format. (Excerpts from *Tide Tables* presented in this chapter are taken from the NIMA publication based on NOS camera-ready masters.) *Tide Tables* and directions for their use are available in electronic form at the NOAA web site (http://co-ops.nos.noaa.gov/).

Tide Tables are published annually in four volumes, as follows: Europe and West Coast of Africa (including the Mediterranean Sea); East Coast of North and South

America (including Greenland); West Coast of North and South America (including the Hawaiian Islands); Central and Western Pacific Ocean and Indian Ocean. Together, these four volumes contain daily predictions for more than 200 *reference stations* or ports (discussed below), and differences and other constants necessary for tide height calculation for about 6,500 other ports/locations. Several other countries (e.g., Great Britain, Canada, Brazil, and Argentina) also publish accurate and useful tables, but these are not discussed in this chapter.

USE OF THE TIDE TABLES

The publication *Tide Tables* includes seven separate sets of tables. Of these, Tables 1, 2, and 3 are required for estimation of tidal heights and are discussed in this chapter. The remaining four tables relate to estimation of the time for sunrise/sunset, moonrise/moonset, and some units conversions (feet to meters and reduction of local mean time to standard time). Sunrise and sunset calculations are covered at the end of this chapter.

Locations for which tidal predictions can be made with the aid of the *Tide Tables* are subdivided into two classes: *reference stations and subordinate stations* (substations):

- **Reference stations** (called *standard ports* by the British) generally include commercially important ports and locations for which a long series of tidal observations are available. Tidal predictions are generally more accurate for reference stations.
- **Subordinate stations** (called *secondary ports* by the British) are locations from which a shorter series of observations is summarized by comparison with simultaneous observations at reference stations, as discussed below.

Tide prediction for reference stations is made using Table 1 (“Daily Tide Predictions”) of the *Tide Tables,* which presents daily tide predictions for high and low water. Table 8-2 of this text, for example, contains an excerpt from Table 1 of the *Tide Tables* for the reference station Newport, Rhode Island, over the months of January, February, and March 1999. This table contains the predicted time and height (in feet and centimeters) of the high and low tides for each day in the year. Reference to Table 8-2, for example, shows that on 1 January, high tides are expected at 0642 and 1906 (tidal heights of 4.8 and 3.9 ft., respectively), and low tides are expected at 0001 and 1255 (tide heights of -0.8 and -0.7 ft., respectively). The significance of a negative number is that the estimated tide height is below the vertical (charted) datum at these times.

All times given in the *Tide Tables* prepared by NOS are in standard time (in the 24-hour system). Therefore, during the period when daylight savings time is in effect, it is necessary to convert either to or from standard time. *Mariners who use tide tables produced by other sources should consult the notes accompanying these tables to see if the same convention is used.* Unfortunately, time conventions are not uniform. For example, Lighthouse Press (1998) reprints the NOS tables directly, so that standard time is used throughout. However, Reed’s (1998) and Eldridge (1998) correct for daylight savings time.

It occasionally happens (even in areas with semidiurnal tides) that there will only be two highs and a low, or two lows and a high in a given day. This occurs because the tides follow the slightly longer lunar day. This can be seen in Table 8-2 for 28 February 1999, for example, when there are two high tides at 0610 and 1831, and a single low tide at 1234.

Examination of the daily predictions for Newport shown in Table 8-2 indicates that, although the majority of the tidal heights are positive (i.e., above datum), low tides are occasionally beneath datum (a negative entry). At these times, the actual water depths will be less than the charted values.

Tide predictions are now made by computers, using algorithms based upon the predictable motions of the sun and moon, measurements of past tide heights, and an allowance for seasonal variation representing average freshet (heavy rains or snow) and drought (dry) conditions. Unusual conditions (higher or lower than average snow or rainfall, etc.), however, will cause the tides to be higher or lower than predicted from the tables. Likewise, changes in winds or barometric conditions cause variations in sea level. Typically, an onshore wind or a low barometer will increase the heights of both the high and low waters compared to predictions based on average values. Likewise, offshore winds or a high barometer will decrease high and low waters relative to predictions. (Consult Bowditch for equations

Newport, Rhode Island, 1999

Times and Heights of High and Low Waters

January

Day	Time (h m)	Height (ft)	Height (cm)
1 F	0001	−0.8	−24
	0642	4.8	146
	1255	−0.7	−21
	1906	3.9	119
2 Sa	0054	−0.8	−24
	0732	4.8	146
	1343	−0.7	−21
	1956	4.0	122
3 Su	0143	−0.7	−21
	0821	4.6	140
	1429	−0.6	−18
	2045	3.9	119
4 M	0230	−0.6	−18
	0909	4.4	134
	1512	−0.4	−12
	2134	3.8	116
5 Tu	0316	−0.4	−12
	0957	4.1	125
	1554	−0.2	−6
	2223	3.6	110
6 W	0401	−0.1	−3
	1045	3.7	113
	1634	0.0	0
	2313	3.4	104
7 Th	0446	0.2	6
	1135	3.4	104
	1713	0.2	6
8 F	0005	3.2	98
	0533	0.5	15
	1226	3.1	94
	1755	0.4	12
9 Sa	0058	3.1	94
	0626	0.7	21
	1319	2.9	88
	1841	0.5	15
10 Su	0153	3.1	94
	0728	0.8	24
	1413	2.7	82
	1933	0.5	15
11 M	0247	3.1	94
	0841	0.8	24
	1508	2.7	82
	2030	0.5	15
12 Tu	0339	3.2	98
	0949	0.7	21
	1600	2.8	85
	2126	0.4	12
13 W	0429	3.4	104
	1039	0.5	15
	1649	2.9	88
	2217	0.3	9
14 Th	0515	3.6	110
	1119	0.3	9
	1736	3.0	91
	2303	0.1	3
15 F	0559	3.8	116
	1157	0.1	3
	1820	3.2	98
	2346	−0.1	−3
16 Sa	0642	3.9	119
	1234	−0.1	−3
	1903	3.3	101
17 Su	0028	−0.2	−6
	0724	4.0	122
	1311	−0.3	−9
	1946	3.4	104
18 M	0110	−0.4	−12
	0806	4.1	125
	1349	−0.4	−12
	2028	3.5	107
19 Tu	0152	−0.5	−15
	0848	4.1	125
	1428	−0.4	−12
	2112	3.6	110
20 W	0236	−0.5	−15
	0932	4.0	122
	1509	−0.5	−15
	2157	3.6	110
21 Th	0322	−0.4	−12
	1018	3.8	116
	1552	−0.4	−12
	2246	3.6	110
22 F	0412	−0.3	−9
	1108	3.6	110
	1639	−0.4	−12
	2339	3.6	110
23 Sa	0506	−0.2	−6
	1203	3.4	104
	1730	−0.3	−9
24 Su	0037	3.6	110
	0607	0.0	0
	1303	3.3	101
	1828	−0.2	−6
25 M	0138	3.7	113
	0717	0.1	3
	1406	3.2	98
	1932	−0.1	−3
26 Tu	0241	3.8	116
	0836	0.1	3
	1509	3.2	98
	2043	−0.2	−6
27 W	0343	4.0	122
	0955	0.0	0
	1610	3.3	101
	2154	−0.3	−9
28 Th	0441	4.2	128
	1103	−0.2	−6
	1707	3.5	107
	2259	−0.4	−12
29 F	0536	4.3	131
	1159	−0.4	−12
	1800	3.7	113
	2356	−0.6	−18
30 Sa	0627	4.4	134
	1247	−0.5	−15
	1850	3.8	116
31 Su	0047	−0.7	−21
	0715	4.4	134
	1330	−0.5	−15
	1937	3.9	119

February

Day	Time (h m)	Height (ft)	Height (cm)
1 M	0133	−0.7	−21
	0802	4.4	134
	1409	−0.5	−15
	2023	3.9	119
2 Tu	0216	−0.6	−18
	0847	4.2	128
	1446	−0.4	−12
	2108	3.8	116
3 W	0255	−0.4	−12
	0930	3.9	119
	1519	−0.3	−9
	2153	3.7	113
4 Th	0333	−0.2	−6
	1014	3.6	110
	1551	−0.1	−3
	2238	3.5	107
5 F	0409	0.1	3
	1058	3.3	101
	1624	0.1	3
	2324	3.3	101
6 Sa	0447	0.3	9
	1144	3.0	91
	1700	0.2	6
7 Su	0013	3.1	94
	0528	0.5	15
	1234	2.8	85
	1740	0.4	12
8 M	0106	3.0	91
	0617	0.7	21
	1328	2.6	79
	1828	0.5	15
9 Tu	0202	2.9	88
	0715	0.8	24
	1426	2.5	76
	1924	0.5	15
10 W	0258	3.0	91
	0825	0.8	24
	1523	2.6	79
	2028	0.5	15
11 Th	0353	3.1	94
	0938	0.6	18
	1617	2.7	82
	2132	0.4	12
12 F	0443	3.4	104
	1037	0.4	12
	1707	3.0	91
	2231	0.2	6
13 Sa	0531	3.6	110
	1124	0.1	3
	1753	3.2	98
	2322	−0.1	−3
14 Su	0616	3.8	116
	1206	−0.1	−3
	1838	3.5	107
15 M	0009	−0.3	−9
	0659	4.0	122
	1246	−0.4	−12
	1921	3.7	113
16 Tu	0054	−0.6	−18
	0743	4.2	128
	1326	−0.6	−18
	2004	3.9	119
17 W	0139	−0.7	−21
	0826	4.2	128
	1407	−0.7	−21
	2048	4.0	122
18 Th	0224	−0.8	−24
	0911	4.1	125
	1448	−0.7	−21
	2134	4.1	125
19 F	0311	−0.7	−21
	0958	4.0	122
	1532	−0.7	−21
	2223	4.0	122
20 Sa	0400	−0.6	−18
	1048	3.7	113
	1618	−0.5	−15
	2316	3.9	119
21 Su	0453	−0.4	−12
	1143	3.5	107
	1709	−0.4	−12
22 M	0013	3.8	116
	0553	−0.1	−3
	1242	3.3	101
	1806	−0.2	−6
23 Tu	0116	3.7	113
	0703	0.1	3
	1347	3.1	94
	1913	0.0	0
24 W	0221	3.7	113
	0827	0.2	6
	1452	3.1	94
	2032	0.0	0
25 Th	0325	3.8	116
	0952	0.1	3
	1554	3.2	98
	2153	0.0	0
26 F	0425	3.9	119
	1059	−0.1	−3
	1651	3.4	104
	2301	−0.2	−6
27 Sa	0520	4.0	122
	1151	−0.2	−6
	1744	3.6	110
	2356	−0.4	−12
28 Su	0610	4.1	125
	1234	−0.3	−9
	1831	3.8	116

March

Day	Time (h m)	Height (ft)	Height (cm)
1 M	0042	−0.5	−15
	0656	4.1	125
	1311	−0.4	−12
	1916	3.9	119
2 Tu	0122	−0.5	−15
	0740	4.1	125
	1344	−0.4	−12
	1959	4.0	122
3 W	0158	−0.5	−15
	0822	4.0	122
	1414	−0.3	−9
	2040	3.9	119
4 Th	0232	−0.4	−12
	0902	3.8	116
	1442	−0.3	−9
	2121	3.8	116
5 F	0303	−0.2	−6
	0943	3.5	107
	1511	−0.1	−3
	2203	3.6	110
6 Sa	0335	0.0	0
	1024	3.3	101
	1542	0.0	0
	2245	3.4	104
7 Su	0409	0.2	6
	1107	3.0	91
	1616	0.2	6
	2331	3.2	98
8 M	0446	0.4	12
	1154	2.8	85
	1655	0.3	9
9 Tu	0021	3.0	91
	0530	0.5	15
	1247	2.6	79
	1740	0.5	15
10 W	0116	2.9	88
	0623	0.7	21
	1346	2.5	76
	1835	0.6	18
11 Th	0216	2.9	88
	0727	0.7	21
	1446	2.6	79
	1940	0.6	18
12 F	0314	3.0	91
	0839	0.6	18
	1543	2.7	82
	2051	0.5	15
13 Sa	0409	3.2	98
	0947	0.4	12
	1635	3.0	91
	2158	0.2	6
14 Su	0459	3.5	107
	1043	0.1	3
	1723	3.4	104
	2257	−0.1	−3
15 M	0547	3.8	116
	1132	−0.2	−6
	1809	3.7	113
	2348	−0.4	−12
16 Tu	0633	4.0	122
	1216	−0.5	−15
	1854	4.1	125
17 W	0037	−0.7	−21
	0718	4.2	128
	1259	−0.7	−21
	1939	4.3	131
18 Th	0124	−0.9	−27
	0803	4.3	131
	1343	−0.9	−27
	2024	4.5	137
19 F	0211	−1.0	−30
	0850	4.2	128
	1426	−0.9	−27
	2112	4.5	137
20 Sa	0259	−0.9	−27
	0938	4.0	122
	1512	−0.8	−24
	2202	4.4	134
21 Su	0349	−0.7	−21
	1029	3.8	116
	1559	−0.6	−18
	2255	4.2	128
22 M	0442	−0.5	−15
	1125	3.5	107
	1651	−0.3	−9
	2353	4.0	122
23 Tu	0542	−0.2	−6
	1225	3.3	101
	1750	−0.1	−3
24 W	0056	3.8	116
	0653	0.1	3
	1330	3.2	98
	1902	0.2	6
25 Th	0202	3.7	113
	0820	0.2	6
	1435	3.2	98
	2031	0.2	6
26 F	0306	3.6	110
	0944	0.2	6
	1537	3.3	101
	2157	0.1	3
27 Sa	0406	3.7	113
	1046	0.1	3
	1633	3.5	107
	2302	0.0	0
28 Su	0500	3.7	113
	1134	0.0	0
	1724	3.7	113
	2351	−0.2	−6
29 M	0549	3.8	116
	1212	−0.1	−3
	1809	3.9	119
30 Tu	0032	−0.3	−9
	0633	3.8	116
	1243	−0.2	−6
	1852	4.0	122
31 W	0106	−0.3	−9
	0715	3.8	116
	1311	−0.2	−6
	1932	4.1	125

TABLE 8-2–Excerpt from Table 1 (Daily Tide Predictions) of *Tide Tables*

that can be used to correct for these meteorological conditions.) Therefore, the tide height predictions should not be regarded as error-free. It is a matter of judgment coupled with local knowledge how much of a safety margin to apply to these predictions. NOAA's *Center for Operational Oceanographic Products and Services* (CO-OPS) provides useful information on the accuracy of tide height predictions and answers to frequently asked questions (FAQs) at the web site (http://co-ops.nos.noaa.gov/).

Estimating tide heights at reference stations is simply a matter of reading Table 1. In principle, an identical table could be prepared for each subordinate station as well. However, the *Tide Tables* would be almost impossibly bulky if daily predictions were provided for all 6,500 subordinate stations. Therefore, it is necessary to devise alternative methods to handle the large number of subordinate stations.

SUBORDINATE STATIONS

Table 2 ("Tidal Differences and Other Constants") of the *Tide Tables,* excerpted in Table 8-3 of this text, shows what are termed "tidal differences and other constants." This table enables data from the reference stations to be used, together with port-specific information, to estimate the heights of tides at subordinate stations. This section explains the numerical procedures required.

The entries of this table include:

- **Station or substation identification number:** For example, Penikese Island is substation number 1103.
- **Place name:** This entry contains a place name corresponding to each location for which predictions are available. In this example, Penikese Island is the name given to substation number 1103.
- **Latitude and longitude:** For accurate work, take the time and trouble to plot this position on the nautical chart, rather than simply rely on the place name. Occasionally, these plots will put you on dry land, but the exercise is instructive in any event.
- **Time and height difference data:** Constants used for adjusting the times and heights of high and low tides at a reference station to those for the subordinate station.

To illustrate how these data are used, please refer to substation 1103, Penikese Island, in Buzzards Bay in Table 8-3. The first two numbers shown in the "differences" columns are the time differences (in hours and minutes) for high water and low water at this substation as compared to a designated reference station. A glance over the "differences" columns indicates that all substations between 1085 and 1193 in numerical sequence shown on this page are keyed to the same reference station, Newport. (Reference stations are selected in an attempt to match the tidal characteristics of the substation. Often these are quite close to the substation, but occasionally these are far removed. A number of substations in Antarctica, for example, are keyed to Galveston, Texas.) These time differences are to be added to the times (algebraic sign important) at the reference station to estimate the times of the corresponding high and low water at the subordinate station. For example, the time differences shown for Penikese Island are -0 hrs 17 minutes for high water and -0 hrs 16 minutes for low water. The significance of the minus signs in these table entries is that both high and low water occur earlier at Penikese Island, than at Newport. Had the signs been positive, the times would have been later. It is noted above, (Table 8-2) for example, that high water would occur at Newport on 1 January 1999 at 0642, and later at 1906. The tide time differences for Penikese Island applied to these times mean that high water will occur 17 minutes earlier, or at 0625, and 1849. In making this subtraction or addition, it is necessary to keep track of the date, as well as the time. For example, the time difference for low tide is -16 minutes. Therefore, the 0001 low tide at Newport 1 January 1999 occurs at Penikese Island at 2345 one day earlier, on 31 December 1998. The next set of differences shown in Table 8-3 are height differences at high and low water. Height difference information in the *Tide Tables* can be expressed in any of three ways:

- First, the table entry may be a number with either a plus or minus sign in front. This is to be interpreted as the quantity to be added or subtracted from the height of the corresponding tide height at the reference station to calculate the height at the subordinate station. The significance of a table entry of -0.2 at high water, for example, is that the height of the high tide at the

No.	PLACE	POSITION Latitude	Longitude	DIFFERENCES Time High Water	Time Low Water	Height High Water	Height Low Water	RANGES Mean	Spring	Mean Tide Level
		North	West	h m	h m	ft	ft	ft	ft	ft
	MASSACHUSETTS–cont. Vineyard Sound Time meridian, 75° W			on Newport, p.48						
1085	Nobska Point	41° 31′	70° 39′	+0 41	+2 05	*0.43	*0.43	1.5	1.9	0.8
	Woods Hole									
1087	Little Harbor	41° 31′	70° 40′	+0 32	+2 21	*0.40	*0.40	1.4	1.8	0.8
1089	OCEANOGRAPHIC INSTITUTION	41° 32′	70° 40′	*Daily predictions, p.44*				1.8	2.3	1.0
1091	Uncatena Island (south side)	41° 31′	70° 42′	+0 12	+0 22	*1.02	*1.02	3.6	4.5	1.9
1093	Tarpaulin Cove	41° 28′	70° 46′	+0 11	+1 23	*0.54	*0.54	1.9	2.4	1.0
	Quicks Hole									
1095	South side	41° 26′	70° 51′	–0 10	+0 09	*0.71	*0.71	2.5	3.1	1.3
1097	Middle	41° 27′	70° 51′	0 00	+0 10	*0.85	*0.85	3.0	3.7	1.6
1099	North side	41° 27′	70° 51′	–0 08	–0 08	*0.99	*0.99	3.5	4.4	1.8
	Buzzards Bay									
1101	Cuttyhunk Pond entrance	41° 25′	70° 55′	+0 01	+0 01	*0.97	*0.97	3.4	4.2	1.8
1103	Penikese Island	41° 27′	70° 55′	–0 17	–0 16	*0.97	*0.97	3.4	4.2	1.8
1105	Kettle Cove	41° 29′	70° 47′	+0 09	+0 02	*1.08	*1.08	3.8	4.7	2.1
1107	Chappaquoit Point, West Falmouth Harbor	41° 36′	70° 39′	+0 10	+0 20	*1.10	*1.07	3.9	4.9	2.1
1109	West Falmouth Harbor	41° 36′	70° 39′	+0 21	+0 18	*1.14	*1.14	4.0	5.0	2.2
1111	Barlows Landing, Pocasset Harbor	41° 41′	70° 38′	+0 24	+0 18	*1.14	*1.14	4.0	5.0	2.2
1113	Abiels Ledge	41° 42′	70° 40′	+0 11	+0 16	*1.11	*1.11	3.9	4.9	2.2
1115	Monument Beach	41° 43′	70° 37′	+0 23	+0 18	*1.14	*1.14	4.0	5.0	2.2
1117	Cape Cod Canal, RR. bridge <6>	41° 44′	70° 37′	+1 15	– – –	*0.99	*0.99	3.5	4.1	1.9
1119	Great Hill	41° 43′	70° 43′	+0 12	+0 11	*1.15	*1.21	4.0	5.0	2.2
1121	Wareham, Wareham River	41° 45′	70° 43′	+0 22	+0 16	*1.16	*1.16	4.1	5.1	2.2
1123	Bird Island	41° 40′	70° 43′	+0 05	–0 02	*1.19	*1.19	4.2	5.2	2.3
1125	Marion, Sippican Harbor	41° 42′	70° 46′	+0 10	+0 12	*1.13	*1.29	4.0	4.9	2.2
1127	Mattapoisett, Mattapoisett Harbor	41° 39′	70° 49′	+0 11	+0 20	*1.09	*1.00	3.9	4.8	2.1
1129	West Island (west side)	41° 36′	70° 50′	+0 09	+0 08	*1.05	*1.05	3.7	4.6	1.9
1131	Clarks Point	41° 36′	70° 54′	+0 14	+0 24	*1.06	*1.00	3.6	4.5	2.0
1133	New Bedford	41° 38′	70° 55′	+0 07	+0 07	*1.05	*1.05	3.7	4.6	1.9
1135	Belleville, Acushnet River	41° 40′	70° 55′	+0 07	+0 09	*1.08	*1.08	3.8	4.7	2.1
1137	South Dartmouth, Apponagansett Bay	41° 35′	70° 57′	+0 25	+0 33	*1.05	*1.05	3.7	4.6	1.9
1139	Dumpling Rocks	41° 32′	70° 55′	+0 01	–0 02	*1.05	*1.05	3.7	4.6	1.9
	Westport River									
1141	Westport Harbor	41° 30′	71° 06′	+0 09	+0 33	*0.85	*0.85	3.0	3.7	1.6
1143	Hix Bridge, East Branch	41° 34′	71° 04′	+1 40	+2 30	*0.77	*0.77	2.7	3.4	1.4
	RHODE ISLAND, Narragansett Bay									
1145	Sakonnet	41° 28′	71° 12′	–0 13	–0 01	*0.88	*0.86	3.1	3.9	1.7
1147	Anthony Point, Sakonnet River	41° 38′	71° 13′	–0 02	–0 02	*1.09	*1.07	3.8	4.8	2.1
1149	Beavertail Point	41° 27′	71° 24′	–0 05	+0 04	*0.99	*1.00	3.5	4.3	1.9
1151	Castle Hill	41° 28′	71° 22′	–0 05	+0 12	*0.94	*0.93	3.3	4.1	1.8
1153	NEWPORT	41° 30′	71° 20′	*Daily predictions*				3.5	4.4	1.9
1155	Conanicut Point	41° 34′	71° 22′	+0 07	–0 06	*1.07	*1.07	3.8	4.7	2.0
1157	Prudence Island, (south end)	41° 35′	71° 19′	+0 08	–0 04	*1.08	*1.07	3.8	4.8	2.0
1159	Bristol Point	41° 39′	71° 16′	+0 18	+0 07	*1.14	*1.14	4.0	5.0	2.1
1161	Bristol Highlands	41° 42′	71° 18′	+0 08	–0 07	*1.18	*1.21	4.2	5.2	2.2
1163	Bristol Ferry	41° 38′	71° 15′	+0 16	+0 01	*1.16	*1.14	4.1	5.1	2.2
1165	Fall River, State Pier	41° 42′	71° 10′	+0 19	–0 01	*1.25	*1.25	4.4	5.5	2.4
	RHODE ISLAND and MASSACHUSETTS Narragansett Bay–cont.									
1167	Fall River, Massachusetts	41° 44′	71° 08′	+0 28	+0 29	*1.26	*1.26	4.4	5.5	2.4
1169	Taunton, Taunton River, Massachusetts	41° 53′	71° 06′	+1 06	+2 21	*0.79	*0.79	2.8	3.5	1.5
1171	Bristol, Bristol Harbor	41° 40′	71° 17′	+0 13	0 00	*1.16	*1.14	4.1	5.1	2.2
1173	Warren	41° 44′	71° 17′	+0 18	–0 01	*1.31	*1.29	4.6	5.7	2.5
1175	Nayatt Point	41° 43′	71° 20′	+0 09	–0 02	*1.31	*1.29	4.6	5.7	2.5
1177	Providence, State Pier #1	41° 48′	71° 24′	+0 11	–0 01	*1.28	*1.29	4.5	5.6	2.4
1179	Pawtucket, Seekonk River	41° 52′	71° 23′	+0 18	+0 09	*1.31	*1.29	4.6	5.8	2.5
1181	East Greenwich	41° 40′	71° 27′	+0 13	+0 03	*1.14	*1.14	4.0	5.0	2.1
1183	Wickford	41° 34′	71° 27′	+0 09	+0 02	*1.08	*1.07	3.8	4.7	2.0
1185	Narragansett Pier	41° 25′	71° 27′	–0 11	+0 11	*0.91	*0.93	3.2	4.0	1.7
	RHODE ISLAND, Outer Coast									
1187	Point Judith Harbor of Refuge	41° 21.8′	71° 29.4′	–0 01	+0 32	*0.87	*0.54	3.1	3.1	1.7
1189	Block Island (Great Salt Pond)	41° 11′	71° 35′	+0 02	+0 07	*0.74	*0.71	2.6	3.2	1.4
1191	Block Island (Old Harbor)	41° 10′	71° 33′	–0 17	+0 12	*0.83	*0.86	2.9	3.6	1.5
1193	Watch Hill Point	41° 18′	71° 52′	+0 41	+1 16	*0.74	*0.71	2.6	3.2	1.4
				on New London, p.56						
1195	Westerly, Pawcatuck River	41° 23′	71° 50′	–0 21	+0 03	*1.02	*1.00	2.6	3.1	1.5
	CONNECTICUT, Long Island Sound									
1197	Stonington, Fishers Island Sound	41° 20′	71° 54′	–0 32	–0 41	*1.05	*1.05	2.7	3.2	1.5
1199	Noank, Mystic River entrance	41° 19′	71° 59′	–0 22	–0 08	*0.89	*0.90	2.3	2.7	1.4
1201	West Harbor, Fishers Island, N.Y.	41° 16′	72° 00′	0 00	–0 06	*0.97	*0.97	2.5	3.0	1.4
1203	Silver Eel Pond, Fishers Island, N.Y.	41° 15′	72° 02′	–0 16	–0 04	*0.89	*0.89	2.3	2.7	1.3

TABLE 8-3–Excerpt from Table 2 (Tidal Differences and Other Constants) of *Tide Tables*

subordinate station is 0.2 feet lower than the high tide at the corresponding reference station.

- ❏ Second, the table entries may be prefixed with an asterisk, as is the case for Penikese Island. The asterisk is used to denote a multiplicative (rather than additive) correction factor. For example, the factors given in Table 8-3 for the high tide and the low tide are both 0.97 (this is a numerical coincidence) for Penikese Island. Thus, the height of the 0625 high tide at Penikese is the height of the corresponding tide at Newport, 4.8 ft., multiplied by 0.97, or (rounded to one decimal place) 4.7 ft. Likewise, the height of the 1849 high tide at Penikese Island, is the height of the corresponding tide at Newport, 3.9 ft., multiplied by 0.97, or approximately 3.8 ft.
- ❏ Third, table entries may consist of both an asterisk and an algebraic sign, such as (*0.4 + 1.5). In this case, the height of the tide at the reference station is to be multiplied by the number denoted with an asterisk, and then added to the next number. For example, a reference height of 5 ft. would then translate to 0.4 (5.0) + 1.5 = 3.5 ft.

The reason for these different formats in the tide height difference column is that several relationships are considered for correlation of reference stations and substations; the best (most accurate) relationship is chosen for inclusion in the *Tide Tables,* but this "best predictor" varies from station to station.

Tide ranges are shown in the next two columns of Table 2 of the *Tide Tables*, reproduced in Table 8-3 in this text. Two ranges are given: mean range and spring range. The mean range is the difference in height between mean high water and mean low water. At Penikese Island, the mean range is 3.4 ft., as shown in Table 8-3. The spring range is the average semidiurnal range occurring semimonthly as the result of the moon being new or full (syzygy again). Numerically, it is equal to 4.2 ft. in this example. In general, the spring range is greater than the mean range where the type of tide is either semidiurnal or mixed, and is of no practical significance where the type of tide is diurnal. For locations where the tide type is diurnal, the table gives the diurnal range, which is the difference in height between mean higher high water and mean lower low water.

Finally, Table 2 of the *Tide Tables* (reproduced in Table 8-3 of this text) shows the mean tide level—1.8 ft. in the case of Penikese Island. The mean tide level (also termed half tide level) is a plane midway between mean low water and mean high water, measured from chart datum. To estimate the level of mean high water (MHW), add one-half of the mean tidal range to the mean tide level. Thus, for example, MHW at Penikese Island would be 1.8 + 0.5 (3.4) = 3.5 ft.

USE OF A TIDE WORKSHEET

The above discussion shows how the Tide Tables can be used to estimate the time and height of high and low water at either a reference or subordinate station. These same tables can also be used to estimate the height of the tide at any desired time.

The computations of tide heights are conveniently done using a tide table worksheet, one version of which is illustrated in Table 8-4. It provides space to write down the relevant entries from the Tide Tables and directions for making the required computations. You may wish to make copies of the blank forms for later use.

Table 8-5 contains a worked-out example of a tide height calculation for 0900 on 1 January 1999, at Penikese Island. This example is used to illustrate the calculations. Follow through these calculations to ensure familiarity with the procedure. The worksheet given in Table 8-4 has three sections. The top section is used to record the relevant inputs to the problem, the middle section to calculate the times and heights of high and low tides at the reference station (and, if necessary, the substation), and the bottom section to calculate the height of the tide at any time.

Completion of the top and middle sections is simple (although tedious) and is illustrated in Table 8-5. One or two additional comments are appropriate, however. First, take the time to copy correctly the high water and low water time differences and height differences. A common error, made by students and experienced mariners alike, is to apply the low water time difference, for example, to the high water time at the reference station. Second, ensure that you use the correct formula for calculating tide heights at subordinate stations from reference stations. For example, an asterisk in the tide difference for

Substation:________	Date: ________	Look up these values from Table 2, "Tidal Differences and Other Constants." This section can be omitted if the desired location can be found in Table 1, "Daily Tide Predictions", of the *Tide Tables*. Height differences denoted with an asterisk are to be multiplied rather than added to reference station height.
Ref. Station: ________	Substation #: ________	
HW Time Diff: ________	Diff of Hgt. At HW: ________	
LW Time Diff:________	Diff of Hgt. at LW: ________	
Calculations:		Look up heights and times for reference stations in Table 1, Daily Tide Predictions. Add or subtract time differences for substations to Table 1 times for reference stations. Calculate the height at the substation from the height of the tide at the reference station plus or minus the height difference tabulated above, unless denoted with an asterisk — in which case, the tabulated factors should be multiplied by the heights of the corresponding tides at the reference station. Keep in mind that the time differences may place the required reference tide on the day before or after the date in question for the substation. Remember, times given in tables are standard zone time, not daylight savings time. Subtract 1 hour from daylight savings time to calculate zone time.
Ref. Station: ________	Substation:________	
Condition Time Height	Condition Time Height	
LW ________	LW________	
HW ________	HW ________	
LW ________	LW________	
HW ________	HW ________	
LW ________	LW________	
HW ________	HW ________	

Height of Tide at Any Time:		
Location: ________	Time: ________	Date: ________
Duration of Rise or Fall:	________	Length of time between high and low tides that bracket desired time
Time from Nearest Tide:	________	Use the lesser of the times from the last tide, or time until the next tide
Range of Tide:	________	Difference in height between tides on either side of desired time: re that subtracting a negative number is logically equivalent to addition
Height of Nearest Tide:	________	Height of tide closest to desired time
Tabled Correction:	________	From Table 3
Height of Tide at Time:	________	Add above correction if nearest tide is low water, subtract otherwise
Charted Depth:	________	Determined from chart
Depth of Water at Time:	________	Add tide height to charted depth to calculate depth at required time

TABLE 8-4–Tide Table Worksheet

this station means that the tide heights are to be multiplied, rather than added.

The bottom section of the worksheet is used to calculate the height of tide at any time, from knowledge of the daily highs and lows calculated in the middle section of the worksheet. To simplify these calculations, the *Tide Tables* contain Table 3 ("Heights of Tide at Any Time"), reproduced in this text as Table 8-6. It consists of a series of factors, to be added or subtracted from the nearest high or low tide to estimate the height of the tide at any time. Its use is illustrated in the following steps:

❑ Step 1: Enter the desired time and date of tide height prediction in the bottom of the work-

Substation: Penikese Ref. Station: Newport HW Time Diff: -0:17 LW Time Diff: -0:16	Date: 1 January 1999 Substation #: 1103 Diff of Hgt. At HW: *0.97 Diff of Hgt. at LW: *0.97	Look up these values from Table 2, "Tidal Differences and Other Constants." This section can be omitted if the desired location can be found in Table 1, "Daily Tide Predictions", of the Tide Tables. Height differences denoted with an asterisk are to be multiplied rather than added to reference station height.

Calculations:

Ref. Station: Newport			Substation: Penikese		
Condition	Time	Height	Condition	Time	Height
LW	0001	-0.8	LW	2345	-0.8
HW	0642	4.8	HW	0625	4.7
LW	1255	-0.7	LW	1239	-0.7
HW	1906	3.9	HW	1849	3.8
LW			LW		
HW			HW		

Look up heights and times for reference stations in Table 1, Daily Tide Predictions. Add or subtract time differences for substations to Table 1 times for reference stations. Calculate the height at the substation from the height of the tide at the reference station plus or minus the height difference tabulated above, unless denoted with an asterisk — in which case, the tabulated factors should be multiplied by the heights of the corresponding tides at the reference station. Keep in mind that the time differences may place the required reference tide on the day before or after the date in question for the substation. Remember, times given in tables are standard zone time, not daylight savings time. Subtract 1 hour from daylight savings time to calculate zone time.

Height of Tide at Any Time:

Location: Penikese Time: 0900 Date: 1 January 1999

Duration of Rise or Fall:	6:14	Length of time between high and low tides that bracket desired time
Time from Nearest Tide:	2:35	Use the lesser of the times from the last tide, or time until the next tide
Range of Tide:	5.4	Difference in height between tides on either side of desired time: re that subtracting a negative number is logically equivalent to addition
Height of Nearest Tide:	4.7	Height of tide closest to desired time
Tabled Correction:	1.9	From Table 3
Height of Tide at Time:	2.8	Add above correction if nearest tide is low water, subtract otherwise
Charted Depth:		Determined from chart
Depth of Water at Time:		Add tide height to charted depth to calculate depth at required time

TABLE 8-5–Complete Tide Table Worksheet

sheet. This time is 0900, 1 January 1999. (In the event that daylight savings time is in use on the date, ensure that either this time is converted to standard time, or that the calculations in the middle of the worksheet are expressed in daylight savings time.)

❑ Step 2: Compute the duration of rise or fall. Referring to the subordinate station calculations for Penikese Island in Table 8-5, for example, note that 0900 falls between the high water at 0625 and the low water at 1239. The difference between these times (remember that there are 60, not 100 minutes in an hour) is 6 hours and 14 minutes.

❑ Step 3: Compute the time from

Duration of rise or fall, see footnote	Time from the nearest high water or low water														
h. m.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
4 10	0 08	0 16	0 24	0 32	0 40	0 48	0 56	1 04	1 12	1 20	1 28	1 36	1 44	1 52	2 00
4 20	0 09	0 17	0 26	0 35	0 43	0 52	1 01	1 09	1 18	1 27	1 35	1 44	1 53	2 01	2 10
4 40	0 09	0 19	0 28	0 37	0 47	0 56	1 05	1 15	1 24	1 33	1 43	1 52	2 01	2 11	2 20
5 00	0 10	0 20	0 30	0 40	0 50	1 00	1 10	1 20	1 30	1 40	1 50	2 00	2 10	2 20	2 30
5 20	0 11	0 21	0 32	0 43	0 53	1 04	1 15	1 25	1 36	1 47	1 57	2 08	2 19	2 29	2 40
5 40	0 11	0 23	0 34	0 45	0 57	1 08	1 19	1 31	1 42	1 53	2 05	2 16	2 27	2 39	2 50
6 00	0 12	0 24	0 36	0 48	1 00	1 12	1 24	1 36	1 48	2 00	2 12	2 24	2 36	2 48	3 00
6 20	0 13	0 25	0 38	0 51	1 03	1 16	1 29	1 41	1 54	2 07	2 19	2 32	2 45	2 57	3 10
6 40	0 13	0 27	0 40	0 53	1 07	1 20	1 33	1 47	2 00	2 13	2 27	2 40	2 53	3 07	3 20
7 00	0 14	0 28	0 42	0 56	1 10	1 24	1 38	1 52	2 06	2 20	2 34	2 48	3 02	3 16	3 30
7 20	0 15	0 29	0 44	0 59	1 13	1 28	1 43	1 57	2 12	2 27	2 41	2 56	3 11	3 25	3 40
7 40	0 15	0 31	0 46	1 01	1 17	1 32	1 47	2 03	2 18	2 33	2 49	3 04	3 19	3 35	3 50
8 00	0 16	0 32	0 48	1 04	1 20	1 36	1 52	2 08	2 24	2 40	2 56	3 12	3 28	3 44	4 00
8 20	0 17	0 33	0 50	1 07	1 23	1 40	1 57	2 13	2 30	2 47	3 03	3 20	3 37	3 53	4 10
8 40	0 17	0 35	0 52	1 09	1 27	1 44	2 01	2 19	2 36	2 53	3 11	3 28	3 45	4 03	4 20
9 00	0 18	0 36	0 54	1 12	1 30	1 48	2 06	2 24	2 42	3 00	3 18	3 36	3 54	4 12	4 30
9 20	0 19	0 37	0 56	1 15	1 33	1 52	2 11	2 29	2 48	3 07	3 25	3 44	4 03	4 21	4 40
9 40	0 19	0 39	0 58	1 17	1 37	1 56	2 15	2 35	2 54	3 13	3 33	3 52	4 11	4 31	4 50
10 00	0 20	0 40	1 00	1 20	1 40	2 00	2 20	2 40	3 00	3 20	3 40	4 00	4 20	4 40	5 00
10 20	0 21	0 41	1 02	1 23	1 43	2 04	2 25	2 45	3 06	3 27	3 47	4 08	4 29	4 49	5 10
10 40	0 21	0 43	1 04	1 25	1 47	2 08	2 29	2 51	3 12	3 33	3 55	4 16	4 37	4 59	5 20
Range of tide, see footnote	**Correction to height**														
Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
1.5	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8
2.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
2.5	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2
3.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.5
3.5	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.8
4.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0
4.5	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2
5.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.7	2.0	2.2	2.5
5.5	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.4	1.6	1.9	2.2	2.5	2.8
6.0	0.0	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.0
6.5	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.6	1.9	2.2	2.6	2.9	3.2
7.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.4	1.8	2.1	2.4	2.8	3.1	3.5
7.5	0.0	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.5	1.9	2.2	2.6	3.0	3.4	3.8
8.0	0.0	0.1	0.2	0.3	0.5	0.8	1.0	1.3	1.6	2.0	2.4	2.8	3.2	3.6	4.0
8.5	0.0	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.1	2.5	2.9	3.4	3.8	4.2
9.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.2	2.7	3.1	3.6	4.0	4.5
9.5	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.0	2.4	2.8	3.3	3.8	4.3	4.8
10.0	0.0	0.1	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5	4.0	4.5	5.0
10.5	0.0	0.1	0.3	0.5	0.7	1.0	1.3	1.7	2.2	2.6	3.1	3.6	4.2	4.7	5.2
11.0	0.0	0.1	0.3	0.5	0.7	1.1	1.4	1.7	2.3	2.8	3.3	3.8	4.4	4.9	5.5
11.5	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.8	2.3	2.9	3.4	4.0	4.6	5.1	5.8
12.0	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.5	3.0	3.6	4.1	4.8	5.4	6.0
12.5	0.0	0.1	0.3	0.5	0.8	1.2	2.6	1.9	2.6	3.1	3.7	4.3	5.0	5.6	6.2
13.0	0.0	0.1	0.3	0.6	0.9	1.2	1.7	2.2	2.7	3.2	3.9	4.5	5.1	5.8	6.5
13.5	0.0	0.1	0.3	0.6	0.9	1.3	1.7	2.2	2.8	3.4	4.0	4.7	5.3	6.0	6.8
14.0	0.0	0.2	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.5	4.2	4.8	5.5	6.3	7.0
14.5	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.4	3.0	3.6	4.3	5.0	5.7	6.5	7.2
15.0	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.5	3.1	3.8	4.4	5.2	5.9	6.7	7.5
15.5	0.0	0.2	0.4	0.7	1.0	1.5	2.0	2.6	3.2	3.9	4.6	5.4	6.1	6.9	7.8
16.0	0.0	0.2	0.4	0.7	1.1	1.5	2.1	2.6	3.3	4.0	4.7	5.5	6.3	7.2	8.0
16.5	0.0	0.2	0.4	0.7	1.1	1.6	2.1	2.7	3.4	4.1	4.9	5.7	6.5	7.4	8.2
17.0	0.0	0.2	0.4	0.7	1.1	1.6	2.2	2.8	3.5	4.2	5.0	5.9	6.7	7.6	8.5
17.5	0.0	0.2	0.4	0.8	1.2	1.7	2.2	2.9	3.6	4.4	5.2	6.0	6.9	7.8	8.8
18.0	0.0	0.2	0.4	0.8	1.2	1.7	2.3	3.0	3.7	4.5	5.3	6.2	7.1	8.1	9.0
18.5	0.1	0.2	0.5	0.8	1.2	1.8	2.4	3.1	3.8	4.6	5.5	6.4	7.3	8.3	9.2
19.0	0.1	0.2	0.5	0.8	1.3	1.8	2.4	3.1	3.9	4.8	5.6	6.6	7.5	8.5	9.5
19.5	0.1	0.2	0.5	0.8	1.3	1.9	2.5	3.2	4.0	4.9	5.8	6.7	7.7	8.7	9.8
20.0	0.1	0.2	0.5	0.9	1.3	1.9	2.6	3.3	4.1	5.0	5.9	6.9	7.9	9.0	10.0

TABLE 8-6–Exerpt from Table 3 of *Tide Tables*–Height of Tide at Anytime

the nearest tide. In this case, there are two adjacent tides to be compared: the high water, which occurs at 0625, and the low water, which occurs at 1239. The time in question, 0900, is closer to the high water at 0625. The time difference (0900 - 0625) is 2 hours 35 minutes. (Remember that 0900 is equivalent to 0860 for calculation.)

- ❑ Step 4: Compute the range of the tide. The range is the difference between the high water (4.7 ft.), and the adjacent low water (-0.7 ft.), or 5.4 ft. in this example. (Subtracting a negative quantity is equivalent to addition.)
- ❑ Step 5: Enter the height of the nearest tide in the worksheet. Since the nearest tide is the high water at 0625, the number, 4.7 ft., corresponding to this tide height is entered.
- ❑ Step 6: Read Table 3 of the *Tide Tables* (reproduced as Table 8-6 of this text) to determine the factor to be added or subtracted from the height of the nearest tide. Enter the top section of Table 8-3 at the row closest to the duration of rise or fall just determined in step 2. (No interpolation is required.) In this example, the nearest entry is 6 hours and 20 minutes. Read across this row to find the number closest to the time from the nearest high water or low water, which is 2 hours 35 minutes in this example. The closest time to 2:35 listed in this row is 2 hours 32 minutes. Now, read down the column that has the entry 2 hours 32 minutes to the lower table and stop at the table entry in the row that is closest to the range of the tide (5.4 ft. in this example, so 5.5 ft. is the closest row). This entry, termed the correction to heights, is 1.9 in this example, and is entered in the worksheet in Table 8-5.
- ❑ Step 7: Compute the height of the tide at the desired time as the height of the nearest tide plus or minus the table entry. If the nearest tide is high water (as in this example), the table entry is subtracted, and therefore, the height of the tide at 0900 is 4.7 - 1.9 = 2.8 ft. If the nearest tide were low tide, the correction determined in step 6 would be added, rather than subtracted.
- ❑ Step 8: Compute water depth: If it is desired to estimate the depth of water at a particular location, the height of the tide calculated in step 7 is added to the charted depth to determine the depth of water at the desired time.

These above steps are required to estimate tide heights at any time and, also, water depths at any time. Although it takes some time to read through and complete a calculation for the first time, with practice comes familiarity and speed. Be careful to avoid the common errors discussed in the sidebar. These same errors occur in making tidal current calculations. (Practice soon convinces you of the desirability of using a computer for the calculations!) The worksheet helps to ensure accuracy in the event that manual calculations are made. There is nothing more irritating than writing these entries on a piece of scratch paper, losing your place (from some minor distraction such as a large ship bearing down on your vessel), and having to reconstruct calculations from these paper scraps (which have now fallen off the chart table from the wake).

Finally, tide height calculations are useful to estimate the vertical clearance under obstructions. The worksheet given in Table 8-7 structures the calculations. The direc-

COMMON ERRORS IN TIDE HEIGHT CALCULATIONS

Listed below are several common errors in tide height calculations. Check your work carefully to avoid these errors:

- ❑ ***Neglecting to convert from daylight to standard times. All tide data are given in standard times in the government Tide Tables. Check explanatory notes carefully in other publications.***
- ❑ ***Not being alert to date changes when calculating tides at subordinate stations.***
- ❑ ***Applying the high water time difference to low water or the converse.***
- ❑ ***Failing to understand that factors denoted with an asterisk should be multiplied by rather than added or subtracted from the reference station heights.***
- ❑ ***Failing to select the correct reference station for the desired subordinate station.***
- ❑ ***Making arithmetic errors.***
- ❑ ***(Less common) Failing to use the tables for the correct year.***

Preliminary Information:		
Vessel: ___________	Date: ___________	Location: ___________
Navigator: ___________	Time: ___________	Object to be Cleared: ___________

Clearance Computations:

Item	Value	Source/Remarks
1. Published Clearance:	________	Read from applicable chart or other source.
2. Minimum Clearance:	________	Masthead height.
3. Safety Margin:	________	Judgment input (recommended as at least 3 ft.).
4. Required Clearance:	________	Line 2 plus Line 3.
5. Height of Tide at Specified Time:	________	From completed Tide Worksheet.
6. Mean Tide Level:	________	From Table 2 (last column) of Tide Tables for appropriate station.
7. Mean Range:	________	From Table 2 of Tide Tables for appropriate station.
8. Mean High Water:	________	One-half of Line 7 plus Line 6.
9. Clearance Increment:	________	Line 8 minus Line 5 (may be negative quantity).
10. Predicted Clearance:	________	Line 1 plus Line 9 (take note of sign).
11. Sufficient Clearance:	________	Is predicted clearance (Line 10) greater than required clearance (Line 4)?

TABLE 8-7–Vertical Clearance Worksheet

tions for use are reproduced on the worksheet and are clear enough not to require an example. The only judgmental input to the calculations detailed in Table 8-7 is the required safety margin. A safety margin is appropriate to allow for the inaccuracies in the tide height estimation and the possibility that waves caused by wind or wakes will reduce clearance. There are no hard-and-fast rules for selection of an appropriate margin, but many mariners would want at least a 3-foot margin.

COMPUTER PROGRAMS FOR TIDE PREDICTIONS

As noted above, these calculations are not difficult. But they are time consuming and it is all too easy to make errors. Moreover, it is impractical to make hand calculations for multiple times at multiple locations. Fortunately, there are several computer packages available that are easy to use and interpret. These programs vary considerably in numerical complexity, accuracy, and cost. For example, some are revised annually; others are "perpetual." The perpetual programs are slightly less accurate (not updated with the latest NOS data), but substantially less expensive. Some programs imbed tide height calculations in voyage planning software; others are "stand alone."

Output from one such program (Nobeltec/Nautical Software (1996)) is shown in Figure 8-3 for Penikese Island on 1 January 1999. This output includes predictions for each half hour throughout the day. The prediction for 0900 (2.3 ft.) is in reasonable agreement with the 2.8 ft. estimated in Table 8-5. More to the point, generation of this output required only a few mouse clicks. It took much longer to print this table than to perform the calculations. These programs make it easy to generate similar predictions for several destinations and waypoints along the planned route and use this information intelligently.

TIDAL CURRENT

Accompanying the periodic rise and fall of the tide is a horizontal flow of the water, known as the tidal current. The relevance of current

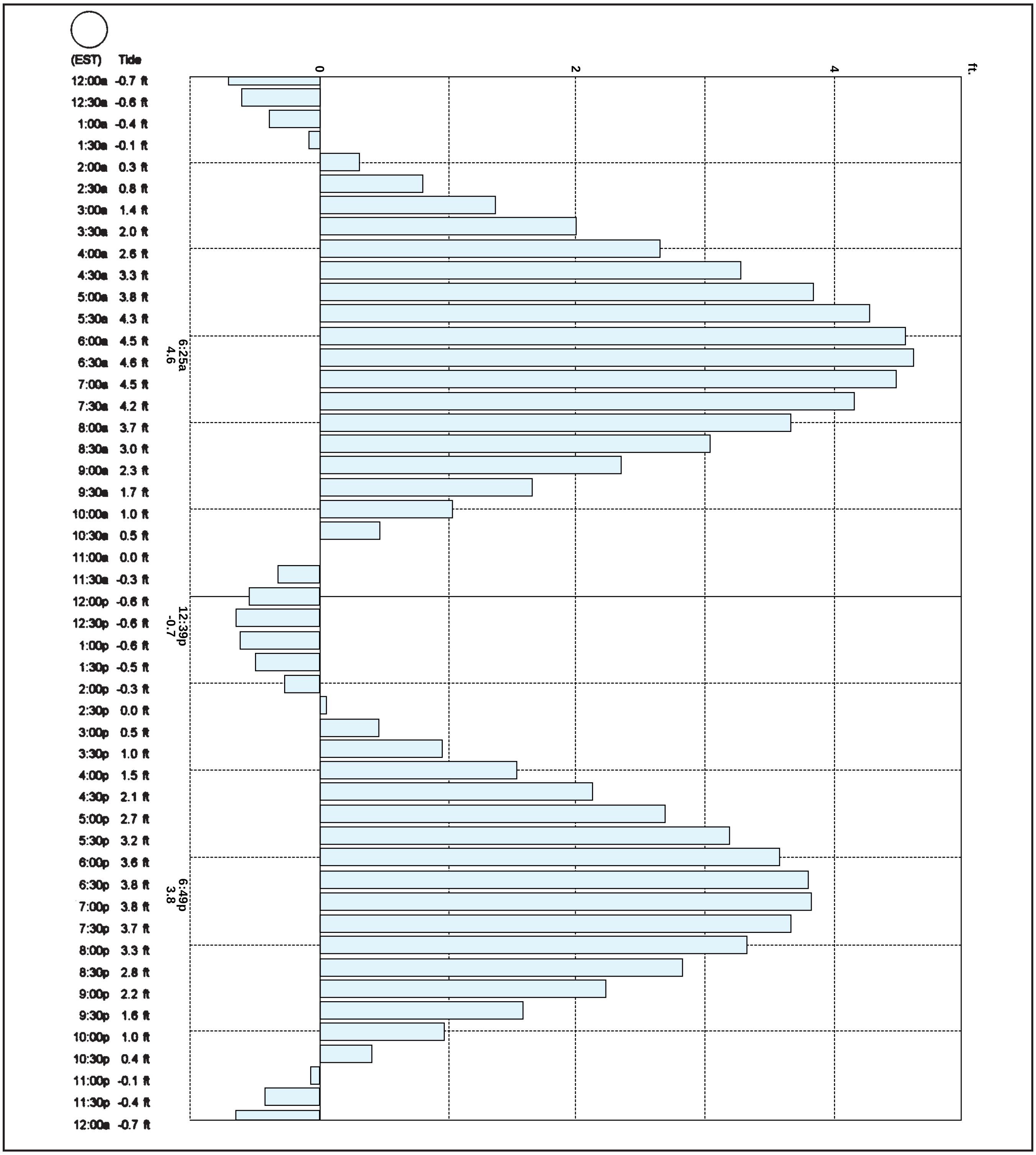


FIG. 8-3–Illustrative Computer Output (Reproduced with Permission from Nobeltec/Nautical Software, Inc.)

information to voyage planning is explored in some detail in Chapters 7 and 11, and therefore, not repeated here.

The *set* (direction towards which the current is flowing) and *drift* (speed) of a current can be estimated in several ways. First, currents can often be observed directly from the movement of the water around stationary objects, such as bridge pilings, lobster traps, or buoys. This phenomenon is commonly termed the “current wake.” With practice, the mariner can learn to judge the speed of the current from the size and other characteristics of the current wake. Rules of thumb developed from experience indicate that a 1-knot current causes a definite ripple, a 3-knot current causes swirls and eddies for several yards, and a 5-knot current causes a boiling wake to stretch out “down current” for perhaps 50 yards. The angle of lean of the harbor buoys is another indication of the direction and strength of the current, but here it is more difficult to provide useful rules of thumb. Some buoys are delicately balanced and lean heavily to the side in light currents. Others require more substantial currents before a definite visual lean is evident. Take the time to study the buoys in your area and expand your store of local knowledge on your next voyage. An alternative procedure is to hold the vessel stationary in the current, relative to, say, a buoy or fixed structure, and drop a piece of wood over the side, timing how long it takes to move from the bow to the stern. If the piece of wood requires t seconds to travel L feet, the current drift (in knots) is approximately 0.59L/t. Second, currents can be calculated as you go, using the methods discussed in Chapter 7 for estimation. That is, current set and drift can be estimated from a comparison of the DR position with a fix. Third, currents can often be estimated or calculated from various published aids, including the *Tidal Current Tables* or *Tidal Current Diagrams,* formerly published by NOS and now available from commercial sources. Finally, publications such as the *U.S. Coast Pilot* (USCP), discussed in Chapter 10, provide useful data or information on currents.

The focus of this discussion is on the use of *Tidal Current Tables,* although passing mention is made of the other sources. At the outset, it is important to make one point quite clear. *The time of high and low water (discussed above) calculated for tides is not, in general, a reliable indication of the times of turning of the current or slack (slow) water.* For some locations (e.g., those on the outer coast), the difference between the times of high or low water and the beginning of the ebb (flowing out of the river or bay) or flood (flowing into the river or bay) current may be small. But, for other locations, such as narrow channels, landlocked harbors, and certain tidal rivers, the time of slack may differ from the time of high or low water by as much as a matter of hours. Therefore, do not use the tide calculations as a surrogate for necessary current calculations. That, so to speak, is the bad news. The good news is that the estimation of tidal currents from the published tables follows a very similar procedure to that employed for tide heights, so learning how to read and use the *Tidal Current Tables* is not such a chore.

As with tides, tidal currents are periodic, and vary with both time and location. Figure 8-4, taken from the *Tidal Current Tables*, shows a time plot of tidal current data for several locations in the United States. As with tides, there is substantial variability in the strength (maximum drift) and temporal pattern of these currents. Average values for maximum currents at locations listed in the *Tidal Current Tables* vary from less than 1 knot to 5 knots or more. At some other

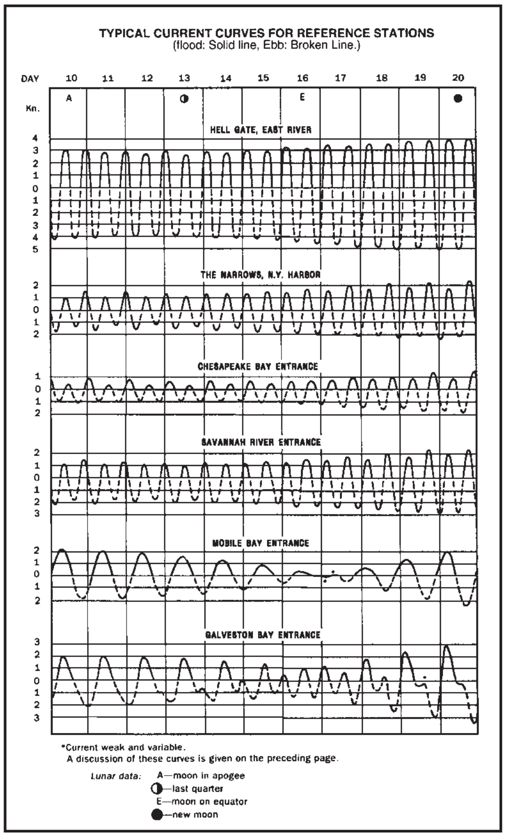


FIG. 8-4–Typical Current Curves for Reference Stations

PHOTO COURTESY OF UNITED STATES COAST GUARD

Commercial vessels often plan trips to take advantage of favorable currents.

locations, such as Seymour Narrows in British Columbia, Canada, currents can be as strong as 14 knots. Although these maximum values may not seem large on initial reflection, particularly to power boaters, a drift as small as 1 or 2 knots can have profound effects on fuel economy (see Chapter 11) and create challenges to seamanship. Anyone who has transited a tough inlet with an ebbing current matched against a stiff onshore wind has a healthy respect for the effects of even a "modest" current and can appreciate the utility of tidal current predictions for selecting the best time of transit. On long passages, small gains in efficiency by selecting the best routing, with due consideration for the effects of currents, translate into large cumulative gains. Commercial vessels often plan trips so as to take advantage of a favorable current.

Uncompensated currents can set the vessel off course (see Chapter 7), as well as affect the SMG. Currents degrade the accuracy of the running fix unless these are considered in its construction. The mariner risks running into dangerous waters and/or becoming lost unless currents are considered and/or frequent fixes are taken in tidal waters (see Chapters 5 and 6).

It is somewhat surprising, but nonetheless true, that there is little relation between the range of the tide and the strength of the maximum current, if comparisons are made among locations. Thus, for example, the maximum currents are relatively weak in areas off the coast of Maine, even though the tidal range is typically large in these areas. Conversely, the currents are relatively large in such areas as Nantucket Island and Nantucket Sound (near the area covered by the 1210-Tr chart), even though the tidal range is relatively small in these areas. However, for a fixed location, the speed of the maximum current (ebb or flood) is correlated with the tidal range. Thus, for example, during periods of the month when the tides at a station are largest (new or full moon, etc.), the maximum currents are also largest. The speed of the current is generally not constant across a body of water, but varies with location. It is generally greatest at mid-channel, and drops off near the shore. But, in winding rivers, the currents are generally largest towards the concave shore (along the "outside" curve). These statements have two important practical implications. First, it is very important to note the exact location (latitude and longitude) for which a prediction is made in such publications as the *Tidal Current Tables*. Second, a careful mariner can (with due regard for shallows or other dangers to navigation) often select a course that reduces the strength of the foul currents encountered, or increases the strength of the fair current.

TIDAL CURRENT TABLES

These tables are based on predictions made by NOS in the United States. Many other countries of the world also produce equivalent tables. Two volumes formerly published by NOS are now published commercially; one titled the *Atlantic Coast of North America,* and the other the *Pacific Coast of North America and Asia*. The *Tidal Current Tables* are organized in a very similar format to the *Tide Tables*. For example, daily predictions are available for reference stations, and currents at subordinate stations are calculated from published tidal current differences. However, the number of reference stations and subordinate stations are far fewer than those given for the *Tide Tables*. Additionally, the locations themselves may differ—even if the station name is the same. This is another reason to plot the latitude and longitude of the station as part of the planning process. Finally, the reference station for a particular substation may differ between the *Tide Tables* and the *Tidal Current Tables*. For example, there are actually two locations near Penikese Island (unusual, since fewer stations are given in the *Tidal Current Tables*) for which current predic-

Pollock Rip Channel, Massachusetts, 1999

F–Flood, Dir. 035° True E–Ebb, Dir. 225° True

January

Day	Slack (h m)	Maximum (h m)	knots
1 F ○	0151	0514	2.0F
	0813	1102	1.9E
	1412	1746	2.3F
	2055	2339	1.8E
2 Sa	0246	0608	2.0F
	0905	1154	2.0E
	1504	1838	2.4F
	2147		
3 Su		0032	1.8E
	0338	0700	2.0F
	0955	1244	2.0E
	1554	1929	2.3F
	2238		
4 M		0122	1.8E
	0429	0750	1.9F
	1046	1334	1.9E
	1643	2018	2.3F
	2328		
5 Tu		0211	1.8E
	0519	0841	1.9F
	1136	1423	1.8E
	1733	2108	2.2F
6 W	0017	0301	1.7E
	0609	0932	1.8F
	1228	1513	1.8E
	1823	2159	2.1F
7 Th	0107	0351	1.7E
	0700	1026	1.8F
	1321	1605	1.6E
	1914	2252	2.0F
8 F	0158	0442	1.6E
	0753	1122	1.7F
	1417	1700	1.5E
	2008	2347	1.9F
9 Sa ◑	0250	0536	1.6E
	0847	1219	1.7F
	1514	1757	1.5E
	2103		
10 Su		0043	1.9F
	0343	0632	1.5E
	0942	1317	1.8F
	1611	1857	1.4E
	2200		
11 M		0140	1.8F
	0435	0728	1.5E
	1036	1413	1.8F
	1708	1955	1.4E
	2256		
12 Tu		0234	1.8F
	0527	0821	1.6E
	1128	1506	1.9F
	1802	2051	1.5E
	2350		
13 W		0325	1.8F
	0617	0911	1.6E
	1218	1555	2.0F
	1853	2141	1.5E
14 Th	0041	0413	1.8F
	0704	0957	1.7E
	1303	1640	2.1F
	1940	2227	1.6E
15 F	0128	0457	1.9F
	0748	1038	1.8E
	1345	1721	2.1F
	2024	2308	1.6E
16 Sa	0211	0536	1.9F
	0829	1117	1.8E
	1425	1758	2.2F
	2105	2346	1.7E
17 Su ●	0252	0611	1.9F
	0909	1154	1.9E
	1503	1832	2.2F
	2144		
18 M		0023	1.8E
	0330	0644	1.9F
	0948	1231	2.0E
	1540	1904	2.3F
	2224		
19 Tu		0100	1.9E
	0408	0717	2.0F
	1028	1310	2.0E
	1619	1939	2.3F
	2303		
20 W		0140	2.0E
	0448	0754	2.0F
	1109	1352	2.1E
	1659	2017	2.4F
	2345		
21 Th		0222	2.0E
	0530	0834	2.0F
	1153	1436	2.1E
	1743	2059	2.3F
22 F	0029	0306	2.0E
	0614	0920	2.0F
	1242	1524	2.1E
	1830	2145	2.3F
23 Sa	0116	0355	2.0E
	0703	1010	2.0F
	1335	1616	2.0E
	1922	2237	2.1F
24 Su ◐	0208	0447	1.9E
	0757	1107	2.0F
	1433	1711	1.8E
	2020	2335	2.0F
25 M	0304	0543	1.8E
	0855	1211	1.9F
	1536	1812	1.7E
	2122		
26 Tu		0041	1.9F
	0404	0644	1.7E
	0958	1322	1.9F
	1642	1918	1.6E
	2229		
27 W		0154	1.8F
	0506	0748	1.7E
	1103	1437	1.9F
	1748	2027	1.6E
	2337		
28 Th		0307	1.8F
	0607	0854	1.7E
	1207	1546	2.0F
	1852	2137	1.6E
29 F	0043	0413	1.8F
	0706	0958	1.8E
	1308	1647	2.2F
	1951	2240	1.7E
30 Sa	0144	0512	1.9F
	0802	1057	1.8E
	1404	1742	2.3F
	2045	2336	1.7E
31 Su ○	0239	0605	2.0F
	0854	1149	1.9E
	1455	1833	2.3F
	2136		

February

Day	Slack (h m)	Maximum (h m)	knots
1 M		0027	1.8E
	0329	0654	2.0F
	0944	1238	1.9E
	1544	1919	2.3F
	2223		
2 Tu		0112	1.8E
	0415	0740	2.0F
	1031	1322	1.9E
	1629	2004	2.3F
	2308		
3 W		0155	1.8E
	0500	0823	2.0F
	1117	1405	1.9E
	1713	2046	2.2F
	2352		
4 Th		0236	1.8E
	0543	0907	1.9F
	1204	1448	1.8E
	1757	2129	2.1F
5 F	0036	0318	1.7E
	0627	0951	1.9F
	1251	1533	1.7E
	1842	2213	2.0F
6 Sa	0121	0402	1.7E
	0713	1039	1.8F
	1341	1620	1.6E
	1930	2301	1.9F
7 Su	0209	0449	1.6E
	0802	1130	1.8F
	1434	1712	1.5E
	2021	2353	1.8F
8 M ◑	0259	0540	1.5E
	0854	1226	1.7F
	1530	1807	1.4E
	2116		
9 Tu		0050	1.7F
	0352	0634	1.5E
	0948	1325	1.7F
	1627	1905	1.4E
	2213		
10 W		0148	1.7F
	0445	0731	1.5E
	1043	1422	1.8F
	1723	2005	1.4E
	2310		
11 Th		0245	1.7F
	0538	0826	1.5E
	1136	1516	1.9F
	1817	2101	1.4E
12 F	0005	0337	1.7F
	0629	0917	1.6E
	1226	1605	2.0F
	1907	2151	1.5E
13 Sa	0055	0424	1.8F
	0716	1004	1.7E
	1312	1649	2.1F
	1952	2236	1.6E
14 Su	0141	0505	1.9F
	0800	1046	1.8E
	1355	1728	2.2F
	2035	2316	1.8E
15 M	0223	0542	1.9F
	0842	1126	1.9E
	1435	1803	2.3F
	2115	2355	1.9E
16 Tu ●	0302	0617	2.0F
	0922	1206	2.0E
	1515	1837	2.4F
	2155		
17 W		0033	2.0E
	0341	0652	2.1F
	1003	1246	2.2E
	1555	1913	2.4F
	2235		
18 Th		0113	2.1E
	0421	0729	2.2F
	1045	1328	2.2E
	1636	1951	2.4F
	2316		
19 F		0155	2.1E
	0502	0810	2.2F
	1130	1413	2.2E
	1721	2033	2.4F
20 Sa	0000	0240	2.1E
	0547	0855	2.2F
	1218	1501	2.2E
	1808	2120	2.3F
21 Su	0048	0328	2.1E
	0636	0946	2.2F
	1312	1552	2.0E
	1901	2213	2.1F
22 M ◐	0140	0420	2.0E
	0730	1043	2.1F
	1411	1649	1.8E
	1959	2313	1.9F
23 Tu	0238	0518	1.8E
	0830	1150	1.9F
	1516	1752	1.7E
	2105		
24 W		0024	1.8F
	0342	0621	1.7E
	0937	1308	1.9F
	1625	1902	1.5E
	2216		
25 Th		0145	1.7F
	0448	0732	1.6E
	1046	1429	1.9F
	1734	2019	1.5E
	2328		
26 F		0302	1.7F
	0554	0846	1.6E
	1155	1539	2.0F
	1840	2133	1.5E
27 Sa	0036	0408	1.8F
	0656	0954	1.7E
	1258	1639	2.2F
	1939	2236	1.6E
28 Su	0136	0505	1.9F
	0752	1053	1.8E
	1354	1732	2.3F
	2032	2330	1.7E

March

Day	Slack (h m)	Maximum (h m)	knots
1 M	0228	0555	2.0F
	0843	1143	1.8E
	1444	1820	2.3F
	2119		
2 Tu ○		0015	1.8E
	0314	0641	2.1F
	0930	1227	1.9E
	1529	1903	2.3F
	2202		
3 W		0055	1.8E
	0356	0722	2.1F
	1014	1307	1.9E
	1611	1943	2.3F
	2243		
4 Th		0132	1.8E
	0435	0801	2.1F
	1056	1344	1.8E
	1650	2021	2.2F
	2322		
5 F		0207	1.8E
	0513	0839	2.0F
	1138	1422	1.8E
	1730	2057	2.1F
6 Sa	0002	0243	1.8E
	0552	0916	2.0F
	1222	1501	1.7E
	1810	2135	1.9F
7 Su	0044	0323	1.7E
	0633	0957	1.9F
	1308	1544	1.6E
	1854	2216	1.8F
8 M	0129	0406	1.6E
	0718	1042	1.8F
	1357	1631	1.5E
	1942	2304	1.7F
9 Tu	0217	0454	1.6E
	0807	1135	1.8F
	1450	1724	1.5E
	2035	2359	1.6F
10 W ◑	0310	0547	1.5E
	0900	1233	1.7F
	1547	1820	1.4E
	2132		
11 Th		0059	1.6F
	0405	0643	1.5E
	0956	1334	1.7F
	1644	1920	1.4E
	2231		
12 F		0201	1.6F
	0500	0741	1.5E
	1052	1432	1.8F
	1739	2018	1.4E
	2327		
13 Sa		0257	1.6F
	0553	0836	1.5E
	1146	1525	1.9F
	1830	2112	1.5E
14 Su	0020	0347	1.7F
	0643	0927	1.7E
	1236	1611	2.0F
	1918	2200	1.7E
15 M	0107	0431	1.9F
	0729	1013	1.8E
	1322	1652	2.2F
	2002	2243	1.8E
16 Tu	0151	0510	2.0F
	0813	1057	2.0E
	1405	1730	2.3F
	2043	2324	2.0E
17 W ●	0232	0547	2.1F
	0855	1139	2.1E
	1448	1808	2.4F
	2124		
18 Th		0004	2.1E
	0312	0625	2.3F
	0938	1221	2.2E
	1530	1846	2.4F
	2205		
19 F		0045	2.2E
	0353	0704	2.4F
	1022	1305	2.3E
	1614	1926	2.4F
	2248		
20 Sa		0129	2.2E
	0436	0747	2.4F
	1108	1351	2.3E
	1700	2010	2.4F
	2333		
21 Su		0214	2.2E
	0522	0834	2.4F
	1158	1440	2.2E
	1749	2059	2.2F
22 M	0022	0304	2.1E
	0612	0926	2.3F
	1253	1533	2.0E
	1843	2153	2.1F
23 Tu	0117	0357	1.9E
	0708	1026	2.1F
	1354	1631	1.8E
	1944	2258	1.8F
24 W ◐	0217	0457	1.8E
	0810	1137	2.0F
	1500	1737	1.6E
	2052		
25 Th		0015	1.7F
	0324	0605	1.6E
	0919	1259	1.9F
	1610	1853	1.5E
	2205		
26 F		0139	1.6F
	0433	0721	1.5E
	1031	1417	1.9F
	1720	2013	1.5E
	2318		
27 Sa		0252	1.7F
	0540	0838	1.5E
	1141	1524	2.1F
	1824	2124	1.6E
28 Su	0024	0354	1.9F
	0642	0945	1.6E
	1243	1622	2.2F
	1921	2223	1.7E
29 M	0121	0449	2.0F
	0738	1041	1.7E
	1338	1714	2.3F
	2011	2313	1.8E
30 Tu	0210	0537	2.1F
	0827	1129	1.8E
	1426	1759	2.3F
	2056	2355	1.8E
31 W ○	0253	0621	2.1F
	0912	1210	1.8E
	1509	1841	2.2F
	2137		

TABLE 8-8–Excerpt from Table 1 (Daily Current Predictions) of *Tidal Current Tables*

No.	PLACE	Meter Depth	POSITION Latitude	POSITION Longitude	TIME DIFFERENCES Min. before Flood	TIME DIFFERENCES Flood	TIME DIFFERENCES Min. before Ebb	TIME DIFFERENCES Ebb	SPEED RATIOS Flood	SPEED RATIOS Ebb	Minimum before Flood knots	Minimum before Flood Dir.	Maximum Flood knots	Maximum Flood Dir.	Minimum before Ebb knots	Minimum before Ebb Dir.	Maximum Ebb knots	Maximum Ebb Dir.
		ft	North	West	h m	h m	h m	h m			knots	Dir.	knots	Dir.	knots	Dir.	knots	Dir.
	BUZZARDS BAY <7> Time meridian, 75° W				on Pollock Rip Channel, p.20													
2041	Gooseberry Neck, 2 miles SSE of		41° 27'	71° 01'	See table 5.													
2046	Ribbon Reef–Sow & Pigs Reef, between		41° 25.3'	70° 58.2'	–0 19	–1 31	–2 44	–1 54	0.4	0.7	0.0	– –	0.8	062°	0.0	– –	1.2	237°
2051	Penikese Island, 0.8 mile northwest of		41° 27.9'	70° 56.2'	–1 37	–0 25	–0 55	–0 57	0.6	0.6	0.0	– –	1.2	050°	0.0	– –	1.1	254°
2056	Penikese Island, 0.2 mile south of		41° 26.6'	70° 55.5'	–1 43	–0 15	–1 30	–2 39	0.4	0.5	0.0	– –	0.7	093°	0.0	– –	0.9	287°
2061	Gull I. and Nashawena I., between		41° 26.2'	70° 54.2'	–2 15	–0 57	–2 01	–2 41	0.5	0.6	0.0	– –	0.9	091°	0.0	– –	1.1	247°
2066	Weepecket Island, south of		41° 30.4'	70° 44.3'	–3 16	–1 07	–1 28	–2 27	0.4	0.4	0.0	– –	0.8	069°	0.0	– –	0.6	255°
2071	Quamquisset Harbor entrance		41° 32.4'	70° 39.8'	Current weak and variable						0.0	– –	0.4	– –	0.0	– –	0.3	– –
2076	West Falmouth Harbor entrance		41° 36.5'	70° 39.3'	Current weak and variable													
2081	Megansett Harbor		41° 38.8'	70° 39.2'	Current weak and variable													
2086	Abiels Ledge, 0.4 mile south of		41° 41.1'	70° 40.4'	+0 26	–0 36	–0 06	–0 23	0.4	0.6	0.0	– –	0.8	035°	0.0	– –	1.0	216°
2091	Dumpling Rocks, 0.2 mile southeast of		41° 32.0'	70° 55.1'	–1 43	–1 03	–1 32	–2 09	0.4	0.6	0.0	– –	0.8	066°	0.0	– –	1.1	190°
2096	Apponagansett Bay		41° 35'	70° 57'	Current weak and variable													
2101	Clarks Cove		41° 36'	70° 55'	Current weak and variable													
2106	New Bedford Harbor and approaches				Current weak and variable													
2111	West Island and Long Island, between		41° 35.6'	70° 50.4'	Current weak and variable						0.0	– –	0.3	– –	0.0	– –	0.4	– –
2116	West Island, 1 mile southeast of	6	41° 34.0'	70° 48.6'	–0 43	–0 43	–1 28	–1 42	0.4	0.5	0.0	– –	0.7	079°	0.0	– –	0.8	203°
2121	Nasketucket Bay		41° 37.1'	70° 50.2'	Current weak and variable						0.0	– –	0.3	– –	0.0	– –	0.3	– –
2126	Mattapoisett Harbor		41° 38'	70° 47'	Current weak and variable													
2131	Sippican Harbor		41° 41'	70° 44'	Current weak and variable						0.0	– –	0.3	– –	0.0	– –	0.4	– –
2136	Wareham River, off Long Beach Point		41° 44.0'	70° 43.0'	–1 41	–0 31	–1 22	–1 23	0.3	0.4	0.0	– –	0.6	022°	0.0	– –	0.6	202°
2141	Wareham River, off Barneys Point		41° 44.7'	70° 42.4'	–1 49	–0 27	–1 22	–1 31	0.4	0.4	0.0	– –	0.7	010°	0.0	– –	0.6	185°
					on Cape Cod Canal, p.16													
2146	Onset Bay, south of Onset Island		41° 43.9'	70° 38.7'	Current weak and variable													
2151	Onset Bay, south of Wickets Island		41° 44.1'	70° 39.3'	Current weak and variable													
	CAPE COD CANAL																	
2156	CAPE COD CANAL, railroad bridge		41° 44.5'	70° 36.8'	*Daily predictions*						0.0	– –	4.0	070°	0.0	– –	4.5	250°
2161	Bourne Highway bridge		41° 45'	70° 35'	–0 03	–0 01	–0 03	–0 04	0.8	0.9	0.0	– –	3.3	065°	0.0	– –	4.0	245°
2166	Bournedale		41° 46'	70° 34'	–0 07	–0 03	–0 09	–0 10	0.8	0.8	0.0	– –	3.4	030°	0.0	– –	3.6	210°
2171	Sagamore Bridge		41° 46'	70° 33'	–0 09	–0 04	–0 11	–0 13	0.7	0.6	0.0	– –	2.8	095°	0.0	– –	2.5	275°
2176	Cape Cod Canal, east end	15	41° 46.5'	70° 30.0'	–0 13	–0 06	–0 17	–0 19	0.6	0.6	0.0	– –	2.4	065°	0.0	– –	2.6	245°
	NARRAGANSETT BAY <8>				on Pollock Rip Channel, p.20													
2181	Sakonnet River (except Narrows)		– – –	– – –	Current weak and variable													
2186	Black Point, SW of, Sakonnet River	15	41° 30.4'	71° 13.2'	–2 54	–1 55	–2 13	–2 26	0.2	0.2	0.0	– –	0.4	012°	0.0	– –	0.4	194°
2191	Almy Point Bridge, south of, Sakonnet River	15	41° 37.3'	71° 13.2'	–3 00	–2 10	–2 30	–3 13	0.2	0.8	0.0	– –	0.4	034°	0.0	– –	1.5	180°
2196	Tiverton, Stone bridge, Sakonnet R. <9>		41° 37.5'	71° 13.0'	–2 58	–5 02	–2 26	–3 06	1.4	1.6	0.0	– –	2.7	010°	0.0	– –	2.7	190°
						–2 54			0.3				0.6	010°				
						–0 36			1.3				2.5	010°				
2201	Tiverton, RR. bridge, Sakonnet R. <10>		41° 38.3'	71° 12.9'	–3 26	–5 06	–2 48	–3 41	1.2	1.4	0.0	– –	2.3	000°	0.0	– –	2.4	180°
						–3 04			– –				– –					
						–1 15			0.8				1.5	000°				
2206	Common Fence Point, northeast of	10	41° 39.5'	71° 12.5'	–2 38	–4 50	–2 32	–2 41	0.1	0.2	0.0	– –	0.2	026°	0.0	– –	0.3	210°
						–2 25			0.0				0.1	058°				
						–0 58			0.1				0.1	046°				
2211	Brenton Point, 1.4 n.mi. southwest of	7	41° 25.9'	71° 22.6'	–1 03	–0 38	–1 20	–1 04	0.2	0.4	0.0	– –	0.4	347°	0.0	– –	0.6	170°
2216	Castle Hill, west of, East Passage	15	41° 27.4'	71° 22.7'	–0 06	–0 42	–1 07	–0 29	0.4	0.7	0.0	– –	0.7	013°	0.0	– –	1.2	237°
2221	Bull Point, east of	10	41° 28.8'	71° 21.0'	–1 10	–0 47	–1 10	–1 33	0.6	0.8	0.0	– –	1.2	001°	0.0	– –	1.5	206°
2226	Mackerel Cove		41° 28.5'	71° 22.8'	Current weak and variable													
2231	Newport Harbor, S and E of Goat Island		41° 29'	71° 20'	Current weak and variable													
2236	Rose Island, northeast of	15	41° 30.2'	71° 19.9'	–1 57	–0 07	–1 17	–2 08	0.4	0.5	0.0	– –	0.8	310°	0.0	– –	1.0	124°
2241	Rose Island, northwest of	15	41° 30.4'	71° 21.1'	–1 38	–0 26	–1 38	–1 39	0.4	0.5	0.1	105°	0.7	007°	0.1	102°	1.0	190°

TABLE 8-9–Excerpt of Table 2 (Current Differences and Other Constants) of *Tidal Current Tables*

tions are available, neither of which corresponds in latitude or longitude to that used for Penikese Island in the *Tide Tables*. In this case, the difference in location is not great, but it is at other locations (e.g., near San Francisco, California). Moreover, Penikese is referenced to the daily predictions for Newport, Rhode Island, in the *Tide Tables*, but to Pollack Rip Channel near the entrance to Nantucket Sound in the *Tidal Current Tables*, which is not even shown on the 1210-Tr chart!

USE OF THE TIDAL CURRENT TABLES

The publication, *Tidal Current Tables*, consists of five separate sets of tables. Of these, Tables 1, 2, and 3 are required for estimation of tidal currents at any time. Table 4 of the *Tidal Current Tables* is used for estimation of the duration of slack water (particularly important for divers), and Table 5 (Atlantic Coast only) presents data for rotary tidal currents. These latter two tables are discussed only briefly here, but are relatively easy to use from the directions included in the *Tidal Current Tables*.

The *Tidal Current Tables* also contain information on how currents are combined (vector addition) and provide Current Diagrams, which graphically portray currents in several locations. Only a brief discussion of these tables and charts is included in this text, because of size and scope constraints, but clear directions are provided in the *Tidal Current Tables*. (It almost goes without saying, that this publication is very important and should be aboard any vessel.)

Tidal current prediction for reference stations is made using Table 1 ("Daily Current Predictions") of the *Tidal Current Tables*, which presents daily predictions of the times of slack water, and of maximum current (flood and ebb). Table 8-8 of this text, for example, contains an excerpt from Table 1 of the *Tidal Current Tables* for the reference station, Pollack Rip channel, over the months of January, February, and March of 1999.

At the top of this table, the direction of the flood (035 degrees true) and the ebb (225 degrees true) is given for the reference station. Note that the flood and ebb directions are not necessarily reciprocal (180 degrees apart). The set of the current is given because the directions for flood and ebb are not always obvious, and, moreover, the accurate direction is necessary to current sailing computations. Directions of flood and ebb at any subordinate station keyed to this reference station are not necessarily the same as those for the reference station and must be read from a separate table. For each day, three columns of data are provided: the times of slack water and the time and velocity of maximum current. Refer, for example, to the table entry for 27 February 1999. Slack water times are estimated to occur at 0036, 0656, 1258, and 1939. As with the *Tide Tables*, standard times in the 24-hour system are employed in those publications that reproduce the NOS *Tidal Current Tables* exactly. Other conventions are used in some cases. Read the directions that accompany the tables that you are using.

Times and strengths of maximum currents on this day are 0408 (when the current is 1.8 knots and flooding, denoted by the letter F next to the current velocity), 0954 (when the current is ebbing, denoted by the letter E, at a speed of 1.7 knots), 1639 (2.2 knot flood), and 2236 (1.6 knot ebb).

At some locations on the West Coast of the United States, the pattern of floods, slacks, and ebbs is more complex. Slacks, for example, do not always follow a flood or ebb. These special current patterns are explained in the *Tidal Current Tables*.

The accuracy of these predictions is generally taken to be within one-half hour, although deviations of as much as one hour or more can occur. Therefore, a prudent mariner plans to arrive at a particular entrance or strait at least one-half hour before the time estimates given in the tables, to ensure passage at a slack or favorable current.

SUBORDINATE STATIONS

Table 2 ("Current Differences and Other Constants") of the *Tidal Current Tables*, excerpted in Table 8-9 of this text, provides the current differences and other constraints necessary for predictions at subordinate stations. The entries of this table include:

- **Station or substation identification number:** For example, substation 2051 is assigned to the station located 0.8 miles northwest of Penikese Island. There is no correspondence between the number assigned to a particular location in *Tide Tables* and that assigned in the *Tidal Current Tables*.
- **Place name:** As noted, the actual position should be plotted, rather than relying on the published place name.

Substation: ________ Time Differences: ___ Min. Bef. Flood: _____ Flood: __________ Min. Bef. Ebb: ______ Ebb: ____________	Ref. Station: ________ Speed Ratios: ________ Flood: ____________ Ebb: ______________	Date: ________ Directions: ______ Flood: ________ Ebb: _________	Look up these values from Table 2, "Current Differences and Other Constants." This section can be omitted if the desired location can be found in Table 1, "Daily Current Predictions." Pay careful attention to any footnotes applicable to the station.
CALCULATIONS: Ref. Station: ____________ Condition Time Speed Slack ____________ Ebb ____________ Slack ____________ Flood ____________ Slack ____________ Ebb ____________ Slack ____________ Flood ____________ Slack ____________ Ebb ____________	Substation: ____________ Condition Time Speed Slack ____________ Ebb ____________ Slack ____________ Flood ____________ Slack ____________ Ebb ____________ Slack ____________ Flood ____________ Slack ____________ Ebb ____________		Look up times and speeds for reference station in Table 1. Add or subtract time differences for substations to Table 1 times for reference station (pay attention to date). Estimate the drift at the substation by multiplying the appropriate speed ratio by the drift at the reference station. Remember, times given in these tables are standard time in the 24-hour system.
VELOCITY OF CURRENT AT ANY TIME: Location: ________	Time: ____________	Date: ________	
Interval Between Slack and Desired Time:	____________		Time difference between desired time and nearest slack.
Interval Between Slack and Max Current:	____________		Time difference between slack and maximum current that bracket desired time.
Max Current:	____________		Drift of maximum current (ebb or flood) closest to desired time.
Tabled Correction:	____________		From Table 3—be careful to use correct table if more than 1.
Calculated Velocity:	____________		Multiply correction by max current.
Direction:	____________		Take direction from top data block.

TABLE 8-10–Current Table Worksheet

- **Location:** The latitude and longitude of the station or substation are given. As with the *Tide Tables*, these coordinates are approximate, and occasionally plot on dry land.
- **Time differences:** Four time differences are given, that correspond to minimum current (generally slack water) before flood, flood, minimum before ebb, and ebb. For Penikese Island, station 2051, these time differences are keyed to Pollack Rip Channel (look for this station in the Time Differences column) and are numerically equal to - 1 hour, 37 minutes, - 0 hours 25 minutes, - 0 hours 55 minutes, and -0 hours 57 minutes, respectively. As with tidal predictions, it is convenient to use a structured worksheet (reproduced in Table 8-10) for tidal current computations. A worked out example is given in Table 8-11. In transcribing information from this table to the worksheet, pay particular attention to ensure that the correct numbers are entered. As with the tidal data, these time differences are to be added (algebraic sign important) to the

Substation: Penikese	Ref. Station: Pollack	Date: 27 February 1999	Look up these values from Table 2, "Current Differences and Other Constants." This section can be omitted if the desired location can be found in Table 1, "Daily Current Predictions." Pay careful attention to any footnotes applicable to the station.
Time Differences:	Speed Ratios:	Directions:	
Min. Bef. Flood: -1:37	Flood: 0.6	Flood: 050	
Flood: - :25	Ebb: 0.6	Ebb: 254	
Min. Bef. Ebb: - :55			
Ebb: - :57			

CALCULATIONS:

Ref. Station: Pollack Rip			Substation: Penikese			Look up times and speeds for reference station in Table 1. Add or subtract time differences for substations to Table 1 times for reference station (pay attention to date). Estimate the drift at the substation by multiplying the appropriate speed ratio by the drift at the reference station. Remember, times given in these tables are standard time in the 24-hour system.
Condition	Time	Speed	Condition	Time	Speed	
Slack			Slack			
Ebb			Ebb			
Slack	0036	0	Slack	2259	0	
Flood	0408	1.8	Flood	0343	1.1	
Slack	0656	0	Slack	0601	0	
Ebb	0954	1.7	Ebb	0857	1.0	
Slack	1258	0	Slack	1121	0	
Flood	1639	2.2	Flood	1614	1.3	
Slack	1939	0	Slack	1844	0	
Ebb	2236	1.6	Ebb	2139	1.0	

VELOCITY OF CURRENT AT ANY TIME:

Location: Penikese Time: 0900 Date: 27 February 1999

Interval Between Slack and Desired Time:	0221	Time difference between desired time and nearest slack.
Interval Between Slack and Max Current:	0224	Time difference between slack and maximum current that bracket desired time.
Max Current:	1.0	Drift of maximum current (ebb or flood) closest to desired time.
Tabled Correction:	1.0	From Table 3—be careful to use correct table if more than 1.
Calculated Velocity:	1.0	Multiply correction by max current.
Direction:	254	Take direction from top data block.

TABLE 8-11–Current Table Worksheet

corresponding times at the reference station. For example, the first current at Pollack Rip Channel on 27 February 1999 is a slack before flood at 0036. The time difference corresponding to this current at Penikese Island is - 1 hour 37 minutes earlier. Therefore, the corresponding current occurs at (0036 - 0137) or 2259 the previous day at Penikese Island. To see this, note that 0036 on 27 February is equal to 2396 on 26 February; 2396 - 0137 = 2259. The next current is a flood current which occurs at Pollack Rip Channel at 0408—equivalent to 0343 at Penikese Island, from the - 25 minute time difference.

❏ **Speed ratios for flood and ebb:** These factors are to be multiplied by the drift of the corresponding current at the reference station. Numerically, the speed ratios are 0.6 for the flood and ebb current alike at station 2501, but they differ at many other locations. These are entered into the top data block of the worksheet in Table 8-11.

❏ **Average speeds and directions of the various currents:**

Directions are given with respect to true north, and average speeds are given to the nearest 0.1 knot. These average speeds are of general interest, but are not used for individual predictions.

Note that the table of current differences and other constants uses the phrases "Min. before Flood" and "Min. before Ebb," rather than "slack." This is because in some locations the current does not diminish to a true slack water or zero speed stage. Indeed, reference to Table 8-9 shows that the minimum current before flood at Rose Island, northwest of (station #2241) is 0.1 knots, not zero.

THE TIDAL CURRENT WORKSHEET

The top two blocks of the worksheet can be completed, and show the times of the slack and maximum currents at the subordinate station as calculated above. To estimate the speed of the current at any time, it is necessary to use Table 3 ("Speed of Current at Any Time") from the *Tidal Current Tables*, reproduced here as Table 8-12. Note that two separate tables are given for this purpose, each referenced to different stations. (The same is true for the Pacific Coast stations.) Pay careful attention to ensure that the correct table is selected. The entries for this table are the factor to multiply the estimated maximum current at the substation to calculate the current at any time. Directions are given in the worksheet, and not repeated here.

Table 8-11 provides a worked out numerical example. The estimated current at 0900 on 27 February 1999 is 1.0 knot (ebb) and has a set of 254°. As with similar tide height computations, it is necessary to take care in the computations to avoid numerical errors.

LATE BREAKING NEWS

NOAA has recently completed a major statistical study of the accuracy of tidal current predictions. Results of this study are being evaluated as this edition of ACN goes to press. A major policy decision to revise these tables may be made in the near future. This decision could result in the removal of 50 percent or more of the tidal current subordinate stations now listed in the *Tidal Current Tables*.

COMPUTER PROGRAMS

As with tide height computations, software for tidal current computations is commercially available. Figure 8-5 shows illustrative output from one program (Nobeltec/Nautical Software) for this station on 27 February 1999. The estimate for 0900 agrees exactly with that computed from the *Tidal Current Tables*.

There are two major advantages to using computer programs for tidal current computations:

- First, computers take the drudgery out of these computations. It is possible to make individual sheets of predictions (such as that illustrated in Figure 8-5) for numerous possible ports and waypoints. This contributes greatly to the efficiency of voyage planning.
- Second, computers greatly reduce the possibility of numerical error.

Use of such programs is highly recommended.

DURATION OF SLACK

It is sometimes of interest to estimate the length of time at which a current will be slack, or nearly so. Divers, for example, are generally constrained to operate in circumstances where the current is nearly slack. As a second example, local knowledge may indicate that certain inlets or bridges are best transited during periods of near slack.

The time predictions for slack current, discussed above, attempt to give the exact instant of zero (or minimum) speed. However, there is a period on each side of slack water when the current is quite weak. In principle, the estimated current at various times could be computed using the above procedure. A plot of the estimated current versus time could then be used to estimate the duration of interval within which the estimated current is arbitrarily small. But, such computations would be tedious, indeed, and subject to numerical error unless a computer program is used.

Fortunately, the architects of the *Tidal Current Tables* have devised a simpler procedure. This involves the use of Table 4 ("Duration of Slack") of the *Tidal Current Tables*, which is reproduced as Table 8-13 of this text. Actually, two separate tables are used, as is the case for Table 3 of the *Tidal Current Tables*, each applicable to different stations.

The duration of slack (in minutes) is correlated with the strength of the maximum current. Thus, the tables provide the duration (in minutes) over which the estimated current will be less than a prespecified

TABLE A

Interval between slack and maximum current

Interval between slack and desired time (h. m.)	h. m. 1 20	h. m. 1 40	h. m. 2 00	h. m. 2 20	h. m. 2 40	h. m. 3 00	h.m. 3 20	h.m. 3 40	h.m. 4 00	h.m. 4 20	h.m. 4 40	h.m. 5 00	h.m. 5 20	h.m. 5 40
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
0 20	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0 40	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
1 00	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3
1 20	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
1 40	----	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4
2 00	----	----	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5
2 20	----	----	----	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6
2 40	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7
3 00	----	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7
3 20	----	----	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
3 40	----	----	----	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.9	0.9
4 00	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9	0.9
4 20	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9
4 40	----	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0
5 00	----	----	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0
5 20	----	----	----	----	----	----	----	----	----	----	----	----	1.0	1.0
5 40	----	----	----	----	----	----	----	----	----	----	----	----	----	1.0

TABLE B

Interval between slack and maximum current

Interval between slack and desired time (h. m.)	h. m. 1 20	h. m. 1 40	h. m. 2 00	h. m. 2 20	h. m. 2 40	h. m. 3 00	h. m. 3 20	h. m. 3 40	h. m. 4 00	h. m. 4 20	h. m. 4 40	h. m. 5 00	h. m. 5 20	h. m. 5 40
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.
0 20	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
0 40	0.8	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
1 00	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4
1 20	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
1 40	----	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
2 00	----	----	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6
2 20	----	----	----	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
2 40	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7
3 00	----	----	----	----	----	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
3 20	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
3 40	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9	0.9	0.9
4 00	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9	0.9
4 20	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0	0.9
4 40	----	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0	1.0
5 00	----	----	----	----	----	----	----	----	----	----	----	1.0	1.0	1.0
5 20	----	----	----	----	----	----	----	----	----	----	----	----	1.0	1.0
5 40	----	----	----	----	----	----	----	----	----	----	----	----	----	1.0

Use table A for all places except those listed below for table B.
Use table B for Cape Cod Canal, Hell Gate, Chesapeake and Delaware Canal, and all stations in table 2 which are referred to them.

1. From predictions find the time of slack water and the time and velocity of maximum current (flood or ebb), one of which is immediately before and the other after the time for which the velocity is desired.
2. Find the interval of time between the above slack and maximum current, and enter the top of table A or B with the interval which most nearly agrees with this value.
3. Find the interval of time between the above slack and the time desired, and enter the side of table A or B with the interval which most nearly agrees with this value.
4. Find, in the table, the factor corresponding to the above two intervals, and multiply the maximum velocity by this factor. The result will be the approximate velocity at the time desired.

TABLE 8-12–Table 3 (Speed of Current at Any Time) from *Tidal Current Tables,* 1999

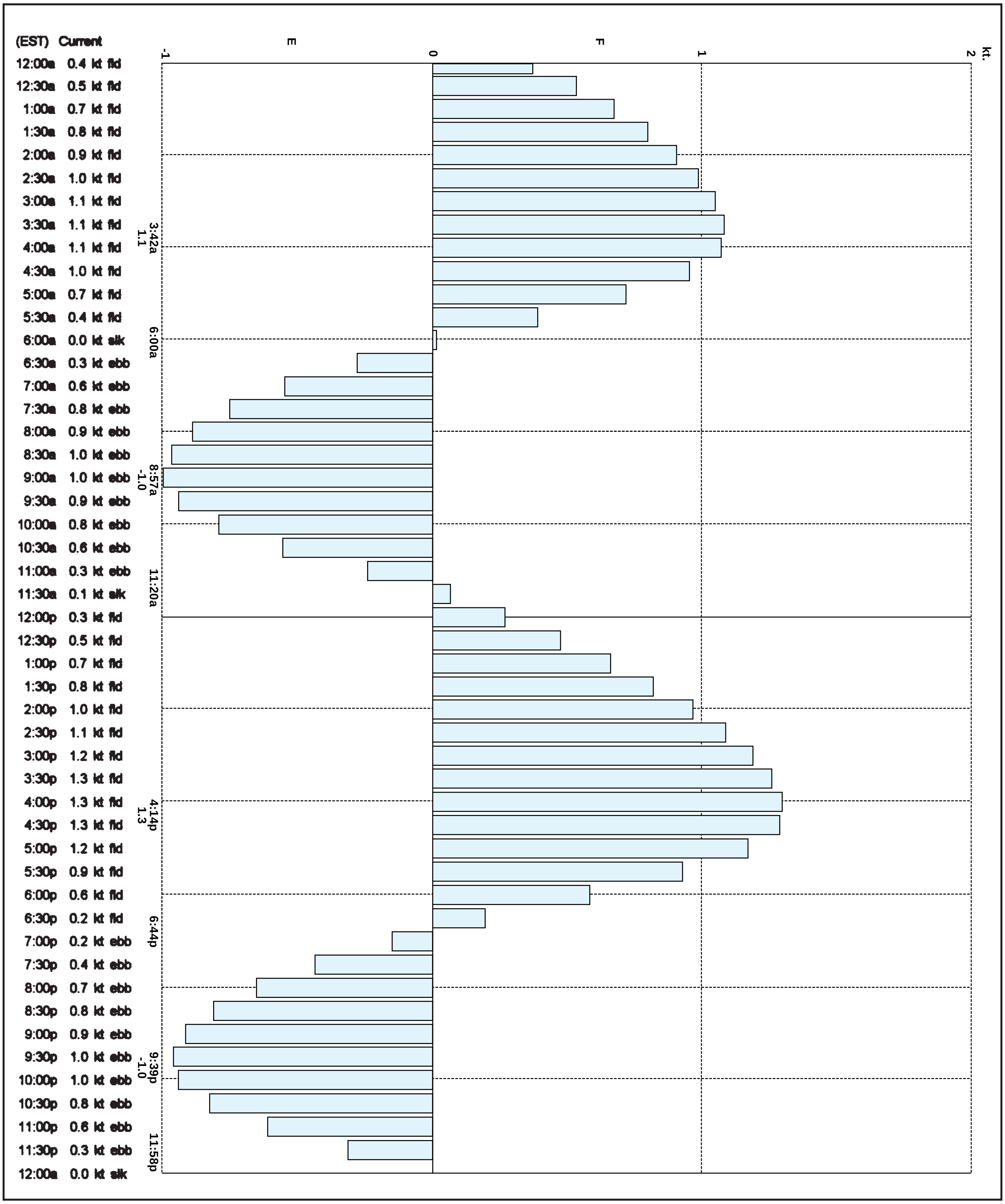


FIG. 8-5–Illustrative Output of Tidal Current Program (Reproduced with Permission from Nobeltec/Nautical Software, Inc.)

value of from 0.1 knots to 0.5 knots, in increments of 0.1 knots, for various values of the drift of the maximum current.

To illustrate, suppose that it is of interest to predict the approximate duration of the slack at 1121 at Penikese Island (substation #2051) on 27 February 1999—an example discussed above. Further, for purposes of this example, take "slack" to mean a current of less than 0.2 knots. Note that the estimated maximum ebb (at 0857) before this slack is 1.0 knot (see the completed current table worksheet in Table 8-11; notice the entries for the substation Penikese), and the estimated flood after this slack (at 1614) is 1.3 knots. Because these maximum currents are not identical, it is necessary to solve the problem in two parts:

- ❏ Consider, first, the time period after the ebb at 0857 but before the slack at 1121. Reference to the directions indicates that Table 8-13 A (top) is the correct table for this station. Enter this table at the column headed 0.2 knots. The correct row corresponds to the maximum ebb current of 1.0 knots. The entry, 46 minutes, is the estimated duration of weak current near the time of slack water. Half of this period, 23 minutes, occurs before slack. Thus, before the slack current, the estimated length of time that the current will be beneath 0.2 knots is 23 minutes, or from approximately 1058 to 1121.
- ❏ Next, consider the period after the slack but before the flood at 1614. Here the maximum current (row to enter the table) is 1.3 knots, closer to the entry 1.5 knots in Table 8-13. The duration of weak current from this table is 31 minutes, of which half, say 16 minutes, would occur on either side of slack. Thus, the period after slack at which the current would be 0.2 knots or less is from 1121 to 1137.
- ❏ Combining these two results, the estimated period at which the current is predicted to be less than 0.2 knots is from 1058 to 1137.

It is easier if the currents on either side of the slack are identical. (It is yet easier to use a computer program for calculation!)

ROTARY CURRENTS (ATLANTIC COAST ONLY)

The preceding discussion is applicable to what are termed *reversing currents* (termed rectilinear by the British). According to NOS, a reversing current is defined as "a tidal current, which flows alternately in approximately opposite directions with a slack water at each reversal of direction." However, some currents are better described as rotary. A rotary current is "a tidal current that flows continually with the direction of flow changing through all points of the compass during the tidal period." Rotary tidal currents are generally found offshore where the direction of flow is not (or is less) restricted by shoreline or other barriers. The rotary currents tend to rotate clockwise in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere. The speed of a rotary current generally varies throughout the tidal current cycle.

Locations where rotary currents prevail are designated by the phrase "see Table 5" in the table of current differences and other constants. Directions are provided in Table 5 of the *Tidal Current Diagrams* and are not reproduced here.

TIDAL CURRENT DIAGRAMS

Tidal Current Diagrams are published for several well-traveled areas of the United States in the *Tidal Current Tables*. As with other tables, these diagrams are no longer distributed to the general public by NOS, but are available from some commercial sources. Figure 8-6 illustrates one such diagram for Vineyard and Nantucket sounds, covering a part of the area on the 1210-Tr chart. Other locations for which *Tidal Current Diagrams* are published include the East River, New York, New York Harbor via Ambrose Channel, the Delaware Bay and River, and the Chesapeake Bay. These current diagrams represent average conditions of the surface currents in the middle of the channel.

For the illustration in Figure 8-6, easterly currents are designated "flood," and westerly currents "ebb." The small numbers in the diagram are the average speeds of the current in knots and tenths at various locations and times. All times, shown at the top and bottom axes of the diagram, are keyed to slack waters at Pollock Rip Channel. These times can be estimated from the daily predictions given in the *Tidal Current Tables*.

Speed lines are shown to the right of the diagram and are used directly with the diagram. By transferring to the diagram the direction

Table A should be used for all places except those listed below for table B.

Table B should be used for Cape Cod Canal, Hell Gate, Chesapeake and Delaware Canal, and all stations in Table 2 which are referred to them.

Duration of weak current near time of slack water

TABLE A

Maximum current	Period with a speed not more than -				
	0.1 knot	*0.2 knot*	*0.3 knot*	*0.4 knot*	*0.5 knot*
Knots	*Minutes*	*Minutes*	*Minutes*	*Minutes*	*Minutes*
1.0	23	46	70	94	120
1.5	15	31	46	62	78
2.0	11	23	35	46	58
3.0	8	15	23	31	38
4.0	6	11	17	23	29
5.0	5	9	14	18	23
6.0	4	8	11	15	19
7.0	3	7	10	13	16
8.0	3	6	9	11	14
9.0	3	5	8	10	13
10.0	2	5	7	9	11

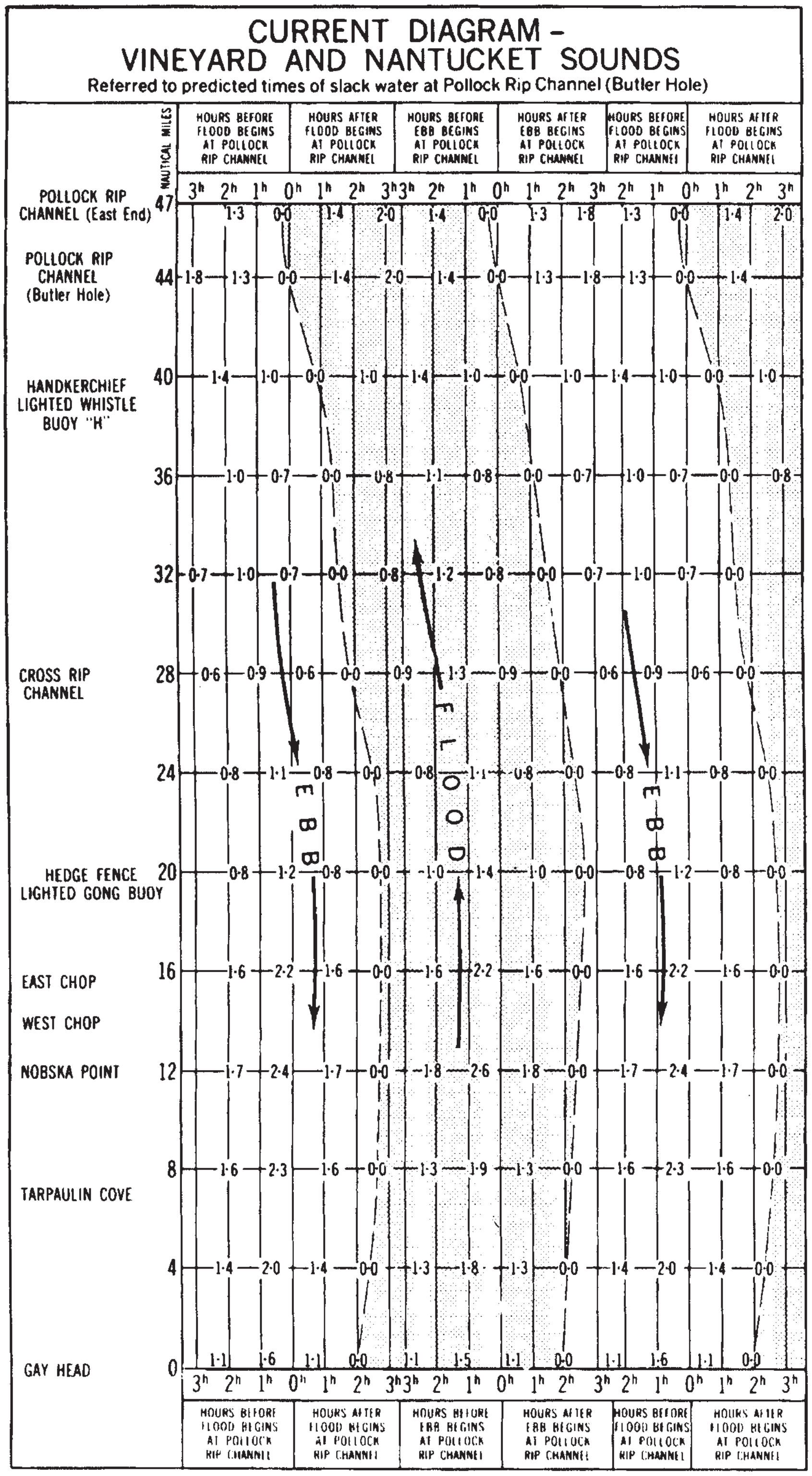
TABLE B

Maximum current	Period with a speed not more than -				
	0.1 knot	*0.2 knot*	*0.3 knot*	*0.4 knot*	*0.5 knot*
Knots	*Minutes*	*Minutes*	*Minutes*	*Minutes*	*Minutes*
1.0	13	28	46	66	89
1.5	8	18	28	39	52
2.0	6	13	20	28	36
3.0	4	8	13	18	22
4.0	3	6	9	13	17
5.0	3	5	8	10	13

When there is a difference between the speeds of the maximum flood and ebb preceding and following the slack for which the duration is desired, it will be sufficiently accurate for practical purposes to find a separate duration for each maximum speed and take the average of the two as the duration of the weak current.

TABLE 8-13–Table 4 (Duration of Slack) from *Tidal Current Tables*

of the speed line equal to the vessel's speed (with a paraline plotter or parallel rules), the diagram will show the general set and drift of the current that would be encountered by any vessel passing through these waters. This diagram also depicts the most favorable time for departing any place shown on the left margin. (Experience suggests that it is easier to use a parallel ruler or paraline plotter if this diagram is removed from the tables and placed on a flat surface.) To determine the set and drift of the current, use the parallel rulers to transfer from the speed lines to the diagram at the left, the direction of the speed line



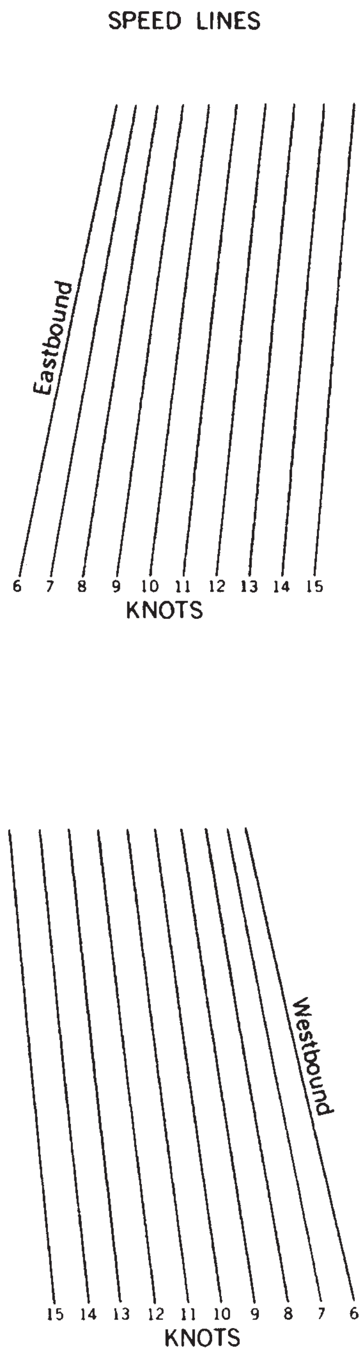


FIG. 8-6–Illustrative *Tidal Current Diagram*

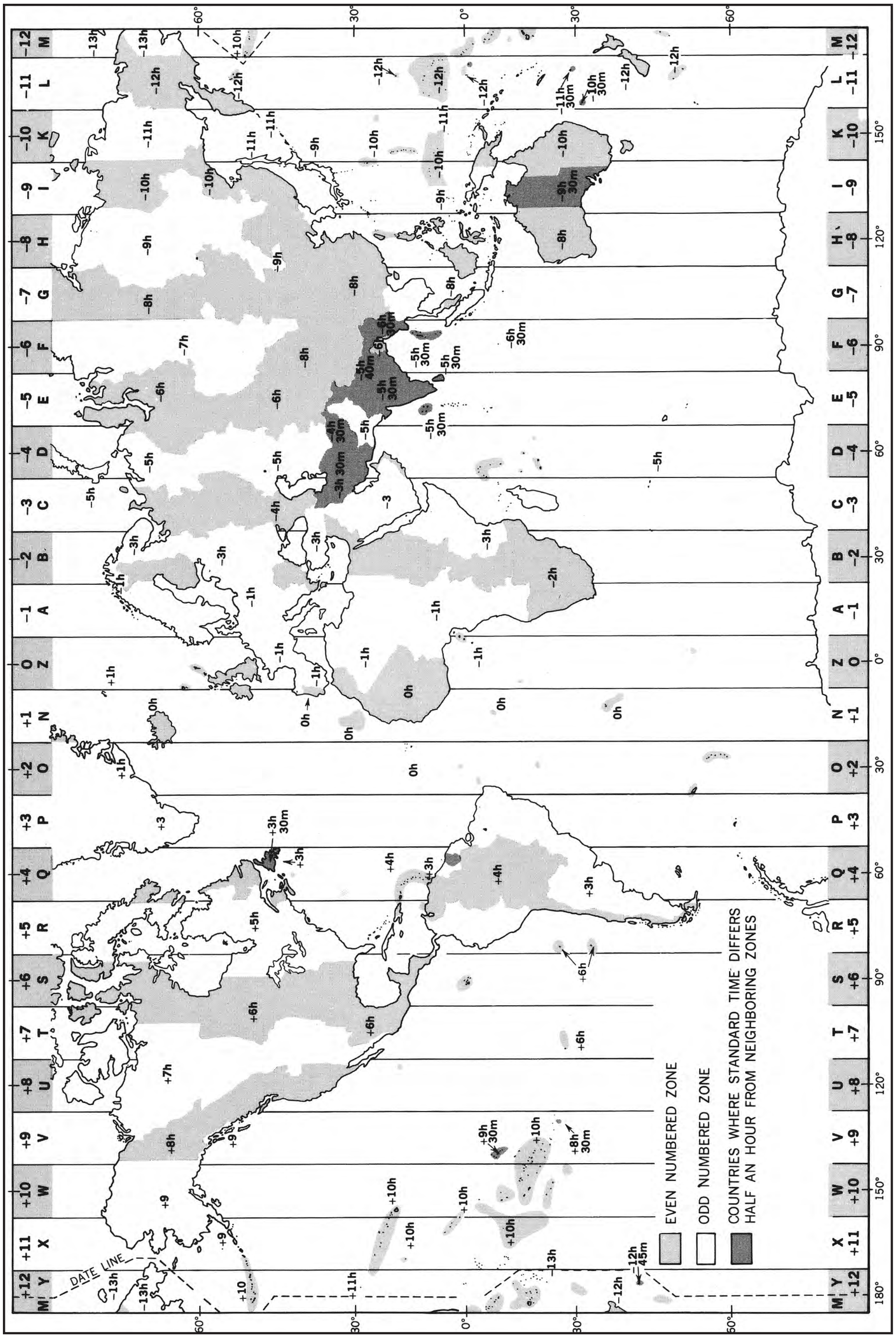


FIG. 8-7–World Time Zone Chart–Source: Bowditch

corresponding to the vessel's speed through the water (STW), moving the edge of the ruler to the point where the horizontal line representing the place of departure intersects the vertical line representing the time of day. If the ruler's edge lies within the shaded portion of the diagram, a flood current will be encountered; otherwise, an ebb current will be encountered. If the ruler's edge lies along the boundary, slack water will be found.

To illustrate, suppose that sportfish *Esplendido*, cruising at 12 knots, enters Pollock Rip Channel at 0800 on 27 February 1999. Reference to the daily predictions (Table 8-8) indicates that the ebb begins at 0656 on this date and flood begins at 1258. The time, 0800, therefore, will be about 1 hour after ebb begins. With parallel rulers, transfer to the diagram the 12-knot speed line "westbound," placing the edge of the ruler on the point where the vertical line "1 hour after ebb begins at Pollack Rip Channel" intersects with the horizontal 47-mile line (the starting point). It will be found that the ruler passes through the unshaded (ebb current) portion of the diagram, the drift averaging approximately 1 knot. *Esplendido* will, therefore, have a favorable ebb current averaging about 1 knot all the way to Gay Head, a welcome consolation after the night's fishing activities.

The most important use of these diagrams is to determine the most advantageous time of departure to maximize fair currents over the intended voyage route. Incidentally, it may not always be possible to ensure fair currents throughout the voyage, even if there is complete flexibility as to starting time. Whether or not a "free ride" is possible depends upon the speed of the vessel (too fast, and it may outrun the following current, too slow, and the current may reverse) and the tidal current patterns at the location in question. For example, it is not possible to ensure a fair current throughout an uninterrupted voyage for southbound vessels transiting the length of the Delaware River.

As noted above, these diagrams represent average conditions. On any day, the currents calculated from the worksheet for Pollack Rip Channel may be larger or smaller than those given in the *Tidal Current Diagram*. The predicted current drift for the day in question can be used to determine approximate correction factors to adjust the averages in the *Tidal Current Diagrams* to the circumstances prevailing on the day when a prediction is required—in which case, a simple ratio can be used.

Differences in the vessel's estimated speed of advance (SOA) as a result of making appropriate use of these diagrams and selecting favorable times of departure can be substantial. For example, ebb currents of as much as 2.4 knots can be encountered in the stretch from East Chop to just west of Tarpaulin Cove. A 12-knot vessel, therefore, could make nearly 14.4 knots if the voyage were perfectly timed, versus only 9.6 knots if an inauspicious time were chosen, a difference of 50 percent in SOA (and fuel economy, as well). These differences could be even more important in the case of slower sailing vessels. A 6-knot vessel could either average 8.4 knots or 4.6 knots, a difference of over 80 percent!

TIDAL CURRENT CHARTS

The last source of tidal current information discussed in this chapter is the Tidal Current Charts. These were published for locations in the United States by NOS for several areas, including Boston Harbor, Narragansett Bay, Narragansett Bay to Nantucket Sound, Block Island and East Long Island Sounds, New York Harbor, Delaware Bay and River, Upper Chesapeake Bay, Charleston Harbor, Tampa Bay, San Francisco Bay, Puget Sound (north), and Puget Sound (south). Now these are no longer published by NOS, although several commercial firms publish smaller versions of these.

Figure 8-7 provides an example, taken from the Narragansett Bay to Nantucket Sound charts. These charts (each a set of charts, really) include a series of 12 copies of a chart of the area covered, superimposed with arrows and numbers to indicate the typical set and drift of the current (at spring tides) for a specific hour in the tidal current cycle for a major reference station. In Figure 8-7, for example, the times are taken with respect to Pollock Rip Channel. Factors are also provided (in the text accompanying these charts) for adjusting the drift estimates from average spring tidal currents to those on the day in question. Therefore, for accurate results, it is necessary to use these charts in conjunction with the *Tidal Current Tables*. (The Narragansett Bay chart, keyed to Newport, Rhode Island, is unique in this series as it is based upon times of tides, rather than tidal currents, and is designed to be used with the *Tide Tables*.)

These charts are most useful for providing a synoptic view of the temporal and spatial distribution of currents—and eliminate an incredible amount of drudgery in making station-by-station computations of current set and drift. Many of the current patterns depicted on these charts are complex—at a given time, currents may be going in one direction in one area, and another just a few miles away. Refer, for example, to the currents in Buzzards Bay and Vineyard South shown in Figure 8-7. As noted below, these diagrams can be used to advantage for determining the best overall routing to follow, the best timing of a voyage, or even, if both the overall route and time are fixed, the specific route that is likely to maximize fair currents or minimize foul currents. Your only complaint after a careful examination of these charts is that one may not be available for the waters where you cruise!

STRATEGIES FOR USING TIDAL CURRENT DATA

This section contains some brief remarks about the use of tidal current information in voyage planning.

- First, it is useful to annotate the voyage-planning chart with the locations for which tidal current predictions are available. Browse through the index found at the back of the tables to identify the potentially relevant locations. In this way, you can identify the available stations that can be used for planning each of the voyage legs. That is, for planning purposes, a different reference station or substation can be used as a surrogate for the current on each leg of the voyage.
- Second, it is useful to make rough computations of the expected currents at various times of day. For this purpose, it is not necessary to make hourly computations, but rather to identify the times and strengths of slack water and maximum tidal current. These approximate calculations are sufficiently accurate for identifying the major timing options of the voyage. For example, it may be apparent that a delay of only a few hours in the start of a voyage offers the advantage of more favorable currents, or that one route option is superior to another in terms of the likely currents at voyage time. Remember that it is the speed with respect to the earth (SMG, SOA) over the course that is important, not the speed through the water (STW). A longer route (in distance) may actually be shorter (in time) than another if the currents are right. In the area of the 1210-Tr chart, a little time spent with the *Tidal Current Tables* or a *Tidal Current Chart* (see Figure 8-7) available for the area will convince you of the proposition that the currents are often flowing in opposite directions in Vineyard Sound, and Buzzards Bay. That is, the currents are generally northeasterly in Buzzards Bay when they are southwesterly in Vineyard Sound and the converse. Starting from a point southwest of Cuttyhunk Island on a voyage to Woods Hole, it might be much faster to go through Buzzards Bay and, later, south to Woods Hole, than to take the shorter route east through Vineyard Sound, depending, of course, on the voyage timing. Reference to the *Tidal Current Chart* also indicates that currents are generally stronger on the north side of Vineyard Sound when these currents are flowing to the southwest. So if Vineyard Sound is selected for the route at the time depicted in the chart, steering a course closer to Martha's Vineyard will result in reduced foul currents on average. Local knowledge gained from experience, or a careful reading of such publications as the USCP (see Chapter 10), helps to establish the importance of currents at various locations and to identify potentially attractive voyage options.

The choice between a longer distance route with fair currents and a shorter distance route with foul currents is easy to evaluate. Let D_1 be the distance (M) on the longer route, X_1 the drift of the fair current along this route, D_2 the shorter distance, X_2 the drift of the foul current, and S the vessel's STW. Given these definitions, it can be shown that the longer distance route will be the shorter time route provided that:

$$D_1/D_2 < (1 + X_1/S) / (1 - X_2/S).$$

Table 8-14 facilitates these computations. To illustrate the use of this formula, approximately one hour after flood begins at Pollock Rip Channel the currents are southwesterly in Vineyard Sound at approximately 1.5 knots and northeasterly in Buzzards Bay at

RATIO OF FOUL CURRENT TO VESSEL'S STW	RATIO OF FAIR CURRENT TO VESSEL'S SPEED THROUGH THE WATER																			
	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38
0.00	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38
0.02	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.27	1.29	1.31	1.33	1.35	1.37	1.39	1.41
0.04	1.04	1.06	1.08	1.10	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.31	1.33	1.35	1.38	1.40	1.42	1.44
0.06	1.06	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.43	1.45	1.47
0.08	1.09	1.11	1.13	1.15	1.17	1.20	1.22	1.24	1.26	1.28	1.30	1.33	1.35	1.37	1.39	1.41	1.43	1.46	1.48	1.50
0.10	1.11	1.13	1.16	1.18	1.20	1.22	1.24	1.27	1.29	1.31	1.33	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.53
0.12	1.14	1.16	1.18	1.20	1.23	1.25	1.27	1.30	1.32	1.34	1.36	1.39	1.41	1.43	1.45	1.48	1.50	1.52	1.55	1.57
0.14	1.16	1.19	1.21	1.23	1.26	1.28	1.30	1.33	1.35	1.37	1.40	1.42	1.44	1.47	1.49	1.51	1.53	1.56	1.58	1.60
0.16	1.19	1.21	1.24	1.26	1.29	1.31	1.33	1.36	1.38	1.40	1.43	1.45	1.48	1.50	1.52	1.55	1.57	1.60	1.62	1.64
0.18	1.22	1.24	1.27	1.29	1.32	1.34	1.37	1.39	1.41	1.44	1.46	1.49	1.51	1.54	1.56	1.59	1.61	1.63	1.66	1.68
0.20	1.25	1.28	1.30	1.33	1.35	1.38	1.40	1.43	1.45	1.48	4.50	1.53	1.55	1.58	1.60	1.62	1.65	1.68	1.70	1.73
0.22	1.28	1.31	1.33	1.36	1.38	1.41	1.44	1.46	1.49	1.51	1.54	1.56	1.59	1.62	1.64	1.67	1.69	1.72	1.74	1.77
0.24	1.32	1.34	1.37	1.39	1.42	1.45	1.47	1.50	1.53	1.55	1.58	1.61	1.63	1.66	1.68	1.71	1.74	1.76	1.79	1.82
0.26	1.35	1.38	1.41	1.43	1.46	1.49	1.51	1.54	1.57	1.59	1.62	1.65	1.68	1.70	1.73	1.76	1.78	1.81	1.84	1.86

TABLE 8-14–When to choose a longer route with fair currents compared to a shorter route with foul currents. Table entries are the ratio of the distances such that the voyage time is the same for both routes. If the actual ratio of distances is less than or equal to the tabulated value, the longer distance route is the shorter time route.

between 0.5 and 0.6 knots. If sailing yacht *Despacio* can make 6.0 knots (STW), under what circumstances would a longer route through Buzzards Bay to Woods Hole require less time? Here, $X_1 = 0.6$ (approximately), $X_2 = 1.5$, and $S = 6.0$, and, therefore, $X_1/S = 0.10$, $X_2/S = 0.25$. Substitution of these values into the above equation shows that the longer distance route is the shorter time route provided that $D_1 < 1.47\ D_2$. In this example, distance D_1 could be nearly 50 percent longer than D_2 and still be the shorter time route. Referring to Table 8-14, read down the column corresponding to $X_1/S = 0.1$ to the row where X_2/S is approximately 0.25. Rows are shown in Table 8-14 for X_2/S equal to 0.24 and 0.26—the corresponding ratios of D_1 to D_2 are 1.45 and 1.49, respectively. Interpolating, the ratio $D1/D_2$ would be 1.47, as determined from the above equation.

The phenomenon of currents going in opposite directions or at different speeds in contiguous waters is not unique to Buzzards Bay/Vineyard Sound. For example, the currents on opposite sides of Whidbey Island in Puget Sound (North) or Vashon Island in Puget Sound (South) exhibit the same patterns.

The computations (referred to above) identify and narrow down the precise times (more accurately, time intervals or "windows") for which more exact current predictions are required or useful. In this more detailed planning phase, you may need or want to make hourly estimates of current. (As a practical matter, these detailed computations are tedious and always subject to numerical error. Just how many computations are made depend upon whether or not a computer is available to automate the computations. Use of the *Tidal Current Charts* or *Tidal Current Diagrams* reduces the computational drudgery if no computer is at hand.) In hazard-strewn waters and in conditions of poor visibility when fixes are not likely to be frequent, hourly computation of currents, estimated positions, and courses to steer (see Chapter 7) might be in order. Alternatively, in open water or if all-weather navigation aids, such as radar or *Global Positioning System* (GPS), are aboard, the use of average currents over a period of several hours might be appropriate.

The navigator should consider the purchase of computer programs

U.S. Naval Observatory
Astronomical Applications Department

Sun and Moon Data for One Day

The following information is provided for New Bedford, Bristol County, Massachusetts (longitude W70.9, latitude N41.6):

```
Saturday
9 June 2001              Eastern Daylight Time

                  SUN
Begin civil twilight       4:36 a.m.
Sunrise                    5:10 a.m.
Sun transit               12:43 p.m.
Sunset                     8:18 p.m.
End civil twilight         8:51 p.m.

                  MOON
Moonrise                  10:44 p.m. on preceding day
Moon transit               3:24 a.m.
Moonset                    8:07 a.m.
Moonrise                  11:26 p.m.
Moonset                    9:04 a.m. on following day
```

Phase of the Moon on 9 June: waning gibbous with 88% of the Moon's visible disk illuminated.

Full Moon on 5 June 2001 at 9:40 p.m. Eastern Daylight Time.

TABLE 8-15–Sunrise, Sunset and Other Information for New Bedford, Massachusetts on 6 June 2001, as Downloaded from the USNO Web Site

to automate the calculation of tide heights or tidal currents. Software that is both powerful and easy to use is now on the market. Use of a computer program speeds up the planning process greatly, and means that many more voyage options can be considered and evaluated. Computers help ensure accuracy as well.

Remember that tidal current predictions are not error free. These predictions should be checked frequently against the vessel's actual progress for voyage decision making.

SUNRISE/SUNSET

It is sometimes of interest to know the times of sunrise and sunset. For example, members of the Coast Guard Auxiliary conduct sunset patrols designed to identify possible distress cases as boaters attempt to start their engines at the end of the day.

There are numerous sources that provide the times of sunrise and sunset. Newspapers often provide this information in their daily weather page(s), as do television stations. Some web sites provide shareware or other calculators for this purpose. For example, the *U.S. Naval Observatory* (USNO) web site

Date		42° N. Rise h. m.	42° N. Set h. m.	44° N. Rise h. m.	44° N. Set h. m.
Jan.	1	07 28	16 39	07 35	16 33
	6	07 28	16 44	07 35	16 38
	11	07 27	16 49	07 33	16 43
	16	07 25	16 55	07 31	16 49
	21	07 22	17 01	07 28	16 55
	26	07 18	17 07	07 24	17 02
	31	07 14	17 14	07 19	17 09
Feb.	5	07 09	17 20	07 13	17 16
	10	07 03	17 26	07 06	17 23
	15	06 56	17 33	06 59	17 30
	20	06 49	17 39	06 52	17 36
	25	06 41	17 45	06 44	17 43
Mar.	2	06 34	17 51	06 35	17 50
	7	06 25	17 57	06 27	17 56
	12	06 17	18 03	06 18	18 02
	17	06 09	18 09	06 09	18 09
	22	06 00	18 14	06 00	18 15
	27	05 51	18 20	05 51	18 21
Apr.	1	05 43	18 26	05 42	18 27
	6	05 34	18 31	05 33	18 33
	11	05 26	18 37	05 24	18 39
	16	05 18	18 42	05 15	18 45
	21	05 10	18 48	05 07	18 51
	26	05 03	18 53	04 59	18 57
May	1	04 56	18 59	04 52	19 03
	6	04 50	19 04	04 45	19 09
	11	04 44	19 09	04 39	19 15
	16	04 39	19 15	04 33	19 20
	21	04 34	19 20	04 28	19 26
	26	04 30	19 24	04 24	19 31
	31	04 27	19 28	04 21	19 35
June	5	04 25	19 32	04 18	19 39
	10	04 24	19 35	04 17	19 42
	15	04 24	19 37	04 16	19 45
	20	04 24	19 39	04 17	19 46
	25	04 26	19 40	04 18	19 47
	30	04 28	19 39	04 20	19 47
July	5	04 30	19 38	04 23	19 46
	10	04 34	19 37	04 27	19 43
	15	04 38	19 34	04 31	19 40
	20	04 42	19 30	04 36	19 36
	25	04 47	19 26	04 41	19 32
	30	04 51	19 21	04 46	19 26

TABLE 8-16–Excerpt from Table 4 ("Local Mean Times of Sunrise and Sunset") of *Tide Tables*

(http://aa.usno.navy.mil/AA/data) offers an easy-to-use calculator that requires entering only the desired city, state, and date. This calculator provides the times of sunrise, sunset, moonrise and moonset among other information. Table 8-15 provides illustrative output from the USNO calculator for 6 June 2001 at New Bedford, Massachusetts. The times for sunrise and sunset are 5:10 a.m. and 8:18 p.m., respectively. This calculator keeps track of daylight savings time as well. Other web sites that offer sunrise or sunset calculations include (http://www.suncreations.com/sun.html/) and that maintained by Australia's National Mapping Agency(http://www.auslig.gov.au/geodesy/astro/sunrise. htm).

Many computer programs for estimation of tides or tidal currents also calculate the times of sunrise and sunset as an added feature. Times of sunrise and sunset can also be calculated (albeit, from a more laborious process) from information provided in Tables 4 ("Local Mean Times of Sunrise and Sunset") and 5 ("Reduction of Local Mean Time to Standard Time") supplied in the *Tide Tables*. Table 8-16 (in this text) provides an excerpt from Table 4, and Table 8-17 (in this text) reproduces Table 5 of the *Tide Tables*.

As shown in Table 8-16, the *Tide Tables* provide the local mean times of sunrise and sunset in 5-day increments for various latitudes, North or South. For most purposes, it is not necessary to interpolate either dates or latitudes. Rather, enter these tables to the nearest date or latitude. However, the times given in the *Tide Tables* are local mean times, not standard times, and it is necessary to convert from one to the other.

Local mean times are referenced to a particular meridian of longitude. At any instant, the local mean times differ for each distinct meridian of longitude. However, it would be inconvenient to have to reset watches whenever moving from one meridian of longitude to another. To simplify matters, 24 *standard time* zones have been established throughout the world, corresponding to the length of the solar day. As a historical footnote, it was the introduction of railroads that created a need for common time units—prior to the 1840s, many communities kept "local time"—which was inconvenient for creating train schedules. *Greenwich Mean Time* (GMT)—one of the 24 time zones—was adopted in the United States at noon on 18

Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time	Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time	Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time
° ′ ° ′	Minutes	° ′ ° ′	Minutes	°	Hours
0 00 to 0 07	0	7 23 to 7 37	30	15	1
0 08 to 0 22	1	7 38 to 7 52	31	30	2
0 23 to 0 37	2	7 53 to 8 07	32	45	3
0 38 to 0 52	3	8 08 to 8 22	33	60	4
0 53 to 1 07	4	8 23 to 8 37	34	75	5
1 08 to 1 22	5	8 38 to 8 52	35	90	6
1 23 to 1 37	6	8 53 to 9 07	36	105	7
1 38 to 1 52	7	9 08 to 9 22	37	120	8
1 53 to 2 07	8	9 23 to 9 37	38	135	9
2 08 to 2 22	9	9 38 to 9 52	39	150	10
2 23 to 2 37	10	9 53 to 10 07	40	165	11
2 38 to 2 52	11	10 08 to 10 22	41	180	12
2 53 to 3 07	12	10 23 to 10 37	42		
3 08 to 3 22	13	10 38 to 10 52	43		
3 23 to 3 37	14	10 53 to 11 07	44		
3 38 to 3 52	15	11 08 to 11 22	45		
3 53 to 4 07	16	11 23 to 11 37	46		
4 08 to 4 22	17	11 38 to 11 52	47		
4 23 to 4 37	18	11 53 to 12 07	48		
4 38 to 4 52	19	12 08 to 12 22	49		
4 53 to 5 07	20	12 23 to 12 37	50		
5 08 to 5 22	21	12 38 to 12 52	51		
5 23 to 5 37	22	12 53 to 13 07	52		
5 38 to 5 52	23	13 08 to 13 22	53		
5 53 to 6 07	24	13 23 to 13 37	54		
6 08 to 6 22	25	13 38 to 13 52	55		
6 23 to 6 37	26	13 53 to 14 07	56		
6 38 to 6 52	27	14 08 to 14 22	57		
6 53 to 7 07	28	14 23 to 14 37	58		
7 08 to 7 22	29	14 38 to 14 52	59		

If local meridian is east of standard meridian, subtract the correction from local time.

If local meridian is west of standard meridian, add the correction to local time.

For differences of longitude less than 15° , use the first part of the table. For greater differences use both parts thus: 47° 23′ is equivalent to 45°+ 2° 23′, the correction for 45° is 3 hours, the correction for 2° 23′ is 10 minutes; therefore the total correction for the difference in longitude 47° 23′ is 3 hours and 10 minutes.

TABLE 8-17–Reproduction of Table 5 (“Reduction of Local Mean Time to Standard Time”)

Date: ______________	Location: _______________	Basic inputs to problem
Latitude: ____________	Longitude: ______________	From Table 2 of *Tide Tables*
Nearest Date: ________	Nearest Lat: _____________	From Table 4 of *Tide Tables*
Time of sunrise/sunset at nearest date and Lat: __________		From Table 4 of *Tide Tables*
Longitude of time meridian:	____________	From Table 2 of *Tide Tables*
Local meridian:	____________	From line 2 above
Difference in longitude:	____________	See below
Correction to Local Mean Time for difference In longitude between time meridian and Position (local meridian):	____________	From Table 5 of *Tide Tables*
Time of sunrise or sunset at position:	____________	Addition/subtraction (see below)
For daylight savings time, add one hour:	____________	As necessary

Notes:

- In the Western Hemisphere, if the position longitude is east of the longitude of time meridian (i.e., if the position longitude is less than the longitude of time meridian), subtract the position longitude from the longitude of time meridian. If the position longitude is west of the longitude of time meridian (i.e., if the position longitude is greater than the longitude of time meridian), subtract the longitude of time meridian from the position longitude.
- If local meridian is east of the standard meridian, subtract the time correction from local mean time. If local meridian is west of the standard meridian, add the time correction to the local mean time.
- Do not interpolate date or latitude given in Table 4 of *Tide Tables*, simply choose the nearest date and latitude.

TABLE 8-18–Worksheet for Estimating the Time of Sunrise or Sunset

Date: 06/09/01	Location: New Bedford, MA	Basic inputs to problem
Latitude: 41° 38' N	Longitude: 70° 55' W	From Table 2 of *Tide Tables*
Nearest Date: 06/10/01	Nearest Lat: 42° N	From Table 4 of *Tide Tables*
Time of sunrise/sunset at nearest date and Lat:	0424	From Table 4 of *Tide Tables*
Longitude of time meridian:	75° 00' W	From Table 2 of *Tide Tables*
Local meridian:	70° 55' W	From line 2 above
Difference in longitude:	4° 05'	See below
Correction to Local Mean Time for difference In longitude between time meridian and Position (local meridian):	0016	From Table 5 of *Tide Tables*
Time of sunrise or sunset at position:	0408	Addition/subtraction (see below)
For daylight savings time, add one hour:	0508	As necessary

Notes:

- In the Western Hemisphere, if the position longitude is east of the longitude of time meridian (i.e., if the position longitude is less than the longitude of time meridian), subtract the position longitude from the longitude of time meridian. If the position longitude is west of the longitude of time meridian (i.e., if the position longitude is greater than the longitude of time meridian), subtract the longitude of time meridian from the position longitude.
- If local meridian is east of the standard meridian, subtract the time correction from local mean time. If local meridian is west of the standard meridian, add the time correction to the local mean time.
- Do not interpolate date or latitude given in Table 4 of *Tide Tables*, simply choose the nearest date and latitude.

TABLE 8-19–Numerical Example of Use of Time Worksheet

November 1883 when the telegraph lines transmitted time signals to all major cities. Prior to that, there were over 300 local times in the United States!

It may seem surprising today, but the introduction of standard time in the United States was very controversial, as related in an interesting book by O'Malley, (1990). O'Malley relates an apocryphal story told by a union leader about an Irishman who asked a train conductor at what time the train departed. When told by the conductor "8 o'clock, standard time", the Irishman complained about use of "standard time" (a reference in his mind to Standard Oil Co.) and noted "They'll be gittin' the wind next, they've got the time now."

GMT was adopted universally in 1884 when the International Meridian Conference met in Washington, DC. After this conference, the International Date Line was established and 24 time zones created. For additional details, see the Greenwich Observatory's web site (http://greenwichmeantime.com/info/gmt.htm) or that maintained by NASA (http://liftoff.msfc.nasa.gov/Academy/Rocket_Sci/clocks/time-gmt.html/). Coordinated Universal Time (UTC) replaced GMT as the World standard in 1986. It is based on atomic measurements rather than the earth's rotation.

Figure 8-7 shows these 24 zones—one for each 360/24 = 15 degrees of longitude. Each is given a separate alphabetical designator. "Z" (Zulu or GMT) is the standard time zone that applies (on the water, at least) to the area of the globe between 7.5° East and 7.5° West. As a second example, "R" (Romeo, or *Eastern Standard Time* [EST]) applies between 67.5° West and 82.5° West and is the standard time zone for the Eastern United States. The numbers on the bottom of Figure 8-7 show the number of hours that each time zone differs from GMT. Consider the Romeo time zone, for example, the number given "+5" is the number of hours to be added to Romeo time to calculate GMT. Thus, if the Romeo time is 1400, the GMT is 1900.

Time zones on land do not match these zones exactly but, rather, tend to follow political boundaries between nations or subdivisions of nations. Land time zones are also depicted in Figure 8-7. For most countries, these are in even hours, but there are several exceptions.

In order to convert local mean time (the time given in the *Tide Tables*) to standard time, it is necessary to adjust for the time (hence, longitude) difference between the local meridian (i.e., the meridian corresponding to the location desired) and the appropriate standard time meridian. Standard time meridians for each of the stations listed in the *Tide Tables* can be found in Table 2 of these tables. For example, consider New Bedford, Massachusetts. Here is how to calculate the estimated time of sunrise on 9 June 2001. First, refer to the index to stations in the back of the *Tide Tables* to determine the station (1133) corresponding to New Bedford, Massachusetts. From Table 2 of the *Tide Tables,* the latitude of this station is 41° 38' N. Refer now to Table 4 of the *Tide Tables* (Table 8-16 of this text) to find the local mean time of sunrise or sunset for the closest date and latitude (42° N on 10 June), 0424. Write down the relevant information (date, location, latitude, nearest date, nearest latitude, and time of sunrise/sunset at nearest date and latitude) on the worksheet for estimating the time of sunrise or sunset (Table 8-19).

Referring to station 1133 in Table 2 of the *Tide Tables* indicates that the longitude of this station is 70° 55' West and that the standard time meridian for this location is 75° West (the Romeo time zone).

The longitude of New Bedford (70° 55' W) is farther east than the longitude of the standard time meridian (75° 00' W). Therefore, local time at New Bedford is *later than* that of the standard meridian. The adjustment for the difference in longitudes (75° 00' – 70° 55' = 4° 05') must correct by subtracting the time adjustment. How much time should be subtracted? Table 5 ("Reduction of Local Mean Time to Standard Time"), which is reproduced in Table 8-17 provides this answer. Enter this table with the difference of longitude between local and standard meridian, 4° 05' in this example, to find the time correction in minutes or hours. The time adjustment read from Table 8-17 is 16 minutes. Standard time is 16 minutes earlier than local time. Completing the example, the standard time of sunrise in New Bedford is the local time of sunrise, 0424, less 16 minutes, or 0408. All times are given as standard times and must be converted to daylight times for the period when daylight time is in effect. Therefore, sunrise is estimated to occur one hour later, at 0508. This estimate is quite close to that determined from the USNO calculator.

To facilitate use of the *Tide Tables* for estimating times of sunrise and sunset, Table 8-18 provides a worksheet suitable for reproduction. Each entry and computation is explained in Table 8-18. Table 8-19 shows this worksheet filled in for the example presented above. Estimation of the times of sunrise or sunset from the *Tide Tables* is not difficult. However, it is very much more convenient to read the newspaper or access the web sites listed above.

SELECTED REFERENCES

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA) Marine Navigation Department web site (http://www.nima.mil/).

Defant, A., (1958). *Ebb and Flow, The Tides of Earth, Air, and Water,* University of Michigan Press, Ann Arbor, MI.

Eldridge Tide and Pilot Book, (1999). Marion Jewett White, Robert Eldridge White, Jr., Linda Foster White, Publishers, Boston, MA.

Graves, F., (1981). *Piloting,* International Marine Publishing Co., Camden, ME.

Hinz, E., (1986). *The Complete Book of Anchoring and Mooring,* Cornell Maritime Press, Centreville, MD.

Lighthouse Press, (1998). *Tide Tables 1999 High and Low Water Predictions East Coast of North and South America, Including Greenland,* Lighthouse Press, Marina Del Rey, CA.

Maloney, E. S., (1985). *Chapman Piloting, Seamanship and Small Boat Handling,* Hearst Marine Books, New York, NY.

Markell, J., (1984). *Coastal Navigation for the Small Boat Sailor,* TAB Books Inc., Blue Ridge Summit, PA.

Mays, J. (1987). Thorough and Versatile Tide Prediction by Computer, *Sea Technology*, May 1987.

Nobeltec/Nautical Software, (1996). *Tides & Currents for Windows®, Version 2.0 Users Guide, 3rd Edition,* Nautical Software, Beaverton, OR.

O'Malley, M. (1990). *Keeping Watch, a History of American Time*, Viking Penguin, New York, NY.

Reed's *Nautical Almanac, North American East Coast 1999,* Thomas Reed Publications Inc., Boston, MA. 1998.

Wylie, F. E., (1979). *Tides and the Pull of the Moon,* The Stephen Greene Press, Brattleboro, VT.

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CHAPTER 9

RADIONAVIGATION

"The winds and waves are always on the side of the ablest navigators."

–Edward Gibbon (1737-1794)

"None so blind as those that will not see."

–Matthew Henry (1662-1714)

INTRODUCTION

At several points in this text, "revolutionary developments" in marine navigation systems are mentioned. Nowhere is evidence of this revolution more dramatic than in the area of radionavigation systems. In years past, small boat skippers were lucky to own a crystal controlled marine radio, capable of transmitting on only four or five channels, and a *radio direction finding* (RDF) set. *Dead reckoning* (DR) positions were typically checked using visual piloting techniques for coastal voyages and celestial fixes for blue water trips. Both radar and loran were bulky, expensive, and limited, for the most part, to merchant vessels and naval ships.

Now, advances in the state-of-the-art of electronics and computers have enabled the manufacture of miniaturized and much less expensive components. Navigation receivers, for example, have decreased in price to levels well within reach of the average boater and have become very much more sophisticated and user friendly.

Additionally, advances in computers have resulted in navigation systems that do many of the tasks formerly done exclusively by the navigator. A modern navigation receiver can do much more than provide a continuous display of latitude and longitude. It can calculate *speed made good* (SMG), *course made good* (CMG), current set and drift, *cross-track error* (XTE), course to steer to reach an intended destination, *time-to-go* (TTG) to reach the destination, and can sound an alarm to warn of arrival. Navigation receivers can share data with radar, autopilot, and computer charting systems for a variety of purposes that would amaze even a merchant marine skipper of 20 years ago.

This chapter provides an introduction to these systems.

Constraints on length and scope limit the discussion to only the most important systems: Loran-C, the *Global Positioning System* (GPS), *Differential GPS* (DGPS), *Wide Area Augmentation System* (WAAS), and radar. Readers interested in more details about these systems, and others not covered in this chapter, should consult the extensive references provided at the end of this chapter.

Radionavigation sets made by different manufacturers share many features, but also differ considerably in other features and details of operation. For this reason, it is impossible to write a single chapter that *explains how to use specific models*. Even if size constraints on this chapter did not prevent a model-by-model discussion, the rapid pace of innovation would quickly render this text obsolete. Rather, this chapter describes the *general principles* of operation of the radionavigation system and common features of sets now in general use. In short, this chapter is not an owner's manual, but serves as a complement or introduction to that document.

Care has been taken in this chapter to avoid excessively technical descriptions. Most mariners, for example, are uninterested in the particular frequency of operation, pulse length, beam width, etc., except insofar as this information is required to understand the use and limitations of the equipment. Again, look to the references at the end of this chapter for these details.

Despite simplification, this is one of the longest and most technical chapters in the *Advanced Coastal Navigation* (ACN) course. It may require reading and rereading to ensure that the concepts are understood. Don't give up. This is important material. Even if you don't own any of this equipment at present, you probably will in the near future.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ***Principles of operation of Loran-C, GPS, and DGPS***
- ***How to use a navigation receiver for coastal piloting***
- ***Principles of operation of radar***
- ***Use of radar for collision avoidance and navigation***
- ***How to plot radar targets***

Equipment Selection—A Brief Digression

Students often ask ACN instructors for specific recommendations on makes and models of radionavigation equipment. The *United States Coast Guard Auxiliary's* (USCGAUX) general policy is to discuss desirable features of equipment, but not to endorse specific products. Here are a few general observations that might prove useful:

- Unless you use this equipment very frequently, simplicity and ease of installation and use are likely to be much more important than advanced features.
- Choose equipment that has easy-to-read (large numerals) and intuitive displays. The need to maintain a proper lookout and complete other necessary tasks means that you may have only a few seconds to read and interpret navigational displays.
- Make sure that it is easy to use the keyboard to enter data, change displays, or perform other functions. Keys that are well separated and offer tactile feedback help to reduce data errors. Remember that you may have to use the keyboard in various circumstances (e.g., heavy seas).
- Reliability and ruggedness should be prized. Unfortunately, it is difficult to learn whether a particular model is reliable. There are several magazines that offer relatively objective product reviews for radionavigation equipment. Lack of reliability during the product test (if observed) should be an important consideration in the ratings.
- Consider the quality of the owner's manual as one of the most important product features. Many manufacturers attach a high priority to novel technical features yet fail to produce understandable manuals. Model-specific instructional videotapes are produced and sold for many products. If clear and easy to follow, the instructional videotape can substitute for a weak owner's manual.
- There are many benefits to interconnection of electronic equipment. Most GPS receivers, for example, have the ability to pass

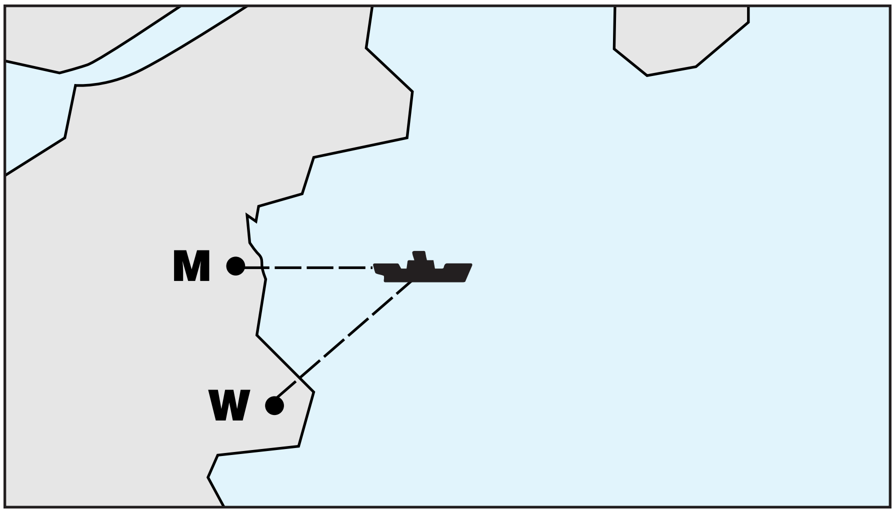


FIG. 9-1–Master and Secondary

information to a radar unit, so that bearings and distances to waypoints, speed, and distance can be displayed on the radar screen. Likewise, navigation receivers can provide information to an electronic charting system, so that the intended track and vessel's actual position can be displayed on a chart facsimile.

Standard protocols (connections) have been devised to enable various units to interchange information. In theory, these work. However, it is generally easier to interconnect units (of the same vintage) made by the same manufacturer. Therefore, it may be worthwhile to try to standardize on one manufacturer in purchasing an electronic system—even if this means that you make trade-offs with respect to individual units. In any event, check with the manufacturers to ensure that the components will be fully compatible.

- ❑ The size and shape of units should fit conveniently in the space available on the bridge. Equipment should be laid out in a logical way to facilitate use. Take care that equipment bulk and placement do not create blind spots that impair your ability to maintain a proper lookout.
- ❑ Although not a criterion for equipment selection, it is appropriate to add another point here: make sure that when you add, change, or remove electronics from your bridge, you swing ship and build a new compass deviation table. Changes to equipment and wiring may affect the deviation table. Also consider making two deviation tabels, one which applies when the electronic equipment is on and another when off.

CHAPTER ORGANIZATION

The chapter presents information on Loran-C and GPS/DGPS/WAAS, followed by material on radar. Because navigation receivers for Loran-C and GPS are very similar from a user perspective (although different internally), the principles of operation of Loran-C and GPS/DGPS/ WAAS are discussed first. Following this discussion, the use of these systems for coastal navigation is explained. Finally, use of radar for navigation and collision avoidance is covered.

LORAN-C

Loran, an acronym for *Long-Range Navigation*, is a highly reliable and accurate long-range navigation system. It was an outgrowth of military research during the 1930s in England and, later, in the United States. The first practical system for civilian maritime navigation (later termed Loran-A) was replaced by Loran-C during the 1970s. The Loran-C system will ultimately be replaced by GPS. The U.S. Government has indicated that adequate notice will be provided in

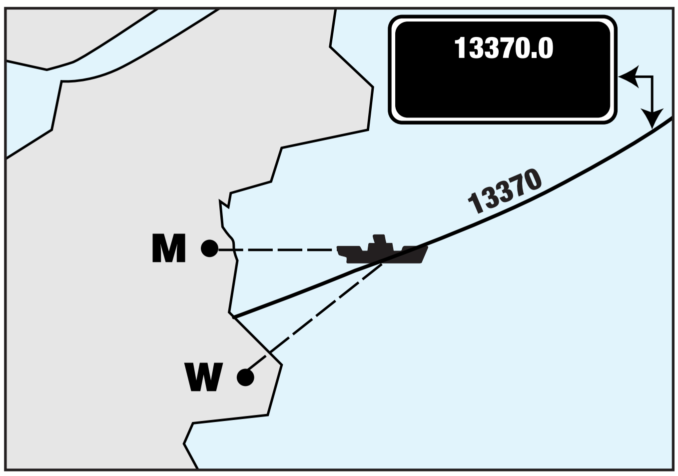


FIG. 9-2–Loran LOP

PHOTO COURTESY OF RAYTHEON MARINE CO.

Integrated GPS/Loran-C Navigation Receiver. Note CDI at top of display.

advance of closure of the Loran-C system.

Loran-C coverage includes virtually the entire United States to a distance offshore of approximately 1,000 nautical miles. There are, however, offshore areas without adequate Loran-C coverage at distances considerably less than 1,000 miles from the U.S. coast. *Coverage Diagrams* are published showing the areas where Loran-C can be used effectively. Other countries also operate loran systems. The absolute accuracy (see below) of Loran-C is between 0.1 and 0.25 nautical miles. Loran-C repeatable accuracy is much greater.

Loran-C Principle of Operation I

In simplified form, Loran-C operates as follows. It consists of two components, an onboard navigation receiver and a chain of three to five land-based transmitting stations (maintained in the United States by the *United States Coast Guard* (USCG)), generally separated by several hundred miles. The onboard receiver can be “tuned” (placed in quotation marks because the tuning principle differs from selection of a frequency) to receive the transmissions from all stations in the chain.

One station in the chain is designated the *master* (denoted by the symbol M), and the remaining two to four stations are designated *secondaries* (denoted by the letters W, X, Y, and Z). The master transmits a signal (actually a complex pulse), followed at predetermined intervals by a transmission from each of the secondaries. The onboard receiver measures the slight *time difference* (TD) required for these separate signals to reach the vessel.

Figure 9-1 (taken from the *Loran-C User Handbook* published by the USCG) illustrates two stations from a hypothetical chain, the master (M) and the whiskey (W) secondary. The TD between arrival of the signals from the master and any of the secondary stations is typically very small, and measured in millionths of a second, designated microseconds, and abbreviated µsec. (Radio waves propagate at essentially the speed of light, 161,829 nautical miles per second. At this speed, it requires approximately 6.179 µsec for the signal to travel one nautical mile.) Modern loran receivers can measure TDs to within 0.1 µsec.

In the illustration in Figure 9-2 the measured TD is 13,370 µsec (shown in the upper right hand corner) and, therefore, the vessel lies somewhere along the 13,370 LOP. This LOP is curved rather than a straight line, because (mathematically) the locus of points located a constant difference in distance between two points is a hyperbola. For this reason loran is sometimes called a *hyperbolic system*. However, on larger scale charts the apparent curvature is very slight.

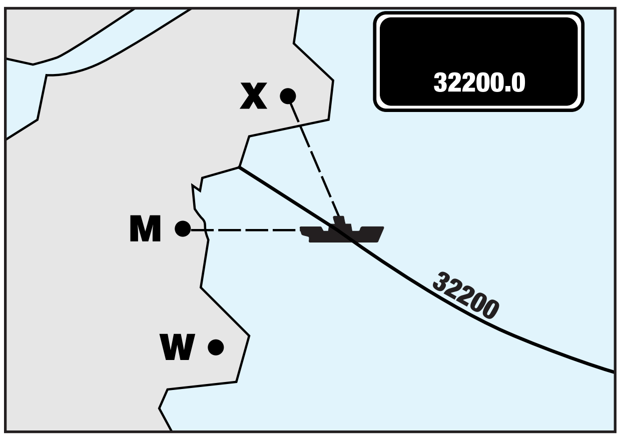


FIG. 9-3–Another Loran LOP

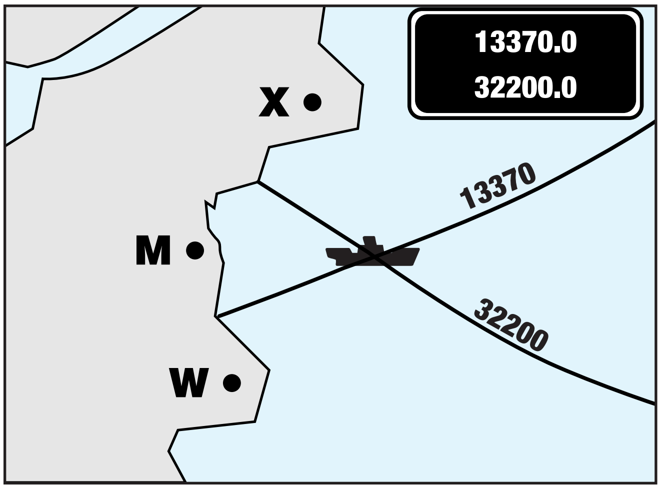


FIG. 9-4–Loran fix determined by TDs

Now, suppose another similar TD measurement is taken between the arrival times for the signals from the master and the Xray secondary, as illustrated in Figure 9-3. The measured TD, 32,200 µsec, is displayed in the receiver, indicating that the vessel lies somewhere along the 32,200-µsec LOP. The intersection of these two LOPs fixes the vessel's position as shown in Figure 9-4. In a similar manner, the TDs for the other master-secondary combinations also determine LOPs and can be used to determine a fix, as well. (Signal strength, crossing angles, and other factors determine the best station pair for position determination.) According to the chart labeling conventions discussed in Chapters 5 and 6, a Loran-C fix is symbolized with a circle enclosing a dot with the word "LORAN" and the time (four-digit, 24-hour time) written next to the fix symbol.

Loran-C Principle of Operation II

(This section is more technical and can be skipped without loss of continuity.) Unlike many other navigation systems that use discrete frequencies for different stations, all loran chains transmit on the same frequency in the low frequency band, 100-kilohertz (kHz). At this frequency, radio is not limited to line of sight, and reception ranges of hundreds of miles are possible. To prevent interference between stations, each chain employs a different time sequence of transmissions, termed the *Group Repetition Interval* (GRI). In the Loran-C chains, these intervals are between 40,000 and 99,990 µsec. The chain designations are four-digit numbers derived from the repetition interval by dividing by ten, e.g., the group repetition interval of the Northeast Chain is 99,600 µsec, so this chain is designated GRI 9960.

The Loran-C chains, their designations, and coverage data can be found in the *Loran-C User Handbook,* Publication 117, of the *Defense Mapping Agency* (DMA) (now the *National Imagery and Mapping Agency* [NIMA]), and other sources. For example, Figure 9-5 shows the location and coverage of the Northeast U.S. chain. For this chain, the master is located in Seneca, NY, and the secondary stations are located in Caribou, ME (Whiskey), Nantucket, MA (Xray), and Carolina Beach, NC (oddly enough, Yankee). Two criteria, a minimum *signal-to-noise* (S/N) ratio and an accuracy specification, define the coverage area enclosed by the dotted lines in Figure 9-5. The accuracy criterion used for this coverage diagram requires that 95 percent of the fixes determined should be within 0.25 nautical mile.

The transmission sequence

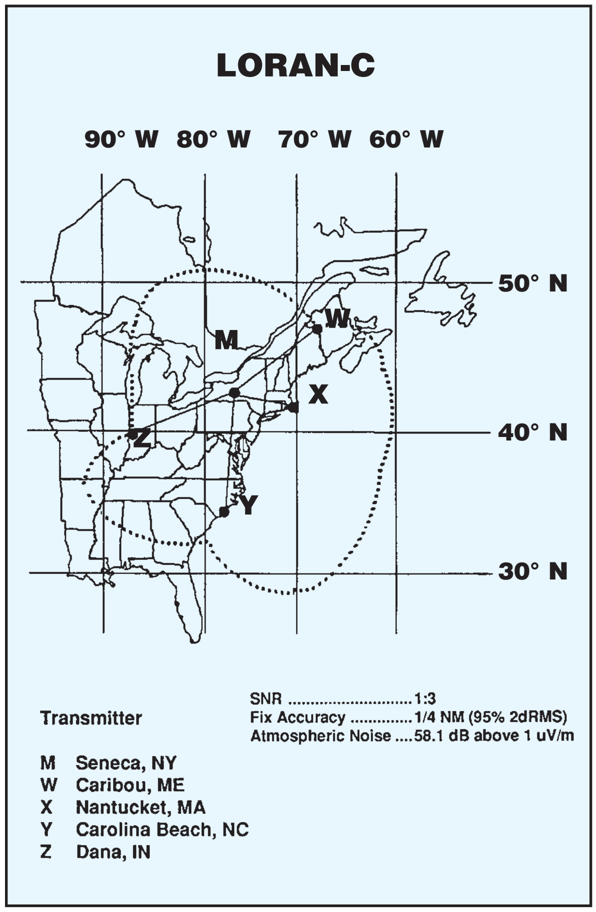


FIG. 9-5–GRI 9960, The Northeast U. S. Loran-C chain

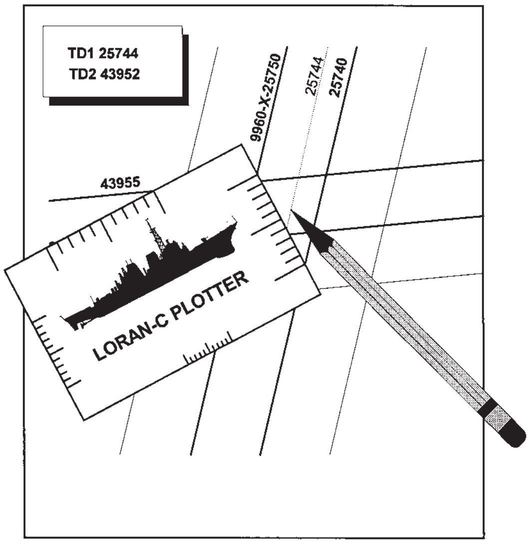


FIG. 9-6–Use of LORAN Interpolator to Plot Position

operates as follows. First, the master station transmits a signal (actually a series of pulses). Next, after receiving the master signal, one of the secondary stations transmits. But, to allow time for the signal from the master to propagate through the coverage area, the secondary station delays its transmission by a prespecified length of time termed the *secondary coding delay* (SCD). The SCD for each station in each chain can be read from a loran coverage diagram, published in the *Loran-C User Handbook*. For the Northeast U.S. chain, the SCD is 11,000 µsec, for example. In turn, after another coding delay, the third station in sequence transmits, etc., until the transmission cycle is completed. The process is initialized again with the transmission of the master. The GRI is selected so as to avoid overlap with other chains using the same frequency.

Computation of the expected time difference between the arrival of the signal from the master and that from one of the secondaries is illustrated as follows. Suppose that your vessel is located at latitude 41° 20' N and longitude 71° 20' W, approximately seven miles south of Newport Neck on the 1210-Tr chart, and that the receiver is set to receive the 9960 chain. The master station at Seneca, NY, is located approximately 258 miles from this assumed position (great circle computation), so the signal from the master will require approximately 6.18 µsec/M x 258M = 1,594 µsec to reach the onboard receiver. (Strictly speaking, radio waves propagation differences over land and seawater should be accounted for, but these are omitted in this illustration.)

The distance between the master and Whiskey station in Caribou, ME, is approximately 451 miles, equivalent to a time delay of 2,787 µsec (i.e., 6.18 µsec/M x 451M = 2,787 µsec). The secondary station transmits after an 11,000-µsec SCD (given in the *Loran-C User Handbook*). The secondary station in Caribou, ME, is approximately 360 nautical miles from the assumed position, and, therefore, it will take an additional 6.18 µsec/M x 360 M = 2,225 µsec for the secondary signal to reach the assumed position.

The loran receiver measures the TD between the arrival of the master signal and the secondary signal, or 2,225 + 11,000 + 2,787 - 1,594 = 14,418 µsec in this example. Aside from rounding errors and slight corrections to allow for variations in signal propagation speed as a result of variations in terrain and other factors, the onboard loran should record this TD for the Whiskey secondary if located at the assumed position.

Examination of the 1210-Tr chart shows that the assumed position is located almost exactly on the 14,420 µsec TD contour, shown in light blue, so this approximate calculation is remarkably accurate.

Loran Overprinted Charts

Many nautical charts (e.g., the 1210-Tr) of coastal scale or smaller are *overprinted* with the loran TD contours shown as faint gray, light blue, or magenta lines with the GRI, station, and µsec printed somewhere along the contour. (Harbor charts usually do not come with loran overprinting.) The TD contours are typically printed at convenient intervals. On the 1210-Tr chart, for example, these are printed at 5- or 10-µsec intervals. Obtaining a position from the loran receiver entails reading the TD display from the navigation receiver, noting the TDs, and locating their position on the chart. Options differ, but most loran receivers automatically select the best GRI and the best two TDs for use. Users wishing to select a different GRI or master-secondary pair can override the automatic feature and select these manually. The specific TDs being displayed by the loran are generally obvious from inspection of the magnitude of the TDs. However, most sets have the capability of displaying these directly, typically on a different *page* of the electronic display. (Because navigation receivers can provide so much data, the display would be impossibly crowded if all were displayed simultaneously. Therefore, the data are segmented into several possible displays, each on one or more pages. A switch on the receiver enables any page to be selected.)

Interpolation of TDs (i.e., position location for TDs between those printed on the contour lines) can be done by eye or, for more precision, by using the interpolator printed on the chart or available as a separate plastic or cardboard overlay. Figure 9-6 shows the use of a Loran-C plotter. In this example, it is desired to plot the vessel's position as measured by the Xray TD 25,744. Contours are overprinted on the chart for 25,740 and 25,750 (shown as 9960-X-25750), respectively. The plotter is aligned so that both ends of the 10-unit scale are placed on the neighboring TD contours. A pencil marks the point 4/10ths along this line. This procedure is repeated at another location and the dots connected to produce a 25,744 contour.

As noted above, Loran-C TD contours are printed on many nautical charts. The accuracy of location of these contours is generally quite high. All nautical charts are not identically accurate, however. With older charts, the location of the TD contours is determined by a slight variation of the simple calculation illustrated above to account for differences in the speed of the propagated signal over land versus water. In such cases, a disclaimer is written on the chart: "the lines of position shown have been adjusted based on theoretically determined overland signal propagation delays. They have not been verified by comparison with survey data." This is exactly the wording on the 1210-Tr chart, for example.

However, in some cases survey data are available, and more sophisticated adjustments are possible. For charts that have these additional adjustments included, the disclaimer is reworded: "the lines of position shown here have been adjusted based on survey data." TD contours are located with more accuracy if adjusted based upon survey data, and so, generally speaking, these charts are more accurate.

It is noted above that harbor charts are not overprinted with TD contours. One important reason why this is so is that the corrections for signal propagation are more complex and variable for nearshore areas than for outlying areas. Additionally, the requirements for navigational accuracy when operating in restricted waterways are often greater than the 0.1 to 0.25 nautical mile accuracy advertised for loran.

Unless the user has a loran with the capability to automatically convert from TDs to latitude and longitude (most do) or has visited the harbor before and noted the TDs corresponding to key features of navigational interest (e.g., buoys, channels, anchorages, etc.), the lack of loran TD overprinting prevents the use of loran for navigation within harbors. Even if the onboard receiver has the capability to display latitude and longitude directly, there are many experienced navigators who would argue that this feature should not be used because of the possible inaccuracy in the TD to lat./lon. conversion in harbor areas. Although this cautious advice is certainly conservative, it overlooks the possible benefits of loran use in

A USEFUL WORLD WIDE WEB ADDRESS

USCG operates a very useful website for users of electronic navigation systems. The site address is http://www.navcen.uscg.gov. The site provides a wealth of information about navigation systems (including Loran-C, GPS, and DGPS) and their status. This site also contains all the Notice Advisories to NAVSTAR Users (NANUs) –rather like the Notice to Mariners but focused on the needs of GPS users.

harbors. The advice offered here is to use loran (if possible), but as a secondary or supplemental navigation tool. That is, navigate using GPS or traditional methods (e.g., DR plots, visual fixes if visibility permits, soundings, etc.) and supplement the available information with GPS or Loran-C readings. Particularly, if the navigator has local knowledge and has calibrated the loran by comparison of loran positions with "ground truth" (knowledge of the actual positions), loran can be a valuable supplemental aid for harbor navigation.

Inspection of the Loran-C TD lines as printed on the nautical chart provides two additional important pieces of information to the navigator. First, the navigator can see the

PHOTO COURTESY OF NORTHSTAR TECHNOLOGIES

Sensor Units for GPS/DGPS

crossing angles of the various loran TD lines. Recall from the discussion on the accuracy of fixes in Chapter 6 that crossing angles of 90 degrees are optimal. The loran navigation receiver generally selects the TDs automatically. Criteria used by the various manufacturers vary, but may or may not include crossing angles. The alert navigator can determine the Loran-C LOPs in use and alter these, if necessary, to ensure that a good crossing angle results. Referring to the 1210-Tr chart, for example, it can be seen that in this area the crossing angles for the magenta (Xray) and blue (Whiskey) LOPs are generally much less than 90 degrees. Were these selected by the receiver, a manual override to select another TD pair would be in order.

Second, it is useful to introduce the concept of *gradient*. The gradient as used in this discussion is the ratio of the spacing between adjacent Loran-C TDs, as measured in nautical miles, and the TD (microseconds) between these lines. For example, in the general area of Brenton Light on the 1210-Tr chart, the Xray TD gradient is approximately 0.82 M per 10 µsec interval, or 0.082 M/µsec. Generally speaking, the smaller the gradient, the better in terms of fix accuracy. Suppose, for example, that the onboard receiver could resolve TDs to 0.1 µsec. With a gradient of 0.082 M/µsec, a 0.1 µsec resolution would translate into a possible position error of 0.1µsec x 0.082 M/µsec = 0.0082 nautical miles, or approximately 50 ft. In this same area the gradients for the Yankee and Whiskey secondaries are 0.138 and 0.118 nautical miles per microsecond, respectively. Considering both gradient and crossing angle, the best TDs in this small area would be Xray and Yankee. (Gradient alone would suggest Xray and Whiskey, but, as noted, these TDs have a poor crossing angle.)

The above calculations are simple, but tedious if a large number of computations are required. The USCG publishes a useful document, *Specifications of the Transmitted Loran-C Signal*, that contains charts depicting the possible error of position estimates arising from the geometric component of signals from Loran-C chains (actually, in terms of triads of master-secondary pairs). Inspection of these diagrams (together with the range limits of loran coverage) can enable the user to find the best station pairs for use. Most modern Loran-C receivers do this automatically.

Automatic Coordinate Conversion

Early Loran-C receivers displayed only TD information which required the user to make the conversions manually from TDs to latitude and longitude using the published loran chart. This procedure is not difficult, but time consuming and decidedly inconvenient if single-handing. Indeed, a long section of the earlier edition of this text was devoted to a detailed exposition of the tricks of TD interpolation. Now, however, all loran sets being manufactured have automatic coordinate conversion routines built in, so all that is necessary is to enable this function and read out latitude and longitude directly. Some of the earliest sets had crude conversion routines that did not take into account certain propagation corrections, termed *additional secondary phase factors* (ASF). With these earlier sets, use of TDs was clearly preferable for maximum accuracy. However, all the new sets now have highly accurate conversion routines programmed in, so there are now only small differences in accuracy obtainable by using TDs in place of latitude and longitude readouts. Even so, as of this writing, there is no industry standard for lat./lon. conversion routines and, for the most demanding applications, TDs are to be preferred over lat./lon. readouts.

Loran Accuracy

The *absolute accuracy* of the Loran-C system ranges from 0.1 nautical mile to 0.25 nautical mile. Absolute accuracy is calculated by comparing the loran's estimate of the vessel's position with a known position (ground truth). Thus, for example, if you were to go to the Buzzards Light on the 1210-Tr chart and read the loran display, the latitude and longitude shown would be within less than 0.1 to 0.25 nautical miles of the charted position. Accuracy is a function of gradient, crossing angle, and other factors.

However, another accuracy concept is also relevant here, *repeatable accuracy*. In the above example, if you were to note the apparent TDs (or latitude and longitude) of the Buzzards Light on the loran and either write these down or save them in the loran's memory and later return to the same indicated position, the vessel would be much closer to Buzzards Light. The repeatable accuracy is of the order of 75 feet or even less. Indeed, some mariners claim to have nearly collided with buoys and fixed *aids to navigation* (ATONs) once the apparent coordinates were entered into the memory!

GLOBAL POSITIONING SYSTEM

GPS is a satellite-based radionavigation system developed and operated by the U.S *Department of Defense* (DOD). DOD developed GPS originally to meet its needs for worldwide coverage (not available with Loran-C). Initial research in the early 1970s was successful and full-scale development was completed by 1984. In late 1992, the system was operable. Since then, additional satellites have been deployed and other enhancements have been made. GPS reached *Full Operational Capability* (FOC) on July 17, 1995.

GPS permits land, sea, and airborne users to determine their three-dimensional position, velocity, and time 24 hours per day, in all weather, anywhere in the world, with accuracy greater than any other system now available.

GPS consists of three segments: space, control, and user:

- **Space segment:** This segment includes 24 operational satellites in six circular orbits 20,200 *kilometers* (km) (10,900 M) above the earth with a 12-hour period. The satellites are spaced in orbit so that at any time a minimum of six satellites will be in view to users anywhere in the world. Satellites continuously broadcast position and time data to users throughout the world.
- **Control segment:** This segment consists of a master control station in Colorado Springs, with five monitor stations and three ground station antennas located throughout the world. The monitor stations track all GPS satellites in view and collect range information from the satellite broadcasts.
- **User segment:** This segment consists of the receivers, processors, and antennas that allow users to receive GPS signals and compute position, velocity, and time.

GPS Principle of Operation

GPS is based on satellite ranging. NAVSTAR is the name of the satellite used in the GPS. Each GPS satellite transmits an accurate position and time signal. The user's navigation receiver measures the time delay for the signal to reach the receiver, which (using the velocity of propagation) can be converted to the apparent range (*pseudorange*) from the satellite to the receiver. The word pseudorange is used because inaccuracies in the clock in the navigation receiver will result in corresponding error in the estimated range. If the receiver's clock is fast (slow), the apparent time of travel from the satellite to the receiver—hence, apparent range—is too small (great). More on this topic is given below.

Measurement of a range from one satellite enables the user's position to be specified somewhere on a sphere with radius equal to this range. Measurement of the range from another satellite determines another sphere of position. The intersection of these two spheres is a circle. Measurement of the range from a third satellite determines another sphere of position, which (absent measurement errors) will intersect with the circle determined from the first two measurements at only two points. Measurement of the range from a fourth satellite reduces the possible positions to only one. (Actually, because the

USE CORRECT CHART DATUM FOR GPS RECEIVERS

GPS receivers must be set to the same chart datum as used in the production of the nautical chart. Otherwise, substantial position errors may result. As shipped, most receivers are set to the chart datum commonly used in the United States. However, users should check to ensure that the proper chart datum is used. Charts for foreign waters use a variety of reference points. The horizontal chart datum is listed on the chart. Consult the owner's manual for the GPS to learn how to adjust the chart datum.

marine user is located somewhere on the earth, three measurements are satisfactory.)

It is noted above that errors in the clock aboard the navigation receiver can lead to errors in range determinations from each of the satellites. If the clock is in error, then the radius of each sphere is either too small or too large. This is true because each of these errors results from the clock error in the receiver. Therefore, each is off (plus or minus) by the same amount.

If there is no receiver clock error, all *lines of position* (LOPs) determined from TD measurements will intersect at a common point—the user's location in space. But, what if the receiver's clock is in error? In this event, the LOPs will not intersect at a common point. However, because (see above) all range measurements must be in error by the same amount, it is possible for the receiver to use an iterative approach to estimating the correct position. In principle, this problem can be solved by assuming a series of possible clock errors (either fast or slow). For each assumed clock error, a series of pseudoranges can be determined and checked to see if the resulting spheres of position meet at a common point. If so, the clock error is determined. If not, additional assumptions can be evaluated. Although tedious to describe, the problem can be solved very quickly with computer chips imbedded in the navigation receiver. Students sometimes ask why not use more accurate clocks in navigation receivers to eliminate this extra work. The answer is that highly accurate clocks are very expensive, whereas powerful computer chips are comparatively cheap. Thus, it pays to couple a cheap clock with a computer, rather than use an expensive clock.

System Accuracy

GPS was designed to provide two levels of service:

PHOTO COURTESY OF NORTHSTAR TECHNOLOGIES

Steering screen on modern GPS receiver shows graphical display of vessel and provides relevant information on bearing, distance, and XTE.

- ❑ **Standard Positioning Service (SPS):** This is intended for general public use. SPS signal accuracy was intentionally degraded to protect U.S. national security interests. *Selective Availability* (SA) is the name given to the process to control (degrade) system accuracy. The accuracy for SPS (95 percent probability) is that the user's position can be determined within 100 meters horizontally. In accordance with a Presidential Directive, SA was turned off a few minutes past midnight EDT after the end of 1 May 2000. According to information posted in the *Interagency GPS Executive Board's* (IGEB) web site (http://www.igeb.gov), the United States has no intent to use SA again. To ensure that potential adversaries of the United States do not use GPS, the military intends to develop and deploy systems and methods for regional denial in lieu of global degradation of signal accuracy.

❑ **Precise Positioning Service (PPS):** This in intended for use by DOD and other authorized users. The accuracy for PPS is 16 meters (95 percent probability).

The accuracy listed above is absolute accuracy. Because of the continually shifting relation of the satellites and the user, the repeatable accuracy of GPS is the same as the absolute accuracy. In theory, civil GPS receivers should now match the accuracy of PPS (16 meters) under normal circumstances without any modification to the receiver.

DIFFERENTIAL GPS

Because the (original) accuracy of SPS was not deemed adequate for harbor entrance and approach navigation, the USCG developed another system called *Differential GPS* (DGPS). This system reached *Initial Operational Capability* (IOC) on January 30, 1996, and FOC in 1999.

DGPS is the regular GPS with an additional correction added. The correction signal improves the accuracy of the GPS signal, whether or not SA is enabled. The USCG Maritime Differential GPS Service includes two control centers and over 50 remote broadcast sites (located in former RDF sites). This service broadcasts correction signals on marine radiobeacon frequencies to improve the accuracy of GPS-derived positions. DGPS was designed to provide 10-meter accuracy in the designated coverage area. This coverage area includes the coastal continental United States, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. However (Dubay and Johns, 2001), DGPS is reported to provide 1-meter horizontal positioning accuracy (95 percent) when the user is less than 100 nautical miles from the DGPS transmitting site. Accuracy then degrades at a rate of approximately 1-meter per hundred nautical miles as the user moves away from the transmitting site.

DGPS receivers gather navigational signals from all GPS satellites in view, together with differential corrections from a nearby DGPS site. Coverage diagrams for the DGPS system are available on the USCG's *Navigation Center* (Navcen) website (http:///www.navcen.uscg.gov).

GPS or DGPS fixes are plotted using a circle with a dot inside and may have GPS or DGPS noted along with the time.

GDOP/HDOP

As is the case with conventional LOPs, there are optimal angles of intersection of GPS LOPs. The optimum case would be to have one satellite directly overhead and the other three spaced 120° around the receiver on the horizon. The worst case would occur if the satellites were spaced closely together or in a line overhead.

The phenomenon by which fix accuracy is degraded is referred to as *geometric dilution of position* (GDOP). The GDOP depends upon the geometry of the satellites in relation to the user's receiver. There are several related ideas. For mariners, the *horizontal dilution of precision* (HDOP) refers to the effects of the satellite geometry on position (latitude and longitude) errors. Many receivers have a *sky view*, which displays the azimuth of the various satellites. These also display HDOP and an estimate of the user's probable position error.

HINT: ALERT NAVIGATORS

Alert navigators realize that it is easy to make mistakes in entering data into navigation receivers–particularly when underway. They preplan and do as many of the data entry chores as possible when dockside. Entries are checked and double-checked. The course and distance between all waypoints is measured on the nautical chart. When the waypoint is activated, the receiver should read approximately the same as measured on the chart. If not, there is an error somewhere.

WIDE AREA AUGMENTATION SYSTEM (WAAS)

Another DGPS-type system, intended primarily for use by aircraft, has been developed/funded by the *Federal Aviation Administration* (FAA). Development of this system, termed the *Wide Area Augmentation System* (WAAS), along with DGPS, was recommended by a 1994 *Telecommunications and Information Administration*

(NTIA) study. WAAS became available for use in August 2000.

The WAAS (Queeney, 2001) consists of 25 ground-based monitor stations, termed *wide area ground reference stations* (GRS). Position errors determined at these GRS are transmitted to a *wide area master station* (WMS) for analysis and processing. The corrections are relayed to a ground earth station (GES) and transmitted to two geosynchronous communication satellites. The corrections are broadcast on the same frequency as one of the GPS signals. A WAAS-capable GPS receiver is able to use this information to correct estimated positions in the same way as a DGPS receiver. The WAAS system was designed to provide uniform 7-meter (95 percent) accuracy, regardless of the location of the receiver within the WAAS service area (Dubay and Johns, 2001). Actual accuracy (Queeney, 2001) of WAAS is reported to be better than 3 meters.

NEED FOR DGPS/ GPS RECEIVERS

Now that SA has been turned off, it is reasonable to ask if it is necessary to purchase a DGPS or WAAS capable GPS receiver. The answer depends upon your specific needs. Users who wish to have navigational accuracy of ten meters or better will need to have DGPS or WAAS. Moreover, as new features are developed, these are typically introduced into the "high-end" receivers. A user desiring other receiver features may find that these are available only on WAAS capable or DGPS receivers.

GPS/DGPS/ WAAS ACCURACY

The accuracy of GPS—particularly if augmented with DGPS or WAAS—raises additional issues relative to chart accuracy. Before GPS, when the vessel's position was estimated by traditional methods, it was understood that vessels' geographical positions could be as much or more than 1 M in error (particularly on the open ocean). Given this potential uncertainty, mariners gave a wide berth to hazards, such as shoals and obstructions, depicted on charts. There was general acceptance that the available navigational information and cartographic processes used by the chartmaker to position the hazards were more accurate than the typical position uncertainty of a vessel.

Now the accuracy of GPS-derived positions (particularly those determined with DGPS/WAAS) often exceeds that of charts used for navigation. *All mariners should continue to give wide berths to charted hazards until charting worldwide can be brought to the required new accuracy. Check to ensure that the GPS receiver is set to the correct horizontal chart datum for the chart in use and refer to the source diagram to find the hydrographic survey on which various parts of the charts are based.*

The specified NIMA chart accuracy for harbor, approach, and coastal charts is that features plotted on a chart will be within 1 *millimeter* (mm) at chart scale with respect to the identified chart datum, at a 90 percent confidence interval. NOAA has similar accuracy specifications. For a large-scale chart of 1:15,000, a 1-mm error translates to ±15 meters (16.2 yards), which is approximately the same as that for the GPS PPS. For a smaller-scale chart of 1:80,000, the chart error is 80 meters (86.4 yards), which becomes the limiting factor in position plotting accuracy. Currently, NOAA surveys are being conducted to DGPS accuracy. However, for surveys conducted prior to the mid-1990s, the accuracy requirement was only 1.5 mm at the scale of the chart.

Navigation receivers have the capability of displaying information according to several horizontal chart data. The horizontal datum of each chart is listed on the chart. The user should check that the horizontal datum in use by the receiver matches that of the chart; otherwise, substantial position errors (with respect to features depicted on the chart) may result.

NAVIGATION RECEIVERS

A navigation receiver takes position information from the Loran-C, GPS, DGPS, or WAAS. In some cases, these are distinct units. More expensive GPS units also have built-in DGPS sensors. In other cases GPS receivers can accept information from DGPS position sensors (i.e., sensors only without the display unit). Some navigation receivers can accept information from multiple systems. Use of these receivers is described below.

The relatively low cost of most receivers makes it possible for boaters to afford to carry backup units. Portable battery-powered units are especially suitable.

The modern navigation receiver provides the capability of display-

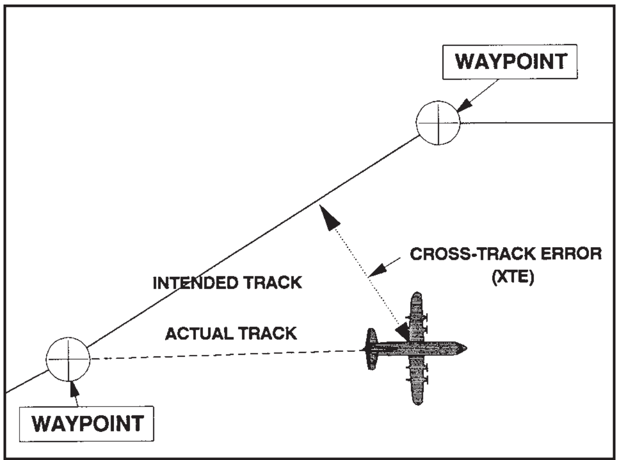


FIG. 9-8–Cross-Track Error Illustrated

ing the vessel's position continuously. The receiver also contains a clock and small computer. Because time and position data are available, it is possible to calculate the vessel's *speed over the ground* (SOG) (with various averaging times), *speed made good* (SMG) since passing the latest waypoint (see below), *course made good* (CMG), and related quantities.

Many receivers have the capability of displaying the vessel's track. Most are capable of being integrated with chart plotters, which overlay the position information on an electronic chart.

ELECTRONIC NAVIGATION

One of the very useful features of all modern navigation receivers is the ability to define *waypoints* (WP or WPT). Waypoints are pre-specified locations that are stored in the receiver's memory. Options differ, but most navigation receivers enable the user to enter waypoints in terms of latitude/longitude, TDs (for Loran-C receivers), and/or range and bearing from the present position or another waypoint. Navigation receivers differ in terms of the number of waypoints that can be stored.

Waypoints might correspond to the mariner's dock, ATONs such as lights or buoys, wrecks, areas of productive fishing, or simply imaginary reference points that are used as turn points or leg markers for an intended voyage. Navigation receivers differ considerably in the ease (and number of keystrokes) with which waypoints can be entered and in the allowable number/type of characters and icons that can be stored with the waypoint. Some receivers provide only for numeric identification of waypoints. Others allow the user to store an icon (e.g., a replica of an anchor, a buoy, or other symbol) and an alphanumeric descriptor. This is an important feature of the receiver.

Waypoints can be entered in advance of a voyage, using the latitude and longitude or TDs of the position identified on the chart. Alternatively, waypoints can be entered by actually voyaging to the waypoint and entering the coordinates automatically in the receiver's memory. The advantage of this latter method for Loran-C receivers is that, because repeatable accuracy rather than absolute accuracy is involved, the waypoints are more accurate. The trick is to enter these waypoints on a day with excellent visibility when these can be readily identified. For example, the entrance buoys to an inlet or harbor can be "memorized" by the navigation receiver while on a leisurely cruise. Then, on a later day when the ceiling and visibility are zero/zero, these waypoints prove their worth.

Most receivers have built-in batteries that are used to power the memory, so waypoints are not lost whenever the external power is cut or the unit is switched off. Still, it is a good idea to write down the coordinates in a *waypoint log* for future reference. Some mariners list waypoints in a computer program. With certain makes and models of navigation receiver, it is possible to either upload or download waypoints to a *personal computer* (PC). This option can be handy and saves considerable effort if the receiver's memory is lost.

Navigation receivers have some form of "GO TO" key, which enables the user to define a specific waypoint as a destination. Once the waypoint is defined as the destination, the navigation receiver computes and displays the bearing and distance to the waypoint. (At the option of the user, these bearings can be shown in reference to either true or magnetic north.) A track is also defined, from the boat or aircraft's position (when the waypoint was initially activated directly) to the waypoint. If the boat or aircraft drifts off course, most receivers have a *course deviation indicator* (CDI)—an icon to display the location of the course from the vessel's present position.

Figure 9-8 shows an aircraft traveling between two waypoints. The intended track is the line joining the two waypoints. In this example, the aircraft has strayed to

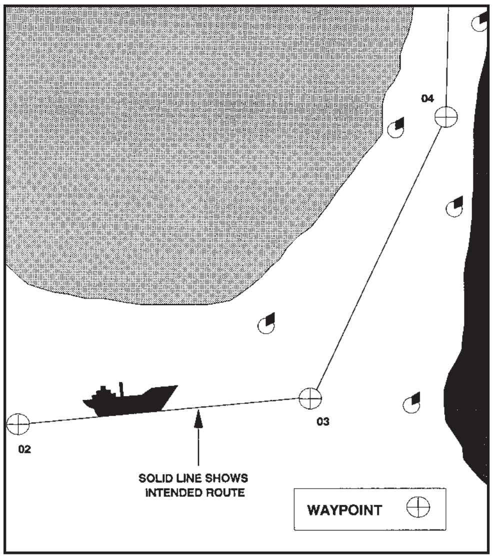


FIG. 9-9–A route is a defined sequence of waypoints.

the right of course and the actual track (shown by the dashed line) is to the right of the intended track. The *cross-track error* (XTE) is defined as the closest distance of the aircraft or vessel from the intended track. It is determined by dropping a perpendicular line from the user's position to the intended track. Navigation receivers have the capability of displaying the XTE as well as the bearing to the destination waypoint.

Most navigation receivers have some *route* capability. As shown in Figure 9-9, a route is described by a defined sequence of waypoints. In this illustration, the route includes waypoints 02, 03, 04, etc. The route is first defined in terms of the numerical sequence of waypoints. Waypoints can correspond to checkpoints, turn points (as shown in Figure 9-9), or to suit some other relevant purpose. Routes can also be given alphanumeric designators. In use, the navigator activates the route function and the next waypoint in the route sequence becomes the destination. When this destination is reached, the receiver sounds an alarm (see below) and changes the destination to the next waypoint in sequence.

Mariners are cautioned to establish routes with due consideration to navigational hazards and the accuracy of the navigation system. For example, in establishing a route based on Loran-C (assuming that waypoints are entered based on lat./lon. coordinates, rather than on a previous visit), the route should be laid out to give shoals 0.1 to 0.25M clearance, if possible. Nearly all navigation receivers have the capability of setting an XTE alarm. This alarm sounds whenever the XTE exceeds a user-defined limit (e.g., 0.05 M). Figure 9-10 illustrates a route laid out to be well clear of the rocks and shoals shown in the illustration. The XTE alarm setting ensures that the vessel will remain in safe water whenever within the XTE boundaries.

Most navigation receivers have the capability to bypass one or more waypoints in a route sequence, as shown in Figure 9-11. (Receivers differ in the ease with which this can be done.) This feature can be handy. However, mariners should remember that it is necessary to check carefully to ensure that the revised routing keeps the vessel in safe water.

Waypoints, routes, and CDIs are so convenient to use that the navigator may become sloppy. As with any navigational tool, it is possible to make unrecognized and catastrophic blunders using a navigation receiver. For example, the receiver will not "complain" if adjacent waypoints in a route are located on opposite sides of an island! Unless you are operating a dredge this will have unpleasant consequences.

Still on the subject of a need for care in using electronics, it is important to check electronic position fixes by as many additional means as possible, such as proximity to DR position, visual fixes, and water depth. It is all too easy to transpose digits when entering waypoints or to make other trivial errors. Whenever possible, it is appropriate to perform "reality checks" on the information presented.

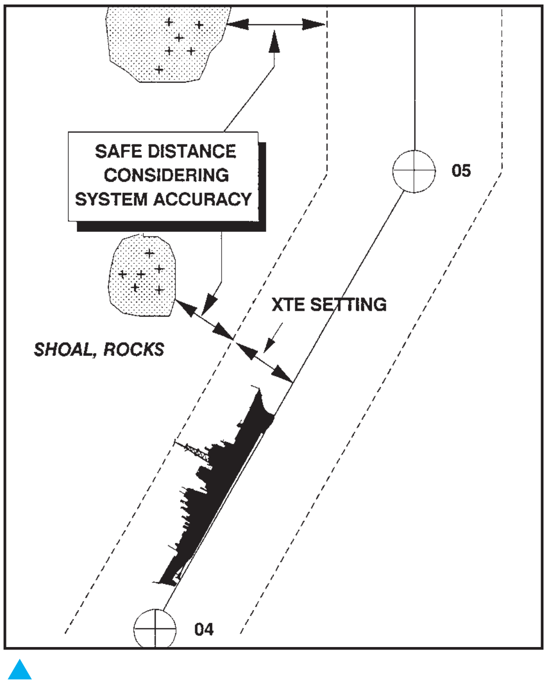


FIG. 9-10–Routes should be well clear of hazards.

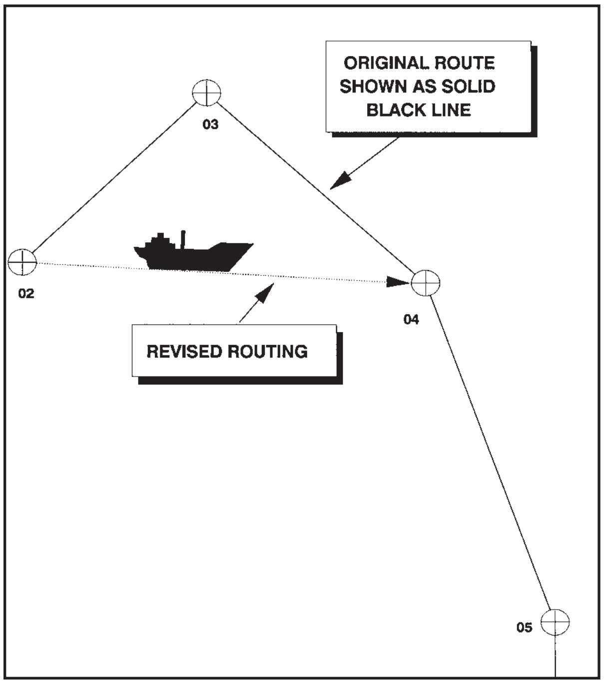


FIG. 9-11–Bypassing a waypoint on a route.

Use of ATONs as Waypoints

Many mariners find it convenient to use ATONs (e.g., entrance buoys, channel markers) as waypoints. The Canadian Coast Guard recommends that mariners do not use ATONs as waypoints because of the risk of collision with the aid or grounding on the danger that the aid is marking (see http:///www.ccg-gcc.gc.ca/dgps/guide_7_e.htm). A practical idea is to offset the waypoint from the ATON 1/4 to 1/2 mile (if there is sufficient sea room) so that the danger of a close encounter with the ATON or the hazard that it marks is relatively small, yet the ATON will still be visible. If ATONs are used as waypoints, mariners are cautioned to monitor the vessel's progress carefully in the vicinity of the waypoint and to use all available means (e.g., depth finder) to avoid encounters with the marked hazard.

OTHER FEATURES

Modern navigation receivers have a variety of other features that facilitate navigation. For example, the navigation receiver can be coupled to an autopilot. With this setup, the autopilot will steer towards the waypoints in the route, obtaining course corrections automatically from CDI in the navigation receiver.

Many receivers are integrated with *electronic charts*—a particularly handy feature. The receiver superimposes the vessel's position and the intended track on an electronic chart of the area. Deviations from track are apparent and easily corrected before these become appreciable. The electronic charts are available on a variety of storage media. However, as with paper charts, electronic charts become outdated and must be replaced with current editions. Also, remember that most electronic charts do not have any facility to add changes that have been noted in the *Local Notice to Mariners.*

Alarms

Most navigation receivers are equipped with *alarms* or indications that warn the mariner if a signal is lost or no longer usable for navigation. You should spend time studying the owner's manual to ensure that you are fully familiar with these indications. Many receivers continue to display position coordinates even in the event of a lost or insufficient signal, which can fool the unwary mariner (see material in Chapter 12).

Most navigation receivers are also equipped with a variety of adjustable alarms. Examples of various alarms include:

- ❏ **Arrival alarm:** This sounds when the vessel passes within a user-adjustable distance from a destination waypoint. As waypoints are often used to mark turn points, it alerts the mariner to put the wheel over.
- ❏ **Passing alarm:** (sometimes termed arrival off-course alarm): This alarm warns the mariner that a waypoint has been passed (technically that the vessel has passed a line perpendicular to the

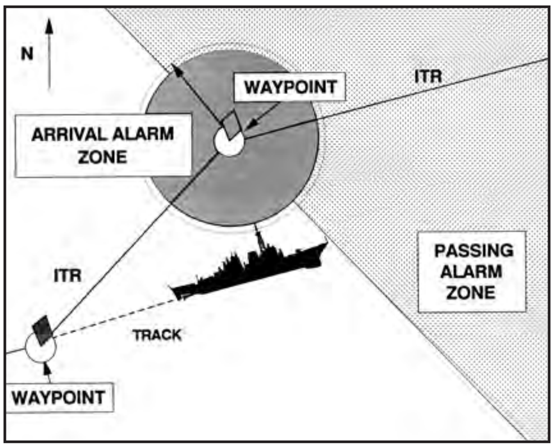


FIG. 9-12–Illustration of the difference between an arrival and a passing alarm.

HEIGHT OF TARGET (FT.)	HEIGHT OF ANTENNA IN FEET 0.0	2.5	5.0	7.5	10.0	15.0	20.0	30.0
0.0	0.0	1.9	2.7	3.3	3.9	4.7	5.5	6.7
2.5	1.9	3.9	4.7	5.3	3.9	4.7	5.5	6.7
5.0	2.7	4.7	5.5	6.1	6.6	7.5	8.2	9.4
7.5	3.3	5.3	6.1	6.7	7.2	8.1	8.87	10.0
10.0	3.9	5.8	6.6	7.2	7.7	8.6	9.3	10.5
12.5	4.3	6.2	7.0	7.7	8.2	9.0	9.8	11.0
15.0	4.7	6.7	7.5	8.1	8.6	9.5	10.2	11.4
17.5	5.1	7.0	7.8	8.4	9.0	9.8	10.6	11.8
20.0	5.5	7.4	8.2	8.8	9.3	10.2	10.9	12.1
22.5	5.8	7.7	8.5	9.1	9.6	10.5	11.2	12.5
25.0	6.1	8.0	8.8	9.4	10.0	10.8	11.6	12.8
27.5	6.4	8.3	9.1	9.7	10.3	11.1	11.9	13.1
30.0	6.7	8.6	9.4	10.0	10.5	11.4	12.1	13.4
35.0	7.2	9.1	9.9	10.6	11.1	11.9	12.7	13.9
40.0	7.7	9.6	10.4	11.1	11.6	12.4	13.2	14.4
45.0	8.2	10.1	10.9	11.5	12.0	12.9	13.6	14.9
50.0	8.6	10.6	11.4	12.0	12.5	13.4	14.1	15.3
55.0	9.0	11.0	11.8	12.4	12.9	13.8	14.5	15.7
60.0	9.5	11.4	12.2	12.8	13.3	14.2	14.9	16.1
65.0	9.8	11.8	12.6	13.2	13.7	14.6	15.3	16.5
70.0	10.2	12.1	12.9	13.5	14.1	14.9	15.7	16.9
75.0	10.6	12.5	13.3	13.9	14.4	15.3	16.0	17.2
80.0	10.9	12.8	13.6	14.3	14.8	15.6	16.4	17.6
85.0	11.2	13.2	14.0	14.6	15.1	16.0	16.7	17.9
90.0	11.6	13.5	14.3	14.9	15.4	16.3	17.0	18.3
95.0	11.9	13.8	14.6	15.2	15.7	16.6	17.3	18.6
100.0	12.2	14.1	14.9	15.5	16.1	16.9	17.7	18.9
110.0	12.8	14.7	15.5	16.1	16.7	17.5	18.3	19.5
120.0	13.4	15.3	16.1	16.7	17.2	18.1	18.8	20.0
130.0	13.9	15.8	16.6	17.3	17.8	18.6	19.4	20.6
140.0	14.4	16.4	17.2	17.8	18.3	19.2	19.9	21.1
150.0	14.9	16.9	17.7	18.3	18.8	19.7	20.4	21.6
175.0	16.1	18.1	18.9	19.5	20.0	20.9	21.6	22.8
200.0	17.3	19.2	20.0	20.6	21.1	22.0	22.7	23.9

TABLE 9-1–The distance to the radar horizon in nautical miles as a function of the antenna height in feet and the target height shows why high antennas are desirable. Note that these ranges are, typically, less than the “advertised” range of the radar.

intended track at the waypoint) without triggering the arrival alarm. Figure 9-12 provides an illustration of the difference between the arrival and passing alarms. The arrival alarm zone is the circular area in this illustration, the passing alarm zone the darker shaded area.

❑ **Cross-track error alarm:** This warns the mariner that the vessel’s XTE has exceeded an adjustable XTE maximum.

❑ **Boundary (border) alarm:** This may be thought of as the mirror image of the XTE alarm, warning the mariner that the vessel has penetrated a “lane” of defined width between two waypoints. This could be used to warn the mariner that the vessel has entered a traffic separation lane. Alternatively, a commercial fisherman, to avoid fishing in an illegal fishing area of defined dimensions, might use this feature. Penalties for fishing within illegal zones can be quite substantial, so many commercial fishing vessels find this feature useful.

❑ **Anchor watch:** This might be thought of as the mirror image


PHOTO COURTESY OF RAYTHEON MARINE CO.

Modern Radar Display Unit

of an arrival alarm. The mariner defines a waypoint where the anchor is dropped and an alarm circle sufficient to accommodate the swing circle of the vessel. The alarm sounds whenever the actual distance from the waypoint exceeds the preset value.

Alarms are potentially valuable, but should not be used to excess. The modern electronic bridge is typically fitted with many alarms, such as navigation receiver, depth sounder (shallow- or deep-water alarms), radar (guard zone penetration), and engine alarms. If overused, these can be very confusing. Also, unless hooked to amplifiers and speakers, these alarms may not be loud enough to be heard over the engine noise. Even with a quiet bridge, an anchor watch alarm that sounds in the night may not be heard in the sleeping compartments unless a remote speaker is rigged.

This completes the discussion of the Loran-C and GPS/DGPS/WAAS systems. Navigation is much easier as a result of the introduction of these new tools/instruments on the bridge.

However, lack of familiarity with these navigation instruments can actually make navigation more confusing. Most recreational boaters use a combination of electronic navigation and seaman's eye for navigation.

RADAR: GENERAL

Radar is the last of the electronic systems to be described in this text. Introduced in Chapter 4, it is described in detail here. Radar is another development that originated in World War II. The name is an acronym for *RAdio Detection And Ranging* coined in the U.S. Navy in 1940 and adopted for general use by the Allied Powers in 1943. The invention of radar, probably more than any other development, changed the necessary skills of the professional mariner from the so-called "three Ls" (Lookout, Log, and Leadline) to those necessary for the modern environment.

Unlike GPS or Loran-C, which require satellite or ground-based transmitters for operation, radar is completely self-contained. A radar set consists of a transmitter, receiver, antenna (either open array or radome), and display unit. Figure 9-13 shows pictures of both the open array and radome antennas.

The radar set alternately transmits, "listens" for the reflected sig-

PHOTO COURTESY OF RAYTHEON MARINE CO.

FIG. 9-13–Open Array (left) and Radome (right) contrasted.

nal, and measures the time for the reflected signal to return. This time is translated into a distance (radar waves travel at the speed of light) and the reflected signal or radar echo is displayed on a circular screen, termed a *plan position indicator* (PPI), that shows the azimuth (bearing) and range of the target or pip.

> **PRACTICAL TIP: USE A RADAR REFLECTOR**
>
> ***Use of a radar reflector increases the likelihood that you will be observed on radar. These devices are relatively inexpensive and easy to install.***

The maximum range of the radar is determined by several factors, including the radar's power and the antenna height. Radar signals are broadcast on frequencies that are essentially line-of-sight, so antenna height is often critical to range. The actual equations for distance in nautical miles to the visible and radar horizons are $D = 1.17^{*} He^{0.5}$ and $D = 1.22^{*} Ha^{0.5}$. Respectively, where D is the distance to the visible horizon (first equation) or radar horizon (second equation), He is the height of eye above the surface of the water in feet and Ha is the distance from the water to the center of the radar antenna in feet. Under certain circumstances, the distance could be substantially greater or lesser than given by these formulas. Table 9-1 shows the distance to the radar horizon in nautical miles as a function of the height of the antenna in feet and the height of the target in feet. Compare this with the distance to the visible horizon given in Chapter 6.) Table 9-1 shows only the distance at which it is normally possible that a target can be "seen" by the radar. As discussed below, detection and identification are complex phenomena and detection ranges may be appreciably shorter than given in Table 9-1.

Radar also has a minimum range at which targets may be detected. This minimum range is related to the radar's pulse length. Radar waves travel at the speed of light; so if, for example, the pulse length were 1 µsec, the wave could travel approximately 984 feet, or 492 feet out and back. With this pulse length, any target closer than 492 feet cannot be detected, because the radar will still be emitting a signal when the return wave bounces back and the receiver will still be off. If p is the pulse length in microseconds, then the minimum radar range is at least 492 p (in feet). Most radar units have a variable pulse length. The minimum range for most small boat radar units is about 30 yards or so, and is usually given in the manufacturer's specifications.

RADARSCOPE INTERPRETATION

For navigational applications—determination of position from range and bearing of known objects as discussed in Chapter 6—radar can be very useful if its characteristics and limitations are understood. Determining a radar fix from observation of the range and bearing of a charted, isolated, and well-defined radar-reflective object is relatively simple. It becomes much more complex, however, if the shoreline is not well defined and/or prominent and radar-reflective targets are few and far between. The reaction of a first-time radar user to the image on the radar screen is often one of disappointment. Novices are often preconditioned to expect a literal image (e.g., as seen by eye or as in a photograph) rather than the initially confusing mass of electronic "blobs" on the screen. A prominent inlet (see below) may be virtually invisible to the radar (at a given range), as may fiberglass or wooden vessels, while a small radar reflector held aloft from a small boat may "bloom." Hilly ground surrounded by low-lying areas may appear as a series of islands. A visually prominent tower on land may present only a small echo because its rounded shape scatters the return signal, whereas a much smaller structure of different shape and materials of construction may present a larger target. With time, patience, and a clear understanding of the characteristics and limitations of radar, navigators can learn to interpret radar imagery with almost the same ease as photo interpretation. Textbook discussions are valuable, but no substitute for on-the-water experience with radar.

The PPI provides a chart-like presentation (plan view). But, the image *painted* on the screen as the antenna rotates is not a literal representation of the shore. The width of the radar beam and the length of the transmitted pulse are two factors that distort the image as it appears on the scope. More specifically, the width of the radar beam acts to distort the shoreline features in bearing and the pulse length may cause offshore features to appear as though part of the landmass. Inlets, for example, cannot generally be seen on radar until the vessel is sufficiently close that the size of the inlet is wider than the antenna's beam width. (Generally, open array antennas have a narrower beam width than radomes, a significant advantage.) Knowledge of the beam width, from the manufacturer's specifications, enables an approximate computation of the maximum distance at which an inlet will be able to be identified. *For this and other reasons, the actual radar image of a scene depends upon the range at which it is observed*.

It is not always easy to determine which features in the vicinity of the shoreline are actually reflecting the echoes painted on the scope. Any uncertainty or ambiguity, of course, undermines the accuracy of the resulting fix. Additionally, certain features on the shore will not be visible on the scope, even if they have good reflecting properties, if they are hidden from the radar beam by other physical features or obstructions. This phenomenon is called masking or radar shadow.

Land Targets

Landmasses are readily recognizable because of the generally steady brilliance of the relatively large areas painted on the PPI. Knowledge of the vessel's position relative to nearby land is an important clue to interpretation. This is one of the reasons why it is desirable to integrate navigation information from a navigation receiver on the radar screen. On relative motion displays (discussed below), landmasses apparently move in directions and at rates opposite and equal to the actual motion of the observer's ship. Actually, most landmasses are readily recognizable; the real problem is to identify *specific features* so that these features can be used for determining a fix. Identification of specific features can be quite difficult because of various factors, including distortion resulting from beam width and pulse length and uncertainty as to just which charted features are causing the echoes. Often the identification of a specific feature (e.g., a tower or light) is based on a contextual association. For example, a light on the end of a recognizable landmass may be identified based upon the fact that the landmass has a characteristic shape and the light is the only radar prominent object on the tip of the landmass.

The following clues or interpretation keys are suggested in *Defense Mapping Agency* (DMA) Publication 1310 (DMA's name has been changed to the *National Imagery and Mapping Agency* [NIMA]):

- ❑ Sandpits and smooth, clear beaches normally do not appear on the PPI at ranges beyond one or two miles because these targets have almost no area that can reflect energy back to the radar antenna. Ranges determined from these targets are not reliable. If waves are breaking over a sandbar, echoes may be returned from the surf. Waves may, however, break well out from the actual shoreline, so that ranging on the surf may be misleading when a radar position is being determined relative to the shoreline.
- ❑ Mud flats and marshes normally reflect radar pulses only a little better than a sandpit. The weak echoes received at low tide disappear at high tide. Mangroves and other thick growth may produce a strong echo. Areas that are indicated as swamps on a chart, therefore, may return either strong or weak echoes, depending on the density and size of the vegetation growing in the area.
- ❑ When sand dunes are covered with vegetation and are well back from a low, smooth beach, the apparent shoreline determined by radar appears as the line of the dunes rather than the true shoreline. Under some conditions, sand dunes may return strong echo signals because the combination of the vertical surface of the vegetation and the horizontal beach may form a sort of corner reflector.
- ❑ Lagoons and inland lakes usually appear as blank areas on a PPI because the smooth water surface returns no energy to the radar antenna. In some instances, the sandbar or reef surrounding the lagoon may not appear on the PPI because it lies too low in the water.
- ❑ Coral atolls and long chains of islands may produce long lines of echoes when the radar beam is directed perpendicular to the line of the islands. This indication is especially true when the islands are closely spaced. The reason is that the spreading resulting from

the width of the radar beam causes the echoes to blend into continuous lines. When the chain of islands is viewed lengthwise, or obliquely, however, each island may produce a separate pip. Surf breaking on a reef around an atoll produces a ragged, variable line of echoes.

- ❏ Submerged objects do not produce radar echoes. One or two rocks projecting above the surface of the water, or waves breaking over a reef, may appear on the PPI. Obviously, when an object is submerged entirely and the sea is smooth over it, no indication is seen on the PPI.
- ❏ If the land rises in a gradual, regular manner from the shoreline, no part of the terrain produces an echo that is stronger than the echo from any other part. As a result, a general "haze" of echoes appears on the PPI, and it is difficult to ascertain the range to any particular part of the land. Land can be recognized by plotting the target (see below). Care must be exercised when plotting because, as a vessel approaches or retreats from a shore behind which the land rises gradually, a plot of the ranges and bearings to the land may show an apparent course and speed.
- ❏ Blotchy signals are returned from hilly ground because the crest of each hill returns a good echo, although the valley beyond is in a shadow. If high receiver gain (one of the adjustable controls on some radar sets) is used, the pattern may become solid except for the very deep shadows.
- ❏ Low islands ordinarily produce small echoes. When thick palm trees or other foliage grow on the island, strong echoes often are produced because the horizontal surface of the water around the island forms a sort of corner reflector with the vertical surfaces of the trees. As a result, wooded islands given good echoes and can be detected at a much greater range than barren islands.

Atmospheric Targets

Radar has the capability of detecting moisture in the form of rain and snow. Commercial aircraft use radar for weather avoidance. Mariners can use radar in the same way.

Vessels as Targets

Vessels, unlike landmasses present only a small pip on the PPI. But other objects, such as small islands, rocks, and *aids to navigation* (ATONs) also present small targets. Other clues, in addition to target size, are required to classify the target as a vessel. For example, a check of the vessel's position can indicate that no land is within radar range. The size of the pip can also be used to exclude the possibility of land or precipitation, both usually having a massive appearance on the PPI. The rate of movement of the pip on the PPI can eliminate the possibility of aircraft.

Having eliminated the foregoing possibilities, the appearance of the pip at a medium range as a bright, steady, and clearly defined image on the PPI indicates a high probability that the target is a steel ship. Unless equipped with special *radar reflectors*, detection of wooden or fiberglass vessels is more problematic.

The pip of a ship target may brighten at times and then slowly decrease in brightness. Normally, the pip of a ship target fades from the PPI only when the range becomes too great. In heavy seas, however, small vessels can be lost in radar shadow and appear only as intermittent targets.

Radar Shadow

While PPI displays appear to offer a chart-like presentation if landmasses are being scanned by the radar beam, there may be sizable areas missing from the display because of certain features being blocked from the radar beam by other features. A shoreline, which is continuous when the ship is at one position, may not be continuous when the ship is at another position and scanning the same shoreline.

The radar beam may be blocked from a segment of this shoreline by an obstruction such as a promontory. An indentation in the shoreline, such as a cove or bay, appearing on the PPI when the ship is at one position may not appear when the ship is at another position nearby. Thus, radar shadow alone can cause considerable differences between the PPI display and the literal chart presentation. This effect in conjunction with beam width and pulse length distortion of the PPI display can cause even greater differences. For this and other reasons, users need to gain experience in radar interpretation.

RADAR USES

From the above it should be clear that marine radar is useful for two broad applications, navigation and collision avoidance. (As noted above, radar can also be used for weather avoidance.)

ALL

TYPE OF MOTION	TYPE OF DISPLAY	KEY CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
RELATIVE MOTION	UNSTABILIZED (SHIP'S HEAD UP SHU)	Relative motion display with own ship at center and instantaneous relative bearing of targets displayed. Plan view rotates in direction opposite to turn.	Relatively low cost (no gyrocompass input required). Relative bearings of targets may be easier to see than with stabilized (NU) displays.	Off-screen plotting on maneuvering board required to determine target speed and direction. Bearing accuracy adversely affected by yaw.
RELATIVE MOTION	STABILIZED (NORTH UP NU)	Relative motion display with own ship at center. Linked to gyrocompass to display continuous north-up picture on PPI. Absolute bearing of targets displayed. Own ship's heading displayed by heading flash.	Direct readout of actual target bearing and on screen plotting is possible. Target smearing due to ship's yaw is reduced. Targets retain same position on-screen when own ship turns, lowering the likelihood that targets will be lost.	Unless "base course up" mode available, can cause interpretation difficulties when ship's course is far from north. Units are more expensive than SHU radar.
TRUE MOTION	North up or ship's head up alternatives exist, but North up more common.	Own ship and other moving objects displayed in true motion. Stationary objects such as land, buoys, etc., remain stationary. Display most resembles "chart view" on PPI.	Simplest to understand and visualize. True motion radars can generally be operated as relative motion radars, so has all advantages of relative motion display, if necessary.	Cost, complexity of operating controls, need to reset display as own ship moves to edge of display.

TABLE 9-2–Types of Radar Display

With respect to navigation, radar can be used to "see" land objects and ATONs under conditions of darkness or otherwise restricted visibility. In this sense, radar navigation is analogous to electronic piloting. That is, the techniques of navigation with radar are nearly identical to those used for visual piloting (e.g., determination of range or bearing to identified objects, determination of LOPs, fixes etc.) except that the objects are detected and identified with the radar rather than the eye. The trick in using radar for this purpose involves learning the appearance of targets on a radar screen, rather than as seen by eye. As noted above, this is not a simple process and facility comes only with experience.

The second major application of radar is for collision avoidance. That is, radar is used to detect and identify other vessels and the radar data are used to assess the likelihood of collision. This requires familiarity with radar plotting—or, at least, systematic observation of targets—as discussed below.

RADAR PLOTTING: REGULATORY IMPLICATIONS

The following sections have been written to simplify radar plotting as much as possible. But, it may be necessary to study this material carefully in order to master the topic. Nonetheless, it is important that the operator of any radar-equipped vessel fully understand radar interpretation and plotting.

Mastery of any onboard navigational tool is important. Why, after all, own something you can't use? But, knowledge of the use of radar is important for an additional reason. The *navigation rules* (NAVRULES) or *collision regulations* (COLREGS) explicitly or implicitly mention radar in several sections. For example (in Rule 7, "Risk of Collision") the rules require that:

> *"Proper use shall be made of radar equipment if fitted and operational,* including long-range scanning to obtain early warning of risk of collision and radar plotting or equivalent systematic observation of detected objects." [Emphasis added.]

In other words, if you have working radar aboard, it must be used and used properly. Because this common sense dictum is made so explicit, the mariner may risk a legal liability in the event of a collision for any failure to use the radar properly. Radar ownership, thus, involves certain responsibilities. A complete discussion of this topic is beyond the scope of this section and this brief mention does not purport to give legal advice. Navigators interested in following up on this should contact an appropriate professional.

OUTLINE OF DISCUSSION

The remainder of this chapter is structured as follows. First, a brief discussion on the types of radar displays is presented. Next, radar-plotting techniques are explained through the use of several examples. Finally, other relevant details and situations of interest are covered.

RADAR DISPLAYS

Teaching experience with the ACN course shows that the different types of radar displays frequently confuse students—particularly as many of the texts on this subject assume (without explicit mention) that a so-called stabilized north up display is used, whereas most displays on small boats are unstabilized with ship's head up. This section has been added for clarification.

Three principal types of display are used on marine radar: (i) a relative motion display (ship's head up), (ii) a relative motion display (north up), and (iii) a true motion display (which can be either ship's head up or north up). Key characteristics, advantages, and disadvantages of each of these displays are summarized in Table 9-2. Some radar units can be switched from one display mode to another; other radar units have only one fixed type of display. These three principal types are discussed below.

Unstabilized Ship's Head Up (SHU) Display

Figure 9-14 shows a stylized replica of a radar display or PPI, so named because it presents a plan view (top view) of the scene to the observer. Although this display is particularly convenient, it is important to remember that it was not created by observation from above. Rather, it is "painted" from a point near the ground. Radar shadow (discussed earlier), though not necessarily obvious from the display, is, nonetheless, an important phenomenon. Smaller vessels, for example, can be masked or hidden from view behind larger ships, even though the perspective of the PPI would encourage the naive observer to believe that he/she can "see" what's on the other side of a target. Radar observers should be particularly alert to the possibility that previously unseen targets can emerge suddenly from behind larger targets in congested waterways.

To simplify interpretation of Figure 9-14, extraneous features, such as land echoes, side lobe echoes, sea or rain clutter, etc., are suppressed in this view of the PPI. On the outer edge of this PPI is a ring displaying bearing information. A series of concentric rings (six in this figure) termed *Fixed Range Markers* (FRM) is also shown. The scale of these FRMs is generally adjustable from a switch on the display unit. The number and spacing of the FRMs vary among sets of different manufacture. Normally the FRMs can be switched on or off. Additionally, many radar units have an adjustable intrusion alarm, which alerts the navigator if any target penetrates a user-adjustable zone. In this example (see top of diagram), the scale is set so that a target or pip located at the outermost ring is 6 M distant and, therefore, each of the concentric rings is 1 M apart. The range of the target can be estimated from its position relative to the FRMs. To increase the accuracy of range estimates, most radar units are also equipped with one or more *Variable Range Markers* (VRM) (not shown in Figure 9-14), which insert additional ring(s) in the display at an adjustable distance from the center. The range of the VRM is generally shown on a separate digital readout located on the screen.

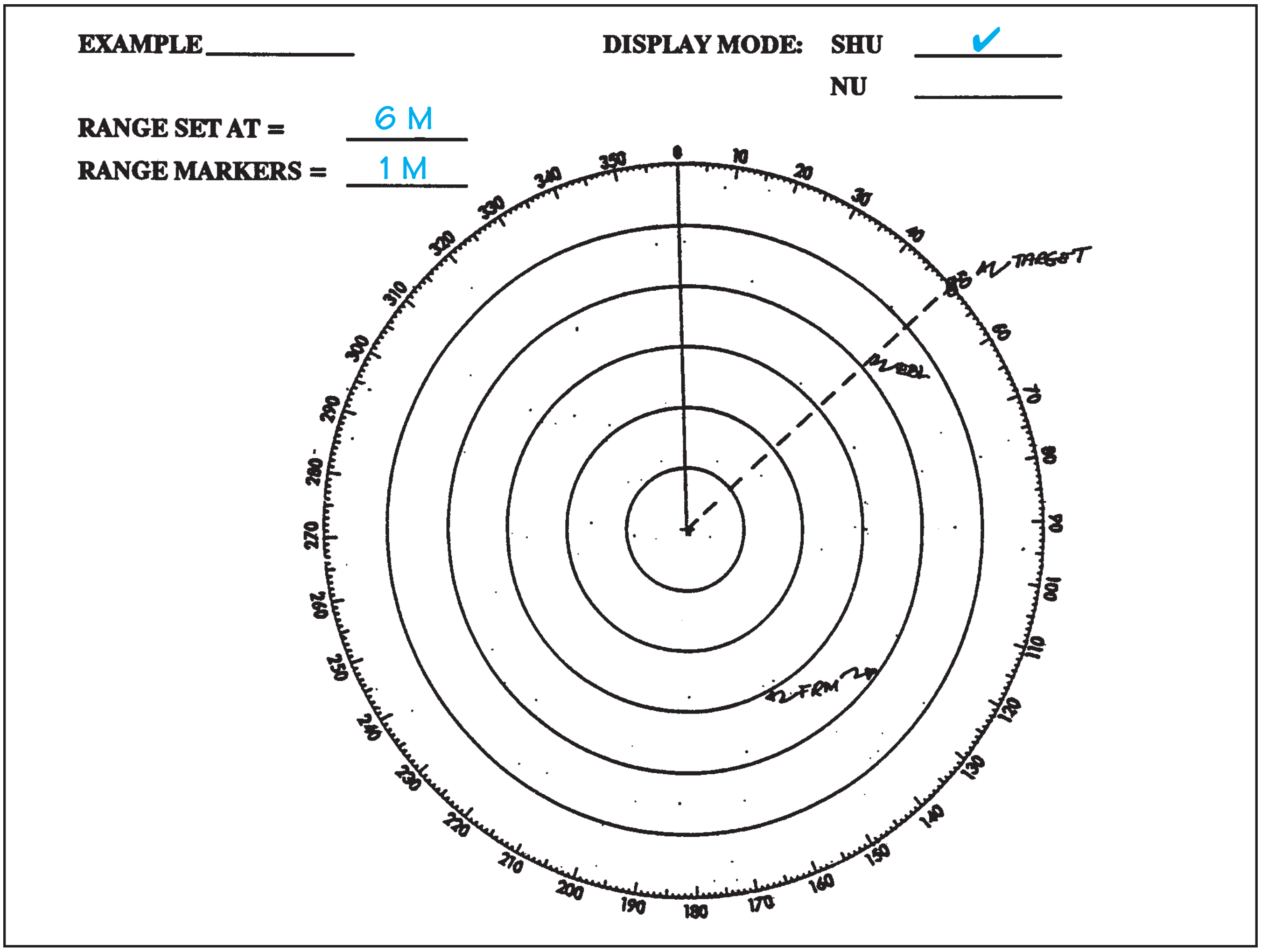


FIG. 9-14–Replica of SHU Radar Display

If accurate range information is required, the VRM (if available) should be used rather than the FRMs. This recommendation is offered for two reasons. First, the VRM generally enables a more precise estimate of range to be made. Second, it occasionally happens that the operator inadvertently switches the range setting on the radar. In this event, the distance corresponding to each range ring is altered. Chapter 12 provides an example where a vessel grounded because the range corresponding to each of the FRMs was misinterpreted. Use of the VRM display prevents this error from being made.

It is not possible to tell the orientation or even the size of the target from the size or the intensity of the radar image alone. As noted above, target detection is a function of many variables, including the target's height, size, shape, aspect, texture, composition, and range. Local knowledge, contextual clues, and radar plotting can often be used to classify the target (e.g., land targets versus targets at sea, vessel versus ATON, fishing vessel versus merchant ship, etc.), as discussed later in this chapter. But, until this classification process is complete, all detected objects are referred to as simply targets or pips.

In the display shown in Figure 9-14, the observer's vessel (termed own ship, or *reference ship* or vessel) is located at the center, and the target's location is, therefore, a relative position. Some radar units have a feature that enables the position of the observer to be offset from the center of the screen. This

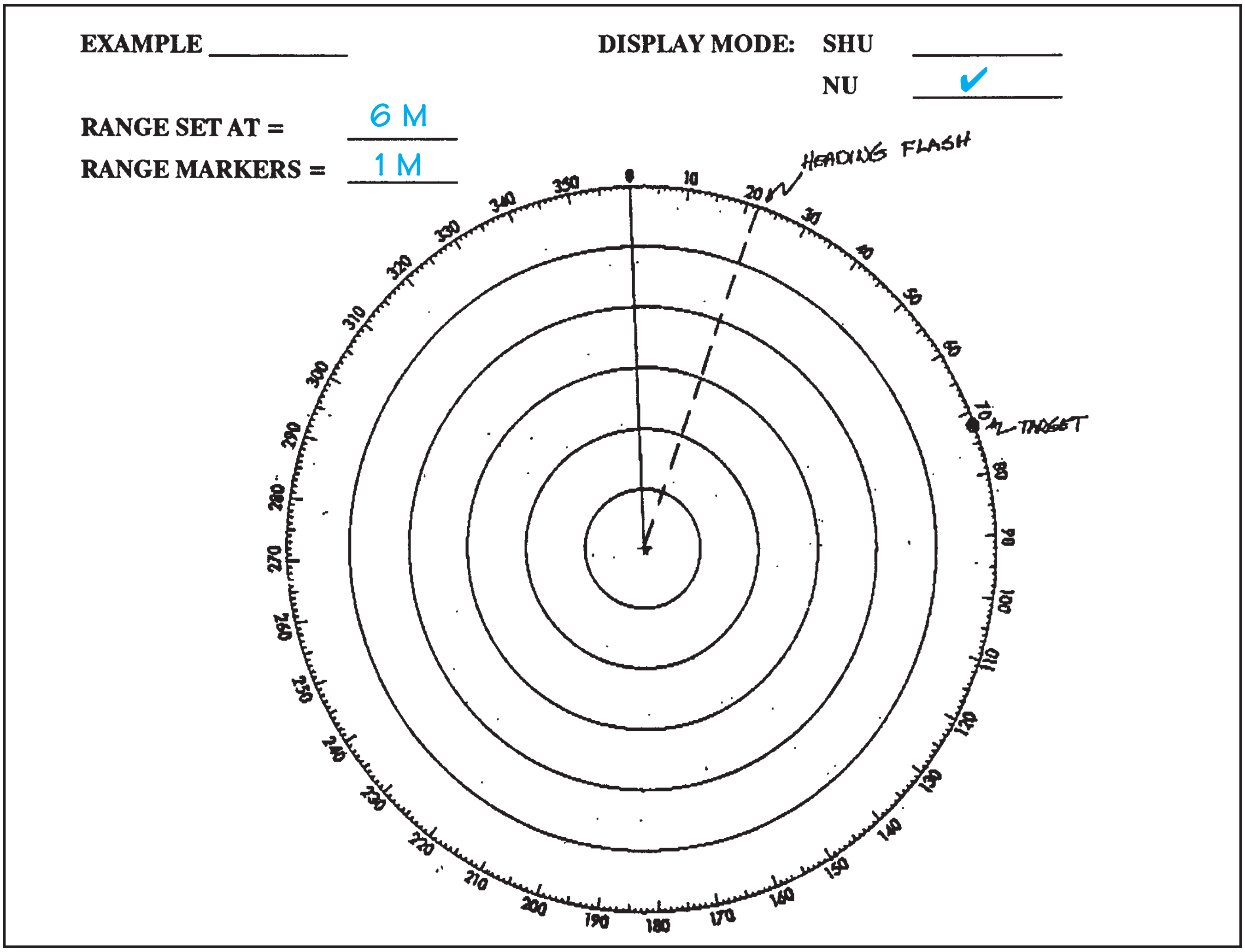


FIG. 9-15–Replica of NU Radar Display

might be done, for example, to provide a greater display area forward of the observer.

The radar display type shown in Figure 9-14 is termed unstabilized with *ship's head up* (SHU). (The notation SHU is checked in the top right corner.) This is the most common display on small boat radar units. The word unstabilized is used because the image in the PPI will change with the reference vessel's heading. A turn to starboard, for example, will cause the target(s) in the image to appear to rotate in a counterclockwise direction. Only relative bearings (to the ship's head) of targets can be read from this display. The target shown in Figure 9-14 has a relative bearing of 050 degrees. To calculate a true bearing from this relative information it is necessary to note the reference ship's compass heading at the time of observation, convert this heading to true heading from the CDMVT sequence, and finally, to add the target's relative bearing to the reference ship's heading. Thus, for example, if the reference vessel were heading 030 compass, the deviation on this heading were 2 degrees east, and the variation were 10 degrees west, the true bearing of the target would be 030 + 002 - 010 + 050 = 072 degrees. With the unstabilized SHU display, true (or magnetic) bearings must be calculated, rather than simply read off the screen. Moreover, it is necessary to note the reference vessel's heading at the instant the relative bearing is measured; otherwise, yaw errors are introduced.

Some unstabilized SHU dis-

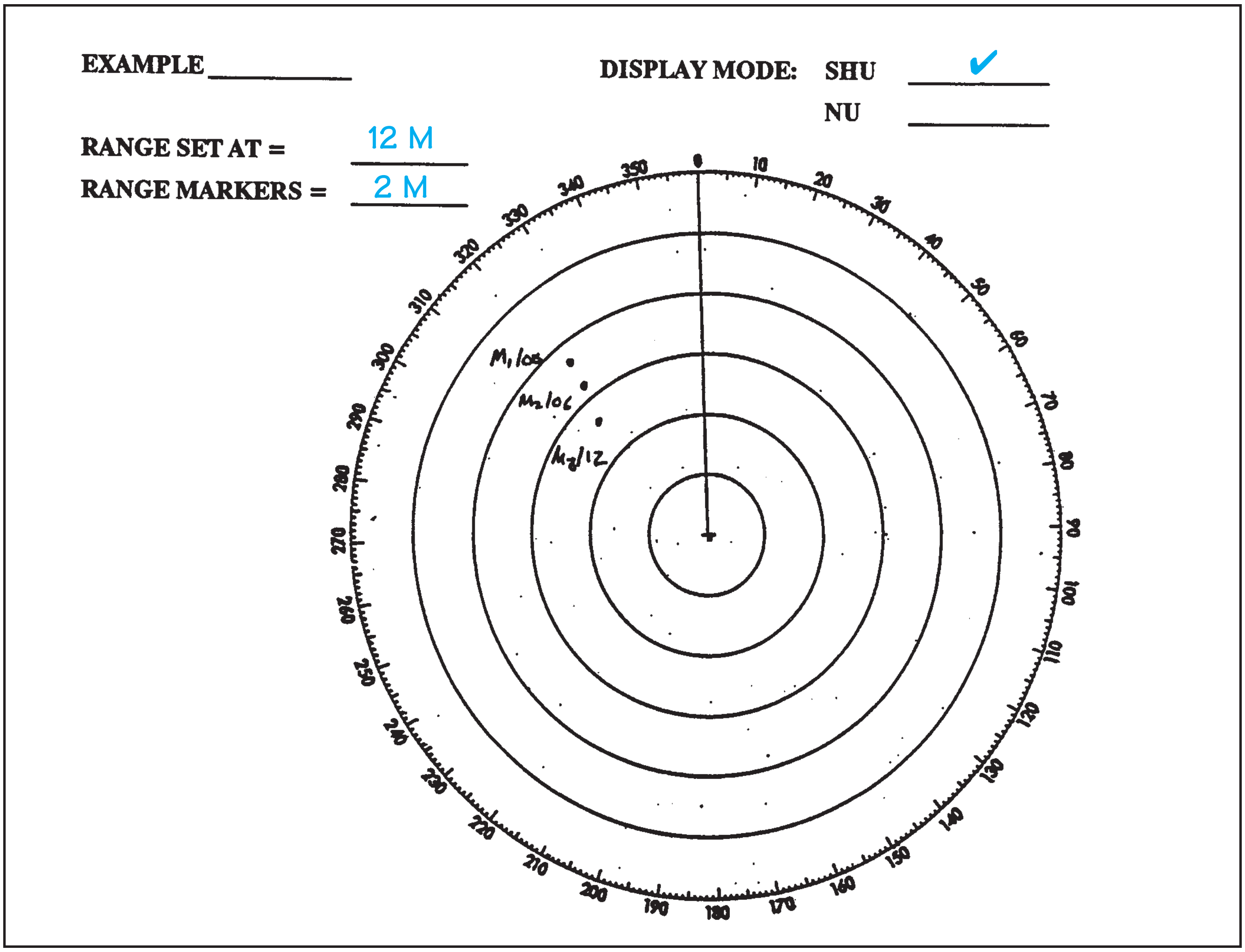


FIG. 9-16–Replica of Radar Display–Target as Seen at Successive Times

plays are capable of displaying the vessel's heading (e.g., from a fluxgate compass) or COG (e.g., from a GPS or Loran-C input). These displays are termed *north referenced unstabilized displays*. Care must be used, however, because the COG may be very different from the vessel's heading at any instant. Heading, not COG is required for bearing calculations.

To increase the accuracy with which relative bearings can be read (particularly for targets that are not located near the edge of the screen), most modern radar units have one or more *electronic bearing markers* (EBM) or *electronic bearing lines* (EBL). These appear as an adjustable spoke on the screen with an off-screen (or on-screen) digital bearing readout. The EBL can be rotated until it is aligned with a target, and the relative bearing read directly. In Figure 9-14, a dotted EBL is shown (actual lines may be solid on the screen but are shown as dotted in this illustration to avoid confusion with other markers).

Stabilized North Up (NU) Display

In contrast to the unstabilized display, some radar units (typically more expensive models that would be found on larger vessels) feature a stabilized display with *north up* (NU) presentation. The stabilized display accepts heading information from the vessel's gyrocompass or, alternatively, from a fluxgate or electronic compass. This information is shown schematically in Figure 9-15, which presents a NU display for the same case as shown in Figure 9-14. In this display, a heading flash (shown by the dashed line) shows own ship's instantaneous heading. The heading flash shows the true or magnetic heading, depending on whether a gyrocompass or fluxgate compass is used. In the example above, the true heading would be 030 + 002 - 010 = 022 degrees, as shown in Figure 9-15. If the reference vessel were to change course, the radar image would not change (as it would with an unstabilized display)—only the heading flash would change position, hence the name *stabilized display*.

As most vessels yaw somewhat, even if the helmsman attempts to maintain a steady course, *target smear* is sometimes a problem with unstabilized displays. Bearing accuracy, in consequence, is generally higher with a stabilized display. Additionally, true (or magnetic) target bearings can simply be read directly from the NU display, without any additional calculations.

Finally, because the target location does not change when the reference ship changes course, targets are less likely to be "lost" (e.g., confused with other targets in the display) by the observer in the event that the reference ship maneuvers. In the example shown in Figure 9-14, there is only one target in view, so the target is unlikely to be lost. However, in a "target-rich environment" (i.e., if many targets are present) it can be difficult to keep track of the individual targets on the SHU display.

True Motion Display

Both the stabilized and unstabilized displays discussed above present a picture of relative, rather than true, motion. Rates of movement of the target, for example, are relative to the reference vessel and not to the ocean or the bottom. For example, if one vessel were steaming north at 10 knots and meeting another vessel on a southbound course moving at the same speed, the relative closure rate is 20 knots. This would be the apparent speed of the target as calculated from successive observations of the target from a relative motion radar. Similarly, land and other fixed features will have an apparent velocity when observed from a relative motion radar. (As noted above, these objects will have apparent motion opposite, but at a speed equal to that of the reference vessel.)

Some radar units are so-called true motion units. These are able to display the actual movements of the reference vessel as well as that of the other targets. (This requires additional computers and some means of determining the vessel's true course and speed.) Land and other fixed targets remain fixed on the display and the vessels move about in very much the same fashion as would be seen by an overhead observer. This advantage comes about at the expense of complexity in operation and cost. Because true motion radar units are (at present) priced out of the reach of all but a small proportion of recreational boaters, these are not discussed further in this chapter.

DISPLAY SCREENS AND OPTIONS

The display types discussed above should not be confused with the display screen. Conventional screens, also called analog displays, were standard at one time. The image displayed on a conventional screen *decays* (becomes less bright) over time until it is *refreshed* with the next revolution of the antenna. Conventional displays require the use of a viewing hood during daytime hours.

Within the past few years, digital or digitized displays, also called raster scan displays (also termed *cathode ray tube* (CRT) displays) have become available. Raster scan displays are an outgrowth of modern television technology. The principal advantage of these new displays is that the image does not decay, but rather remains bright as the antenna revolves. Viewing hoods are not generally required with this display.

Some radar units are equipped with color, rather than monochrome displays. On some models, different colors are used only to differentiate fixed or variable range markers (see below), but on others, different hues are used to denote the intensity of the echo.

More recently, *liquid crystal displays* (LCDs) have become popular. LCDs draw less power (an attractive feature for sailboats), are thinner and lighter, and more easily visible in sunlight. CRTs typically have greater resolution and are easy to read and interpret in low-light conditions. LCD displays are generally the display of choice for sailboats and small open powerboats.

Many radar units are able to display waypoints (from a Loran-C or GPS unit) on the radar screen. These are typically shown as a small circle with a dashed line from the center of the display—a so-called "lollipop." This is a convenient feature.

RADAR PLOTTING— A FIRST EXAMPLE

Radar observations of targets are generally plotted to determine the answers to key questions regarding the likelihood of collision, speed, and course of the target, etc. Plotting may be done manually, as discussed in this chapter, or automatically if the radar has this feature.

Radar plotting is better described by example than abstract discussion of theory. So, let's suppose that you are the navigator aboard the yacht, *Altair*, maintaining a course of 112 degrees at 5 knots, outbound for Bermuda just south of the shipping channel off the mouth of the Delaware Bay. *Altair* is equipped with radar with unstabilized SHU display. At 1000, a radar target can be identified bearing 322 degrees relative (using the EBL) at a range of 7.3 M (using the VRM). Means for identification of targets are discussed later in this chapter. Factors considered in target identification include the vessel's location relative to charted ATONs, known fishing areas, the water depth at the target's location, the range at which the target is detected, and the apparent course and speed of the target. In this example, suppose that there are no ATONs or fixed obstructions at the target's location. *Altair's* navigator tentatively identifies that target as another vessel and decides to monitor the target's progress.

Because *Altair* has an unstabilized display, the navigator calls "mark" when using the EBL to determine the relative bearing, and records the helmsman's response. At 1000, *Altair's* heading is 112 degrees. The navigator records the observation (target bearing, *Altair's* heading, time, and target range) and attends to other duties. *Altair* maintains course and speed. At 1006, the process is repeated and a second observation recorded. The target vessel bears 321 degrees relative at range 6.3 M while *Altair* is on a heading of 110 degrees. (Although range and bearing information can be taken at any interval of time, it is customary to take observations at equally spaced instants in time. Moreover, to simplify later calculations, observations are often taken at intervals of 3, 6, or 12 minutes. For example, if observations are taken every 6 minutes (0.1 hour), the speed of the relative motion is simply 10 times the distance traveled during the interval.)

Because the target's relative bearing appears nearly constant and the target's range is decreasing, a so-called *constant bearing decreasing range* (CBDR) situation, the navigator decides to monitor the target more closely and to prepare a radar plot on a maneuvering board (M board). Interpretation of radar plot is considerably simplified if the reference ship maintains course and speed, so the navigator ensures that Altair keeps on course and speed until all observations are completed.

Whether or not to plot a target requires some judgment. It is generally impractical and unnecessary to plot all targets that appear on the screen. This is particularly true in congested areas, such as harbor entrances or fishing grounds, where the sheer number of targets would preclude plotting of all targets. However, if a collision results, the failure to maintain a plot may have legal implications. At a minimum, all CBDR targets should be plotted or otherwise observed systematically, particularly where visibility is reduced. As noted in Rule 7, systematic observation may be used in lieu of plotting. The easiest way to accomplish this is to place an EBL on the target. If the target appears to "walk down the EBL" towards your vessel, a CBDR situation exists and some corrective action needs to be taken.

To return to the example: at 1012, when *Altair's* heading is 111 degrees, the target bears 316 degrees, at range 5.3 M. Figure 9-16 shows the position of the target as it would be seen at successive times of observation—denoted /XX, where XX refers to the number of minutes past the hour when the observation was taken. As can be seen from the successive PPI images, the relative motion (SHU) of the target is generally southeastward (moving "downscope" and closing from left to right) on the SHU display, and some danger of collision may exist. An M board plot is judged to be appropriate. To facilitate the preparation of the M board plot, the worksheet shown in Table 9-3 has been developed. Directions for filling in the worksheet and the preparation of the plot are given below.

Worksheet Preparation and Plotting

The worksheet shown in Table 9-3 has three sections: a data section, a space for remarks on the plot, and, finally, a guide to the computations. Experience has shown that the use of the worksheet simplifies plotting and interpretation of the results.

BASIC WORKSHEET FOR SOLVING RADAR PROBLEMS ON MANEUVERING BOARD

DATA FOR PLOTTING: EXAMPLE/CASE:______________ OWN SHIP'S COURSE AND SPEED:______________

TIME	DISTANCE IN MILES OR YARD NOTE UNITS	OWN SHIP'S HEADING (TRUE OR MAG	TARGET RELATIVE BEARING	TARGET TRUE MAG BEARING	REMARKS
					DISTANCE AND TARGET TRUE OR MAGNETIC BEARING ARE TO BE PLOTTED ON MANEUVERING BOARD. IF TRUE BEARINGS ARE DESIRED ITS NECESSARY TO CONVERT FROM COMPASS HEADING TO TRUE HEADING USING CDMVT ADD EAST LOGIC. CHOOSE AND LABEL BOTH SPEED AND DISTANCE SCALES ON THE BOARD. ENSURE POINTS ARE PLOTTED CAREFULLY USING THE CORRECT SCALE!
HOW ENTRIES ARE OBTAINED	RECORDED AT TIME OF OBS.	READ FROM RANGE RING OR VRM	READ FROM COMPASS OR GYRO	READ FROM EBL ON RADAR SCOPE	CALCULATED FROM SH + RB (360 MAY HAVE TO BE SUBTRACTED)

SCALE	SD	VALUE
DISTANCE		______________
SPEED		______________

INSERT REMARKS HERE ON MANEUVERING BOARD PLOTS:

COMPUTATIONS:

TOPIC	QUANTITY	VALUE	REMARKS ON CALCULATION
RELATIVE MOTION	DIRECTION OF RELATIVE MOTION:	__________	MEASURED FROM RELATIVE MOTION PLOT-DO NOT ERR BY 180 DEGI
	DIST BETWEEN OBSERVATIONS:	__________	TAKEN FROM LINEAR PORTION OF RELATIVE MOTION PLOT (RMP)
	TIME BETWEEN OBSERVATIONS:	__________	TAKEN FROM INPUTS ON LINEAR PORTION OF RMP
	SPEED OF RELATIVE MOTION:	__________	CALCULATED FROM ABOVE TWO ENTRIES S = 60D/T
CPA	DISTANCE TO CPA:	__________	EXTRAPOLATED OR INTERPOLATED FROM RELATIVE MOTION PLOT
	TRUE OR MAGNETIC BEARING OF CPA:	__________	FROM DRM PLUS OR MINUS 90 DEGREES
	RELATIVE BEARING OF CPA:	__________	FROM TRUE OR MAGNETIC BEARING MINUS OWN SHIP'S HEAD
	DIST FROM LAST OBS TO CPA:	__________	MEASURED FROM RELATIVE MOTION PLOT
	TIME TO TRAVERSE THIS DIST:	__________	FROM T = 60D/S
	TIME OF CPA:	__________	FROM ABOVE PLUS TIME OF LAST OBSERVATION
TARGET MOVEMENT	TARGET COURSE:	__________	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD
	TARGET SPEED:	__________	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD

TABLE 9-3–Basic Worksheet for Solving Radar Problems on Maneuvering Board

The first section of the worksheet to be filled in is the data section. Accordingly, the data on the time of observation, target range, own ship's heading, and target relative bearing are entered, along with own ship's course and speed. To simplify the calculations for the first example, assume that the ship's compass has no deviation. Additionally, this problem is solved in magnetic, rather than true, directions to eliminate the need to consider variation. With these conventions, the target's magnetic bearing can be calculated from the equation, reference ship's head + relative bearing = bearing to target. For example, in the first observation at /00, the target's magnetic bearing is 112 + 322 = 434 degrees. Since this exceeds 360, 360 is subtracted and the calculated magnetic bearing is 074 degrees. The other times, dis-

BASIC WORKSHEET FOR SOLVING RADAR PROBLEMS ON MANEUVERING BOARD

DATA FOR PLOTTING: EXAMPLE/CASE: Altair OWN SHIP'S COURSE AND SPEED: 112° 5 KTS

TIME	DISTANCE IN MILES OR YARD NOTE UNITS	OWN SHIP'S HEADING (TRUE OR MAG)	TARGET RELATIVE BEARING	TARGET TRUE MAG BEARING
1000	7.3	112	322	074
1006	6.3	110	321	071
1012	5.3	111	316	067
HOW ENTRIES ARE OBTAINED: RECORDED AT TIME OF OBS.	READ FROM RANGE RING OR VRM	READ FROM COMPASS OR GYRO	READ FROM EBL ON RADAR SCOPE	CALCULATED FROM SH + RB (360 MAY HAVE TO BE SUBTRACTED)

REMARKS

DISTANCE AND TARGET TRUE OR MAGNETIC BEARING ARE TO BE PLOTTED ON MANEUVERING BOARD. IF TRUE BEARINGS ARE DESIRED ITS NECESSARY TO CONVERT FROM COMPASS HEADING TO TRUE HEADING USING CDMVT ADD EAST LOGIC. CHOOSE AND LABEL BOTH SPEED AND DISTANCE SCALES ON THE BOARD. ENSURE POINTS ARE PLOTTED CAREFULLY USING THE CORRECT SCALE!

SCALE	SD	VALUE
DISTANCE	1	1 M
SPEED	1	1 KT

INSERT REMARKS HERE ON MANEUVERING BOARD PLOTS:

Straight Line & Constant Interval Between Points on RMP indicate Both Vessels Maintaining Course & Speed

COMPUTATIONS:

TOPIC	QUANTITY	VALUE	REMARKS ON CALCULATION
RELATIVE MOTION	DIRECTION OF RELATIVE MOTION:	271	MEASURED FROM RELATIVE MOTION PLOT-DO NOT ERR BY 180 DEGI
	DIST BETWEEN OBSERVATIONS:	2.1	TAKEN FROM LINEAR PORTION OF RELATIVE MOTION PLOT (RMP)
	TIME BETWEEN OBSERVATIONS:	12 Min.	TAKEN FROM INPUTS ON LINEAR PORTION OF RMP
	SPEED OF RELATIVE MOTION:	10.5	CALCULATED FROM ABOVE TWO ENTRIES S = 60D/T
CPA	DISTANCE TO CPA:	2.2	EXTRAPOLATED OR INTERPOLATED FROM RELATIVE MOTION PLOT
	TRUE OR MAGNETIC BEARING OF CPA:	001	FROM DRM PLUS OR MINUS 90 DEGREES
	RELATIVE BEARING OF CPA:	249	FROM TRUE OR MAGNETIC BEARING MINUS OWN SHIP'S HEAD
	DIST FROM LAST OBS TO CPA:	4.9	MEASURED FROM RELATIVE MOTION PLOT
	TIME TO TRAVERSE THIS DIST:	28 Min.	FROM T = 60D/S
	TIME OF CPA:	1040	FROM ABOVE PLUS TIME OF LAST OBSERVATION
TARGET MOVEMENT	TARGET COURSE:	254	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD
	TARGET SPEED:	6.1	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD

TABLE 9-4–Completed Worksheet for First Example

tances, relative bearings, and calculated magnetic bearings are similarly recorded and entered into the worksheet, as shown in Table 9-4.

Next, it is necessary to plot these data. In principle, the *relative motion plot* (RMP) could be prepared either with grease pencil on a transparent plastic overlay on the radar screen itself, on an M board, or on another special purpose chart such as a *radar transfer plotting sheet* (RTPS). But, because an unstabilized display is being used, the radar screen is small, and the navigator may wish to change range scales as the target vessel draws closer, a M board is used for plotting rather than plotting on the radar screen. Two separate plots are prepared: an RMP and a speed or *vec-*

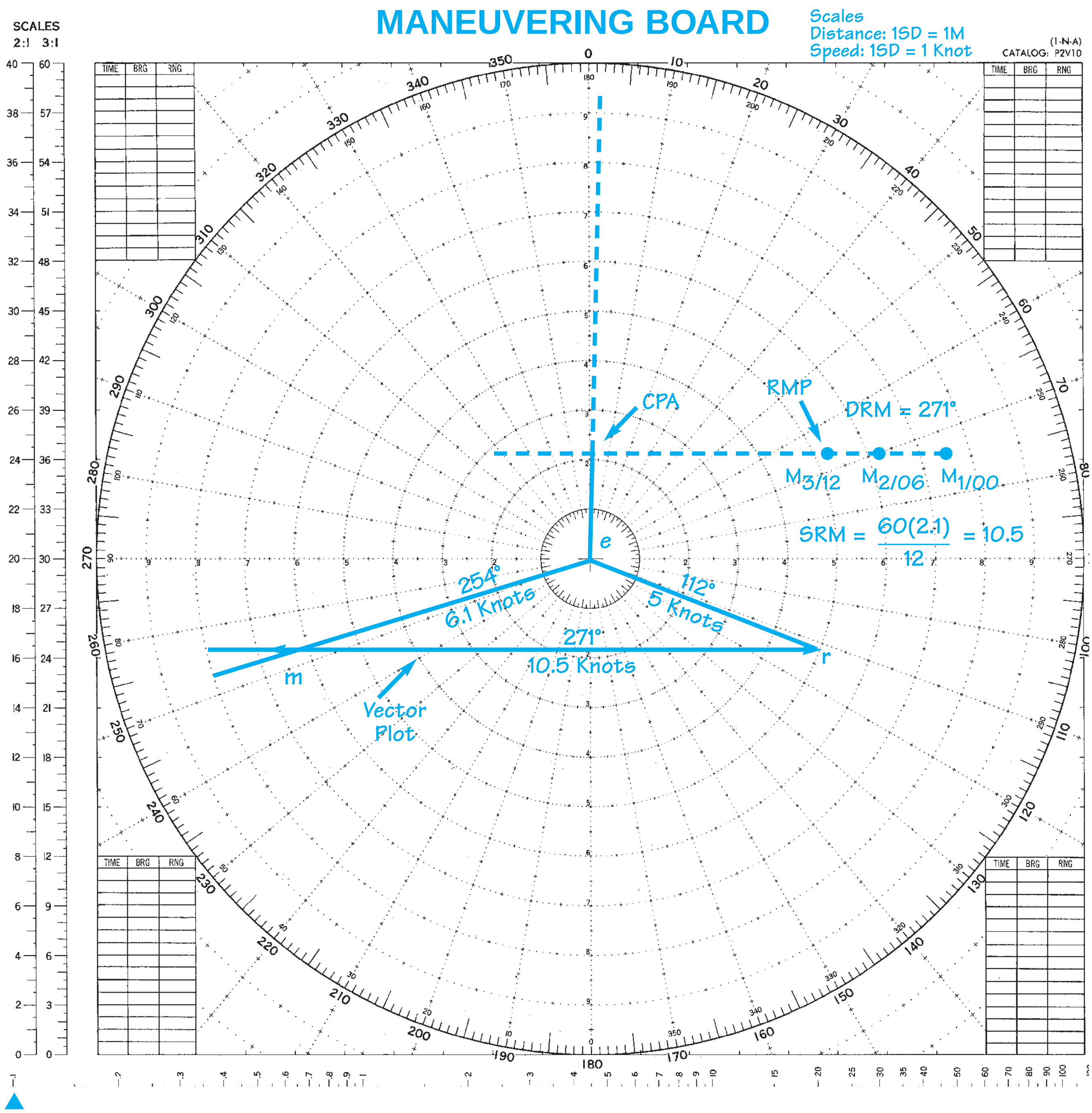


FIG. 9-17–Radar Plot for *"Altair"* Example

tor diagram (VD). It is essential that these two plots not be confused. For convenience, these two separate graphs are generally plotted on the same M board, but the plots are logically distinct.

The first plot required is the RMP. The RMP is used to determine whether or not a danger of collision exists, the *closest point of approach* (CPA), the *direction of relative motion* (DRM), the *time to closest point of approach* (TCPA), and other quantities if required. The second of these plots, the VD, is used to determine the target's course and speed.

Relative Motion Plot (RMP)

To prepare the RMP it is necessary to plot successive observations of the target's distance and either true or magnetic bearing. Although a useful plot can be made from as few as two observations, generally three or more are plotted if time and circumstances permit. Your vessel (*Altair*) is termed the *reference ship* or vessel and is labeled "R" if required. (Symbols for the RMP are, by convention, all uppercase.) In a RMP, own ship is located at the origin (center of the plot) at all times.

The target is termed the *maneuvering ship* and is labeled "M." Successive data points for the maneuvering ship are denoted with the symbol Mi /XX to denote the i^{th} observation and the time when it was made. In this example, the first observation would be denoted M1/00, the second observation M2/06, and the third observation M3/12. The target range and true or magnetic (magnetic in this example) bearings are plotted on the polar diagram (M board). M boards are discussed in Chapter 7.

For ease in plotting, it is sometimes appropriate to plot the target at a different scale than 1 *scale division* (SD) equals 1 nautical mile (M). However, a scale of 1 SD equals 1.0 M is convenient in this example. There is provision on the worksheet to note the scale, but, additionally, it is useful to write the scale on the M board. If scales other than 1:1 are used, it is necessary to factor the scale into the calculations.

Care should be taken in preparing the plot. Small plotting errors are carried through the calculations and can influence the final results substantially. Common errors include failing to use the scale factors (if other than 1:1) and misreading the bearing scale (e.g., plotting 074 degrees as 066 degrees, etc.).

Figure 9-17 shows the M board RMP. The three observations are plotted. For each observation the coordinates are range (M) and magnetic bearing. Passing a straight edge or paraline plotter through these points indicates that all lie approximately on the same straight line and are equally spaced. This situation will occur whenever the reference ship and the maneuvering ship both maintain course and speed. *Altair* has maintained speed and course (by design), so this plot enables the conclusion to be drawn that the target vessel has also maintained course and speed. This conclusion is noted in the worksheet in Table 9-4.

From the RMP it is possible to calculate several useful quantities. These include:

- ❑ First, the *direction of relative motion* (DRM) can be estimated. This is done by connecting the points on the line and sliding the paraline plotter to a line parallel to the DRM but through the origin. The DRM (271 degrees in this example) can be read on the outer (bearing) scale of the M board. The DRM is noted on the M board and the worksheet. It is important to avoid reading the reciprocal direction on the M board. In this instance, successive points lie generally to the left of each other, and this determines the direction. (Note that the DRM, nearly westward in this case, differs from the apparent southeastward motion of the target on the SHU display. These two directions will only be the same when the reference ship is heading north.) The DRM is the first entry on the third (bottom) section of the worksheet.
- ❑ Second, it is useful to calculate the *speed of relative motion* (SRM) from the RMP. If the points are equally spaced and lie in a straight line, the speed is constant. The SRM can be calculated by measuring the distance between the first and last observations on the RMP with a pair of dividers, and calculating the speed using the formula S = 60D/T. In this example, the SRM works out to approximately 10.5 knots. Alternatively, the nomogram on the bottom of the M board (not shown in this illustration) can be used to estimate the SRM. These entries are also given on the completed worksheet in Table 9-4.
- ❑ Third, the RMP can be used to calculate the CPA. As the name implies, the CPA is the smallest distance that the maneuvering ship (the target) will approach the reference ship, to use the common terminology. It is determined by either extrapolating or interpolating the RMP. The CPA is found by drawing a line from the origin perpendicular to the RML. The point where the perpendicular and the RML intersect is the CPA. Although this can be done graphically, it is easier to calculate the bearing from the DRM plus or minus 90 degrees. The distance, approximately 2.2 nautical miles in this example, can be transferred to one of the distance scales with a pair of dividers. By extending

the line from the origin through the CPA to the bearing scale, a true (magnetic) bearing of the CPA can be obtained. In this example, the magnetic bearing of the target at the CPA is approximately 001 degrees. These entries are also shown on the worksheet in Table 9-4. The relative bearing of the CPA can be calculated from the true (magnetic) bearing minus the ship's head. In this example, the relative bearing is 001 degrees magnetic minus 112 degrees (360 must, therefore, be added), or 249 degrees. In other words, at the point of closest approach the target vessel will be approximately 21 degrees abaft *Altair's* port beam.

- ❑ Fourth, the TCPA can be determined, by measuring the distance between the last observation, M3, and the CPA, approximately 4.9 M, and calculating how long it would take to traverse this direction at the SRM. In this example, the TCPA is estimated to be 1040.

To summarize the results for this example, the RMP has enabled the following estimates to be made. The target vessel will pass as close as 2.2 M to *Altair* at 1040 with relative bearing of closest approach 249 degrees. Actions to be taken by *Altair's* crew in this case depend upon additional factors, such as *Altair's* ability to maneuver, visibility, etc. In good weather, *Altair's* skipper would probably elect to maintain course and speed, alert the lookout(s) to the target's position, and continue to monitor the situation until the target vessel was well clear. Other options include attempting to contact the target vessel on VHF/FM (Channel 13) to arrange details of passage, or altering course or speed to increase the separation at CPA. The effect of course or speed adjustments can be evaluated on an M board, but this is beyond the scope of this chapter.

THE VECTOR DIAGRAM

The second plot generally required for complete solution of the radar problem is the speed triangle or vector diagram. It is used to estimate the target's course and speed. There are two principal methods for plotting the vector diagram. The method discussed here can be found in the *Maneuvering Board Manual* or the *Radar Navigation Manual* published by the DMA (now NIMA), and cited in the attached references. Another method, called the *Real Time Method* (RTM), is gaining favor among radar users. This is also described in some of the references but is not discussed here.

Unlike the RMP, which shows distances and bearings, the vector diagram shows speeds and courses of the maneuvering and reference ships. Therefore, it is possible that a different scale would be appropriate for plotting the vector diagram. In this example, however, a scale of 1 knot equals 1 SD is appropriate and is so noted on the M board and worksheet alike.

The vector diagram is a graphical method for vector addition and is used to determine the course and speed of the maneuvering ship. It is simple to use and interpret, and is described in the three steps shown below:

- ❑ First, the reference vessel's course and speed vector is plotted. This vector, labeled er (lowercase letters are used on the vector plot to avoid confusion with the uppercase symbols on the RMP), is plotted on the M board. The vector is drawn outward from the origin in the direction of the course of the reference vessel. The length of vector er is proportional to the speed of the reference vessel. In this example, *Altair's* speed vector has a length of 5 SDs (5 SDs correspond to 5 knots at a 1:1 scale) and is drawn outward on a heading of 112 degrees.
- ❑ Second, the relative motion vector is laid out on the M board. The "tail" of the relative motion vector is the DRM (271 degrees in this example), and is conveniently laid out by moving the paraline plotter parallel to the DRM on the RMP. The length of the relative motion (rm) vector is the SRM (10.5 knots, or 10.5 SDs at the 1:1 scale used in this example), determined from the RMP.
- ❑ Third, the maneuvering vessel's vector, denoted em, is drawn from the origin to the head of the relative motion vector. The orientation of this vector (254 degrees in this example) is the course (magnetic in this example) of the maneuvering or target vessel. The length of this vector (measured as 6.1 SDs, or 6.1 knots at a 1:1 scale) is equal to the speed of the target. The fact that the target's estimated speed is positive confirms the navigator's initial classification of the target as another vessel. If the target were stationary, or

nearly so, it could have been a vessel at anchor (the plausibility of this hypothesis could be checked from the depth of water), dead in the water, or, possibly, a fixed ATON.

This completes the radar plot for the first example. Inspection of both plots shows that *Altair* and the target vessel are almost on opposite courses, and should pass port-to-port at a distance of approximately 2.2 M if both vessels maintain course and speed. In practice, the RMP would probably be continued or otherwise systematically observed to monitor the progress of the maneuvering vessel and ensure that no subsequent course or speed adjustments were required to avoid collision.

AUTOMATIC RADAR PLOTTING AID

Even though there are faster plotting methods than illustrated above, it should be clear that radar plotting could be a chore. To facilitate this process, large ship radar units are equipped with an *Automatic Radar Plotting Aid* (ARPA). ARPA automates preparation of a plot. A target can be designated and a computer in the radar unit makes the necessary computations. ARPA can display all the relevant quantities computed laboriously above.

Several manufacturers have introduced radar units with "Mini-ARPAs" for use on recreational boats. Use of such radar units can reduce cockpit workload considerably—but only if the mariner is fully familiar with their operation.

RADAR PLOTTING— A SECOND EXAMPLE

As a second example, range and bearing data are presented from one reconstruction of a collision that occurred in clear weather between the Polish M/V *Nowy Sacz* and the Cypriot ship *Olympian* under conditions of darkness early one morning on 14 February 1972 approximately 20 M south of Cape St. Vincent, off the Iberian Peninsula, along the coast of Portugal. Although both ships were using radar for navigation, radar observations were not taken nor were M board plots actually made in this case. Nonetheless, sufficient data exist to reconstruct the sequence of radar observations that would have resulted had these actually been taken.

To make the problem concrete, suppose that you are the master of the *Nowy Sacz*, enroute from Casablanca in North Africa to Gdynia, Poland. At 0245, *Nowy Sacz* is making 12.5 knots on a true course of 341 degrees. A radar target is identified with a relative bearing of 124 degrees, approximately 3.7 miles distant. (For purposes of this example, assume that *Nowy Sacz* has an unstabilized SHU display.) By 0300 the target has closed to approximately 2.9 M while still bearing 124 relative. A third observation is taken at 0315, when the target bears 124 degrees relative at a range of approximately 2.2 M. Assume that, because an autopilot was in use, *Nowy Sacz's* heading and speed remained constant at 341 degrees and 12.5 knots, respectively, while the bearings were taken. Prepare an M board plot for these observations and estimate the CPA, course, and speed of the target. What actions, if any, should you take as the master of the *Nowy Sacz* on the basis of these data?

Solution to Second Example

Table 9-5 and Figure 9-18 show the completed worksheet and M board plot, respectively, for this example. From the RMP, it is determined that the DRM is 285 degrees and the SRM is 3 knots. From the M board plot, it is clear that the CPA is 0 M, i.e., a collision situation exists. The TCPA (time of estimated collision) in this case is 0359, and the target's course and speed are estimated to be 331 degrees and 14.6 knots respectively. Incidentally, the Cypriot vessel claimed to be on a course of 290 degrees making only 13 knots, a claim that was rejected by the court on the basis of the evidence presented.

From the M board plot it is clear that the *Olympian* is overtaking the *Nowy Sacz*. So under the NAVRULES (assuming that the vessels were in sight of one another) the *Nowy Sacz* was the stand-on vessel and the *Olympian* should have altered course/speed to avoid collision. The actual situation was somewhat more complex and the *Nowy Sacz* was initially held responsible for the collision that resulted. However, on appeal, this verdict was reversed and the *Olympian* was held to be partially at fault. The actual collision occurred at 0358, in agreement with the predicted TCPA.

This example is instructive in that it shows the value of an M board plot, rather than simple examination of the radarscope images alone. However, even the

BASIC WORKSHEET FOR SOLVING RADAR PROBLEMS ON MANEUVERING BOARD

DATA FOR PLOTTING: EXAMPLE/CASE: NOWY SACZ OWN SHIP'S COURSE AND SPEED: 341° 12.5 KTS

TIME	DISTANCE IN MILES OR YARD NOTE UNITS	OWN SHIP'S HEADING (TRUE OR MAG	TARGET RELATIVE BEARING	TARGET TRUE MAG BEARING
0245	3.7	341	124	105
0300	2.9	341	124	105
0315	2.2	341	124	105
HOW ENTRIES ARE OBTAINED: RECORDED AT TIME OF OBS.	READ FROM RANGE RING OR VRM	READ FROM COMPASS OR GYRO	READ FROM EBL ON RADAR SCOPE	CALCULATED FROM SH + RB (360 MAY HAVE TO BE SUBTRACTED)

REMARKS

DISTANCE AND TARGET TRUE OR MAGNETIC BEARING ARE TO BE PLOTTED ON MANEUVERING BOARD. IF TRUE BEARINGS ARE DESIRED ITS NECESSARY TO CONVERT FROM COMPASS HEADING TO TRUE HEADING USING CDMVT ADD EAST LOGIC. CHOOSE AND LABEL BOTH SPEED AND DISTANCE SCALES ON THE BOARD. ENSURE POINTS ARE PLOTTED CAREFULLY USING THE CORRECT SCALE!

SCALE	SD	VALUE
DISTANCE	2	1 M
SPEED	1	2 KTS

INSERT REMARKS HERE ON MANEUVERING BOARD PLOTS:

CBDR Situation—Straight Line Plot

COMPUTATIONS:

TOPIC	QUANTITY	VALUE	REMARKS ON CALCULATION
RELATIVE MOTION	DIRECTION OF RELATIVE MOTION:	285°	MEASURED FROM RELATIVE MOTION PLOT-DO NOT ERR BY 180 DEG!
	DIST BETWEEN OBSERVATIONS:	1.5 M	TAKEN FROM LINEAR PORTION OF RELATIVE MOTION PLOT (RMP)
	TIME BETWEEN OBSERVATIONS:	30 Min.	TAKEN FROM INPUTS ON LINEAR PORTION OF RMP
	SPEED OF RELATIVE MOTION:	3	CALCULATED FROM ABOVE TWO ENTRIES S = 60D/T
CPA	DISTANCE TO CPA:	0!	EXTRAPOLATED OR INTERPOLATED FROM RELATIVE MOTION PLOT
	TRUE OR MAGNETIC BEARING OF CPA:	NA	FROM DRM PLUS OR MINUS 90 DEGREES
	RELATIVE BEARING OF CPA:	NA	FROM TRUE OR MAGNETIC BEARING MINUS OWN SHIP'S HEAD
	DIST FROM LAST OBS TO CPA:	2.2	MEASURED FROM RELATIVE MOTION PLOT
	TIME TO TRAVERSE THIS DIST:	44 Min.	FROM T = 60D/S
	TIME OF CPA:	0359	FROM ABOVE PLUS TIME OF LAST OBSERVATION
TARGET MOVEMENT	TARGET COURSE:	331°	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD
	TARGET SPEED:	14.6	FROM COMPANION VECTOR PLOT ON MANEUVERING BOARD

TABLE 9-5–*Nowy Sacz/Olympian* Collision

radar observations alone should have alerted both vessels that a collision was likely. Note that the same succession of radar images could have resulted from many combinations of reference and target ship movements. For example, if the *Nowy Sacz* were dead in the water rather than on the course and at the speed indicated, the identical series of radar images could have resulted if the *Olympian* were approaching on a course of 285 degrees at 3 knots. In fact, there are an infinite number of combinations of speed and course for the reference and maneuvering ships that could have produced the same RMP. It is only the vector plot that enables the actual course and speed of the maneuvering ship to be determined.

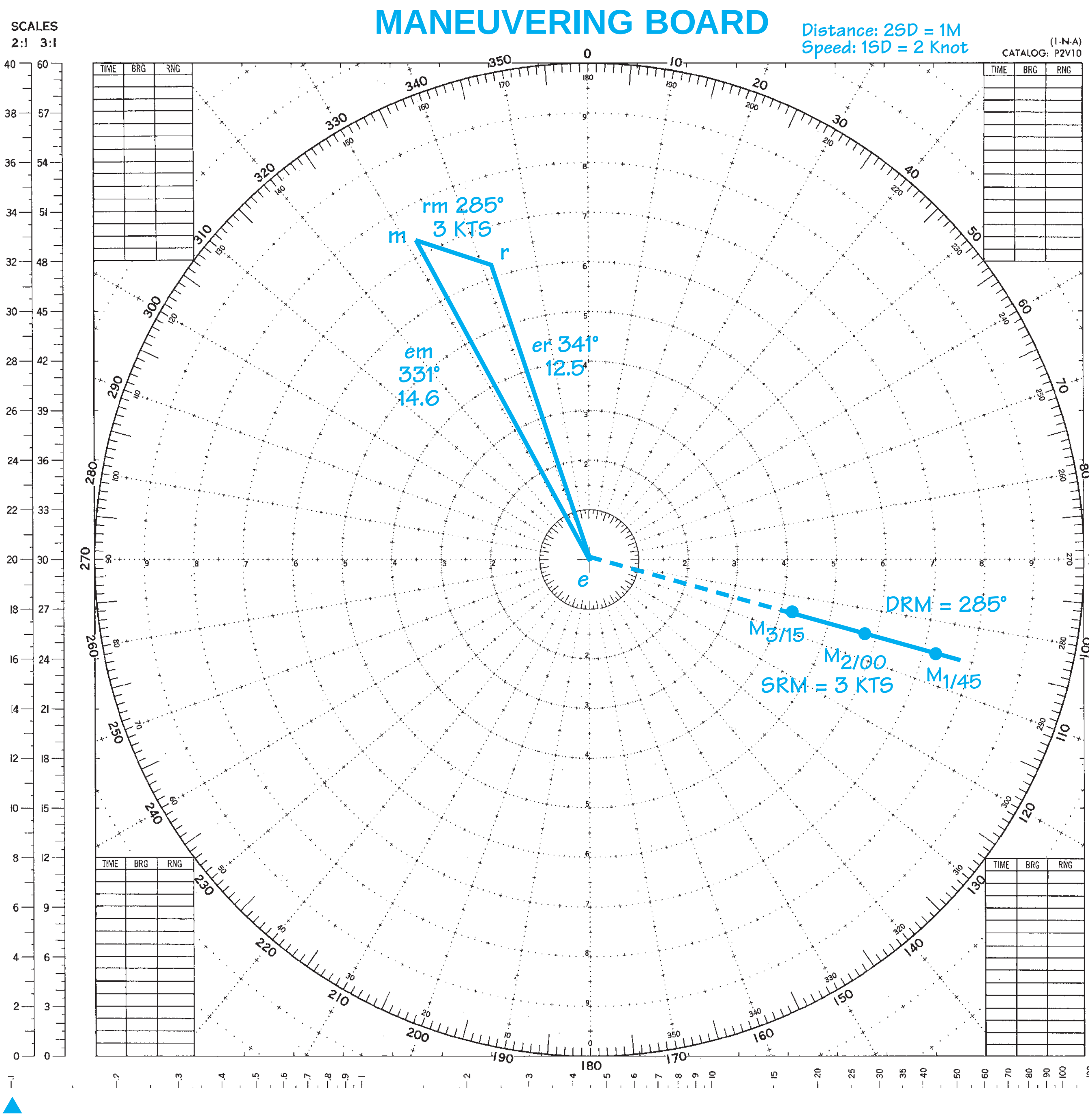


FIG. 9-18–*Nowy Sacz/Olympian*

THIRD EXAMPLE

The third example presented here is of interest because the plot is somewhat complex and presents more of a challenge to interpretation. In all the problems given above, the M board plot was linear and the distances were constant between evenly spaced observations. As noted, this situation results only when both the reference and maneuvering vessels maintain course and speed. Indeed, it is important to note that the reference vessel should maintain course and speed throughout the plotting interval if valid data are to be obtained. However, even if the reference vessel maintains course and speed, the maneuvering vessel(s) may not do so. Thus, it is important to consider some cases involving a maneuvering target.

In this example, the M/V *Pollux* is proceeding due north at a speed of 9 knots inbound to Valdez, Alaska. At XX29 a target is identified bearing 111 degrees at a range of 2.3 M. To avoid tedious computations, it is assumed that a NU display is available and true bearing information is given directly as shown below.

Time	Range (M)	Bearing (Degrees)
xx29	2.30	111
xx35	1.20	111
xx38	0.60	111
xx41	0.35	140
xx47	0.60	225
xx53	1.20	243

Solution

The M board plot shown in Figure 9-19 presents a somewhat more complex picture than the earlier examples. In this case, the points on the RMP do not plot as a single straight line but, rather, appear to fall along two straight lines joined at xx38, indicating that either the reference or the target vessels changed course and/or speed. Since *Pollux* did not change either course or speed, the target vessel must have—possibly to avoid collision. Note that the first three points at 29, 35, and 38 past the hour indicate the classic CBDR pattern.

The object of this exercise is to determine what happened. It is solved by making two RMPs and two vector diagrams. Note the speed scale of 2 SD = 1 knot is used. After plotting the RMP and *Pollux's* speed vector, the relative motion vector should be inserted in the speed diagram. But, in this example there are two relative motion vectors—one valid for the first period, denoted rm1, and another valid after xx38, denoted by rm2. From the plot of the first three points it is determined that the DRM is 291 degrees and the SRM is approximately 11.3 knots. Connecting rm1 to er enables determination of the target vessel's initial course and speed to be 321 degrees and 17 knots, respectively.

To determine the target's course and speed after xx38 it is necessary to plot another vector diagram. But, *Pollux's* course and speed were unchanged, so the same vector, er, is used for the second vector diagram. The RML for the second time period shows that the DRM and SRM are approximately 259 degrees and 6.6 knots, respectively. These computations define the second rm vector, rm2, which is plotted as shown.

Examination of the second vector diagram indicates that the target's speed was reduced to approximately 10 knots, but that the course was unchanged, because rm2 lies along the same radial (approximately) as rm1. This example is particularly interesting because it clearly illustrates the value of plotting. It would be clear from inspection of the radar screen alone that "something" has happened, but only the M board plot enables the navigator to determine exactly what action was taken by the target vessel.

It is useful to consider this example from another perspective, that of the NAVRULES. In this connection, it is instructive to consider the circumstances of visibility:

- ❏ Suppose first that the prevailing visibility is such that *Pollux* and the target vessel are in sight of one another throughout the encounter. In this case, *Pollux* is the give-way vessel, because the target is in *Pollux's* danger zone –that is, between 0 degrees and 112.5 degrees relative bearing. The target, therefore, is a crossing vessel within the meaning of the NAVRULES. (Although the situation is close, the target is within 2 degrees of being an overtaking and, thus, the give-way vessel.) Close or not, *Pollux* should have given way, by either alteration of course or speed to ensure that the vessels passed at a safe distance (see Rule 15).
- ❏ Now suppose that this encounter took place in restricted visibility. In this situation, unlike that of vessels in sight of one another, there are no stand-on or give-way vessels. However (Rule 19), "a vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing or risk of collision exists." The rule continues, "If so, she shall take avoiding action in ample time." Because *Pollux* is equipped with operating radar and able to determine that a risk of collision existed, *Pollux* should have taken appropriate action to minimize the risk of collision.

Therefore, regardless of the prevailing visibility, *Pollux* should have initiated action to avert collision, albeit for different reasons. A complete discussion of the NAVRULES, radar, and collision-avoidance is beyond the scope of this text.

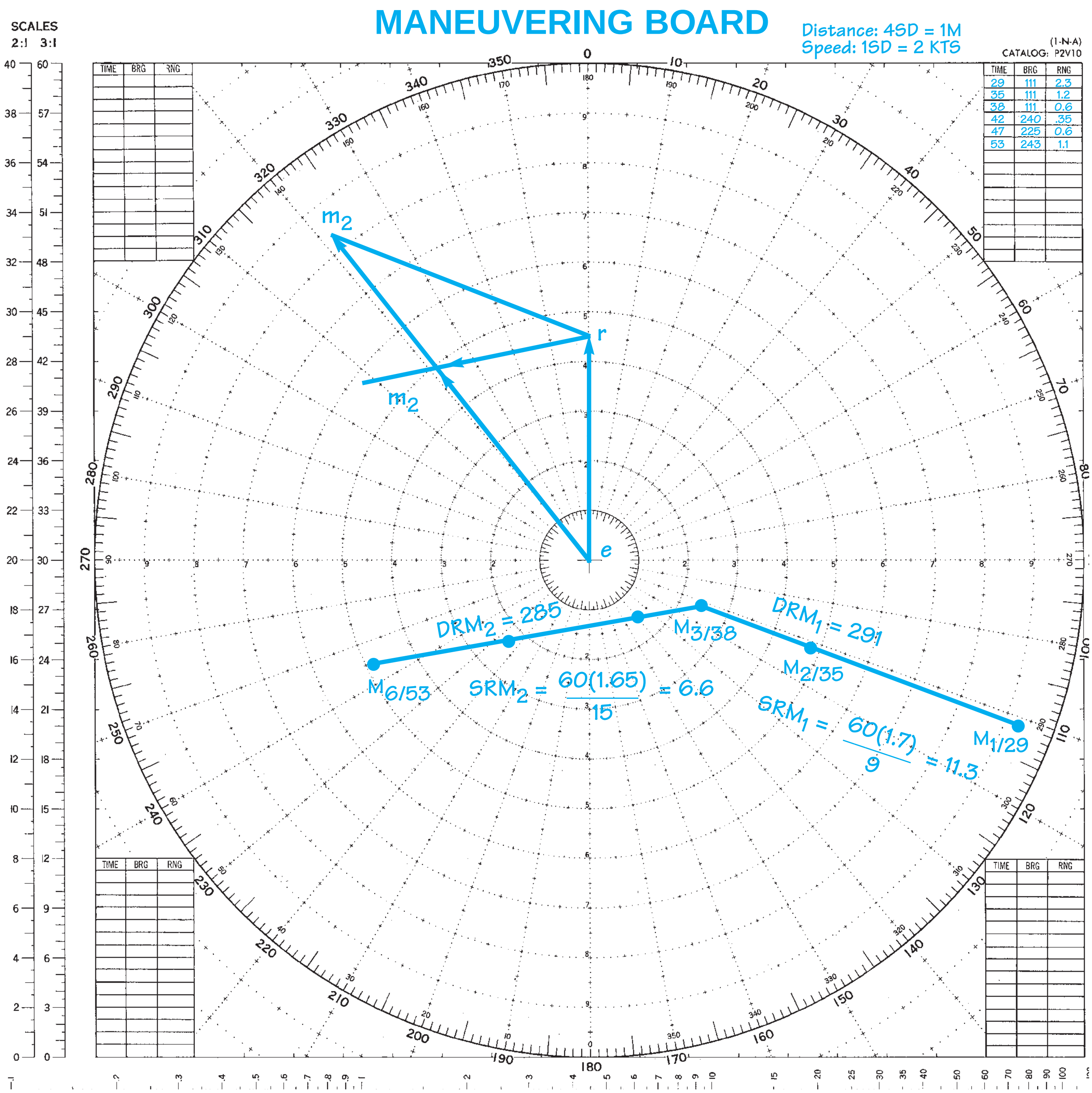


FIG. 9-19–Example Involving M/V *Pollux*

However, the reader is advised to review the references given in the bibliography for more details.

USE OF THE RTPS

A *Radar Transfer Plotting Sheet* (RTPS) can be used as an alternative to an M board for radar plotting. The RTPS is also available from NIMA (No. 5089, DMA Stock No. WOXZP 5089), but is produced in only one size (10-inch).

Figure 9-20 shows the RML for the first example as plotted on the RTPS. Before discussing the plot in detail, a brief review of the RTPS is in order. Basically, the RTPS offers a similar presentation to the M board, except that 6 FRMs are given and scales are adjusted to be multiples of 6 (i.e., 3 miles, 6 miles, 12

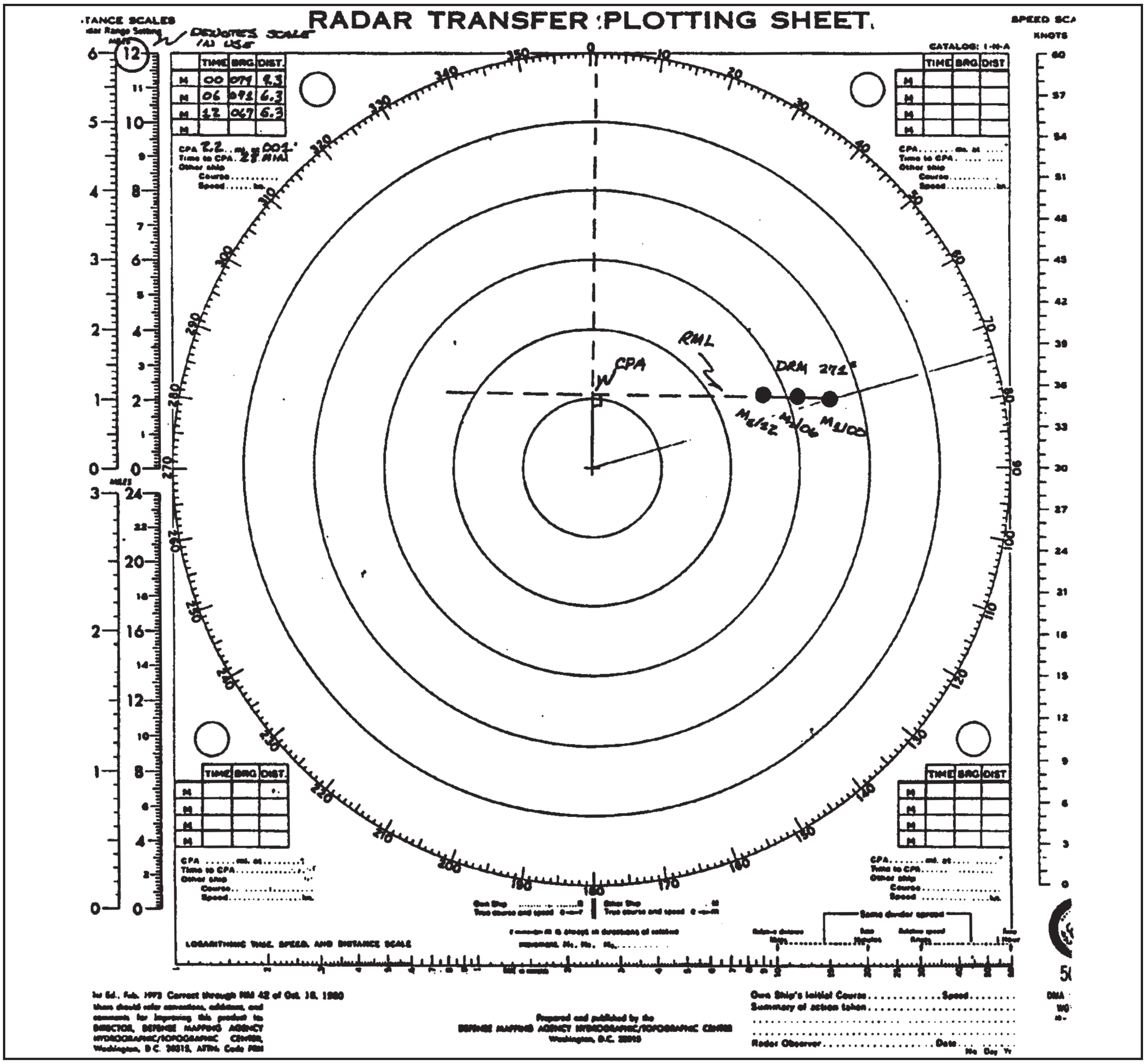


FIG. 9-20–*Altair* Example Plotted on RTPS

miles, and 24 miles). Suppression of a radiating distance (or speed) scale found on the M board presents a less cluttered plot, but auxiliary scales, given on the right- or left-hand side, need to be used and distances (or speed) transferred with a pair of dividers from the auxiliary scales to the plot. Thus, for example, observation Ml/00 is located 7.3 miles at a bearing 074 magnetic. If a 12-mile scale is assumed (i.e., FRMs located 2 miles apart), as denoted by placing a circle around the 12 in the auxiliary scale on the right-hand side, the distance (7.3M) is first measured with a set of dividers on this scale and then transferred to the radar scope facsimile in the center.

Use of an RTPS is particularly convenient if the range scales on your radar set match those on the RTPS. The auxiliary scales eliminate the need to convert from SDs to either distance or speed. However, as most small boat radar units have range scales that differ from the choices presented on the RTPS, use of an M board is recommended.

RADAR PLOTTING: THE STEPS SUMMARIZED

As illustrated in the above examples, the overall steps in radar plotting are as follows:

- **Observation and detection:** A continuous radar watch is maintained and the appearance of targets noted. On the basis of early observation of the range and bearing of the target(s) and other factors, a decision is made whether or not to plot or otherwise monitor the target(s). If practical, the reference ship should maintain course and speed.
- **Plotting and analysis:** If the target(s) is plotted, the plot is used to determine the risk of collision (CPA, TCPA) and nature of the encounter (true and relative bearings). Alternatively, this can be done automatically if the radar has this feature.
- **Selection of evasive action:** Although not discussed in this chapter, M boards can be used to evaluate the effects of course and speed changes to ensure that the vessels pass at a safe distance.
- **Monitoring results:** Radar plots are maintained to monitor the results of any collision avoidance maneuvers to verify their success and/or to select alternative maneuvers.

OTHER SITUATIONS OF INTEREST

There are several other salient points that should be made with respect to the interpretation of radar for collision avoidance.

- First, it is important to note that if the reference ship is *dead in the water* (DIW), aside from whatever drift and/or yaw may be present, the relative motion display behaves almost as though it were a true motion display. Thus, if presented with an ambiguous situation and conditions otherwise permit, you can simply halt the vessel to enable the course and speed of other targets to be observed directly.
- Second, it should be evident that a target which is apparently stationary when viewed from the radar screen of a moving vessel is not DIW, but rather maintaining the same course and speed as the reference ship. Such targets are often observed by vessels transiting inlets or enroute to popular destinations as they keep station relative to other vessels.
- Third, it is often of interest to identify stationary targets such as buoys, or other ATONs. There are several ways to do this. Often the location of the target and absence of other targets will render identification of buoys self-evident. This also highlights the importance of knowing the reference vessel's position accurately and is one of the many reasons why it is convenient to have a loran or GPS that "talks" to the radar and displays the vessel's latitude and longitude on the radar screen.

  In some cases, for example, with a transponder-equipped buoy, the identification is, likewise, self-evident. Frequently, buoys can be identified from the range at which detection first occurs. Detection ranges for buoys vary from perhaps 1/4 M for a conical buoy to 6 M or more for a buoy with a radar reflector. This also shows the value of a continuous radar watch. Sporadic observation will not enable the target's detection range to be estimated with any accuracy. A target detected at 10 or more miles distant, for example, is unlikely to be a buoy. If two targets are present, reducing the gain may enable differentiation to be made; the buoy will disappear first, while the echo of a nearby ship may remain visible.

  As well, M board plots can be used to differentiate between DIW targets, such as buoys and moving vessels. A target that is DIW will have a DRM opposite that of the reference vessel and a speed the same as the reference vessel. This can be determined solely from a RMP, although a vector diagram will, of course, confirm the stationary position of the target. In practice, a vector diagram for a DIW target will result in a small apparent speed due to observation errors, but values close to zero are sufficient confirmation of the target's status.

  From the above, it should be clear that targets on identical (or nearly) courses from the reference ship that have the same speed as the reference vessel appear stationary. Targets moving downscope on the SHU display at greater speed (SRM) than the reference vessel are other vessels on (nearly) reciprocal courses. And "upscope" targets apparently moving downscope at slower speeds (SRM) than the reference ship are vessels being overtaken by the reference ship. These simple rules of thumb can easily be verified with the use of an M board.

- Fourth, it is important to emphasize that the material presented in this chapter gives only a sampling of the possible uses of M boards. Examination of one of the many texts given in the list of references will show additional applications.

CONCLUDING COMMENTS

Proficiency in radar interpretation and plotting comes only with practice. Plotting can (and should) be practiced in the living room or study. There are simulation programs suitable for use on a PC that are helpful for home study.

However, there are important differences between the shipboard environment (e.g., the time available for plotting, the size of the plotting table, if any, the need to divide your attention between plotting and other duties) and actual on-the-water conditions. The problems in this text provide useful opportunities to test your mastery of the subject. But nothing short of extensive on-the-water practice (in good visibility) will enable you to become fully familiar with radar.

Finally, the reader should remember that manufacturers are continually seeking ways of making radar more user-friendly. For example, new displays are now available that integrate (either via split screen or integrated one-screen displays) radar and electronic charts. In the single-screen option, the electronic chart overlays the radar display, which may simplify radar interpretation and facilitate target identification. Keep abreast of these developments by reading the navigation literature.

SELECTED REFERENCES

Anderson, J., (1987). *Exercises in Pilotage,* David and Charles, London, UK.

Block, R. A., Editor, (1983). *Radar Observer Manual* (Fifth Revision), Marine Navigation Textbooks, Houma, LA.

Bole, A. G. and K D. Jones, (1981). *Automatic Radar Plotting Aids Manual,* Cornell Maritime Press, Centreville, MD.

Bowditch, N. (1995). *American Practical Navigator, An Epitome of Navigation,* Pub. No. 9, Defense Mapping Agency Hydrographic/Topographic Center, Bethesda, MD. This publication is available electronically from the *National Imagery and Mapping Agency* (NIMA) Marine Navigation Department web site (http://www.nima.mil/).

Brogdon, W., (1995). *Boat Navigation for the Rest of Us—Finding Your Way by Eye and Electronics,* International Marine, Camden, ME.

Brooke, G. A. G. and S. Dobell, (1986). *Radar Mate,* Adlard Coles Ltd., London, UK.

Burger, W., (1978). *Radar Observer's Handbook for Merchant Navy Officers,* 6th edition, Brown, Son & Ferguson, Ltd., Glasgow, Scotland.

Cahill, R. A., (1983). *Collisions and Their Causes,* Fairplay Publications, London, UK.

Canadian Power and Sail Squadrons, (1999). *Navigating With GPS,* Ontario, Canada.

Carpenter, M. and W. Waldo, (1975). *Real Time Method of Radar Plotting,* Cornell Maritime Press, Centreville, MD.

Chinery, M., (1994). *Simple GPS Navigation,* Fernhurst Books, West Sussex, UK.

Clissold, P., (1970). *Radar in Small Craft,* Thomas Reed Publications Limited, London, UK.

Coolen, E., (1987). *Nicholls's Concise Guide to Navigation,* Vol. 1, Brown, Son & Ferguson, Ltd., Glasgow, Scotland.

Coolen, E., (1984). *Nicholls's Concise Guide to Navigation Examinations,* Vol. 2, Brown, Son Ferguson, Ltd., Glasgow, Scotland.

Dahl, B., (1986). *The Loran-C Users Guide,* Richardsons Marine Publishing Inc., Evanston, IL.

Dahl, B., (1993). *The Users Guide to GPS,* Richardsons Marine Publishing Inc., Evanston, IL.

Defense Mapping Agency, Hydrographic/Topographic Center, (1983). *Loran-C Correction Table, Northeast, USA,* 9960, DMA Stock No. LCTUB 2211 200 C, Washington, DC.

Defense Mapping Agency, Hydrographic/Topographic Center, (1984). *Maneuvering Board Manual,* Pub. No. 217, 4th edition, Bethesda, MD.

Defense Mapping Agency, Hydrographic/Topographic Center, (1985). *Radar Navigation Manual,* Pub. No. 1310, 4th edition, Bethesda, MD.

Defense Mapping Agency, Hydrographic/Topographic Center, (1988). *Radar Navigational Aids,* Pub. No.117, DMA Stock No. RAPUB 117, Bethesda, MD.

Departments of Transportation and Defense, (1999). *Federal Radionavigation Plan 1999,* NTIS Springfield, VA.

Dixon, C., (1999). *Using GPS,* Second Edition, Sheridan House, Dobbs Ferry, NY.

Dubay, C. and T. Johns, (2001). WAAS, DGPS and the Mariner's Toolkit, available electronically at (http://www.navcen.uscg.gov/news/archive/2001/may/WAAS-DGPS.htm/).

French, J., (1977). *Small Craft Radar,* Van Nostrand Reinhold Company, New York, NY.

Hoffer, W., (1979). *Saved! The Story of the Andrea Doria—The Greatest Sea Rescue in History,* Summit Books, New York, NY.

SELECTED REFERENCES

Holdert, H. M. C. and F. J. Bozek, (1984). *Collision Cases, Judgements, and Diagrams,* Lloyd's of London Press Ltd., Legal Publishing and Conferences Divisions, London, UK.

Hurn, J., (1989). *GPS: A Guide to the Next Utility,* Trimble Navigation, Sunnyvale, CA.

Hurn, J., (1989). *Differential GPS Explained,* Trimble Navigation, Sunnyvale, CA.

McClench, D., Ed. (1967). *Primer of Navigation by George W. Mixter* 5th Edition, Van Nostrand Reinhold Co., New York, NY.

Melton, L., (1986). *The Complete Loran-C Handbook,* International Marine Publishing Co., Camden, ME.

Melton, L., (1987). *Piloting with Electronics,* International Marine Publishing Co., Camden, ME.

Ministry of Defense (Navy), (1987). *Admiralty Manual of Navigation, BR 45 (1),* Volume 1, Her Majesty's Stationary Office, London, UK.

Monahan, K. and D. Douglass, (2000). *GPS Instant Navigation, A Practical Guide from Basics to Advanced Techniques,* 2nd Edition, Fine Edge Productions, Bishop, CA.

Moss, W. D., (1965). *Radar Watchkeeping,* The Maritime Press Ltd., London, UK.

Motte, G. A. and T. M. Stout, (1984). *Chartwork and Marine Navigation for Fishermen and Boat Operators,* Second Edition, Cornell Maritime Press Centreville, MD.

Oudet, L., (1960). *Radar and Collision,* D. Van Nostrand Company, Princeton, NJ.

Pierce, J. A. (1989). Memoirs of John Alvin Pierce: Development of Loran. *Journal of the Institute of Navigation,* Vol. 36, No. 1, pp. 1-8.

Pike, D., (1977). *Electronic Navigation For Small Craft,* Granada Publishing, London, UK.

Queeney, T., (2001). A New Way to Increase GPS Accuracy, *Professional Mariner,* Issue 56, p 49 et seq.

Safford, E. L., (1971). *Modern Radar: Theory, Operation and Maintenance,* Tab Books, Blue Ridge Summit. PA.

Sonnenberg, G. J., (1988). *Radar and Electronic Navigation,* 6th Edition, Butterworths, London, UK.

United States Coast Guard Academy, (1990). *Loran-C Engineering Course Notes,* New London, CT.

United States Coast Guard, (1992). *Loran-C User Handbook,* COMDTPUB P16562.6, Washington, DC.

United States Coast Guard, (1984). *Radionavigation Systems,* G-NRN, Washington, DC.

United States Coast Guard, *Specifications of the Transmitted Loran-C Signal,* COMDINST 16562.4, Washington, DC.

United States Power Squadrons®, (1997). *GPS Global Positioning System, An Introduction to the Global Positioning System,* Raleigh, NC.

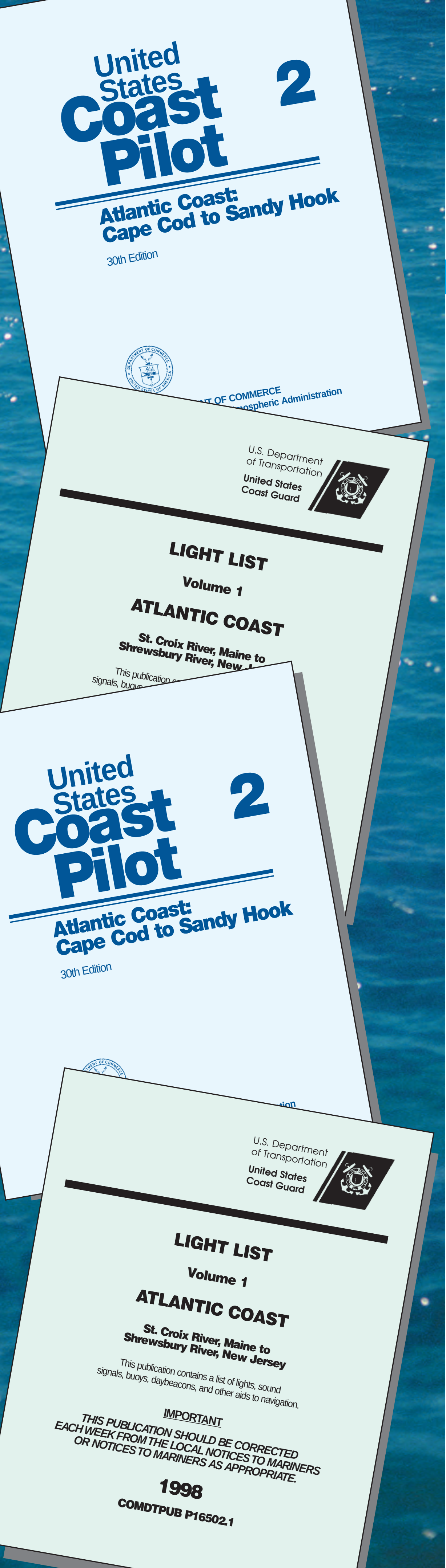
Van Wyck, S. M. and M. H. Carpenter, (1984). *The Radar Book,* Cornell Maritime Press, Centreville, MD.

Walsh, G., (1988). Coastal Navigation, the Basics: Radar Tactics and the Rules of the Road, *Ocean Navigator,* September/October p.55 et seq.

West, J., (1988). *Boat Owner's Guide to Radar,* International Marine Publishing Company, Camden, ME.

West, J., (1978). *Radar for Marine Navigation and Safety,* Van Nostrand Reinhold Company, New York, NY.

Wylie, F. J., Editor, (1982). *The Use of Radar at Sea,* Royal Institute of Navigation, Naval Institute Press, Annapolis, MD.



CHAPTER 10

NAVIGATION REFERENCE PUBLICATIONS

"Many receive advice, few profit by it."

–Publilius Syrus, First Century BC

"Any ship can be a survey ship…**once**."

–Capt. T.W. Richards, NOAA

INTRODUCTION

By this point in the course/text, you should be quite familiar with the 1210-Tr chart and, more generally, the amount, variety, and utility of material depicted in the modern nautical chart. Nonetheless, space and format constraints limit the amount of information that can be placed on the chart. Therefore, the mariner needs additional material to help provide for the safe and efficient navigation of the vessel. A variety of additional publications are available, some published by commercial enterprises, and others of government origin. This chapter provides a brief overview of relevant government publications, including the *United States Coast Pilot* (USCP), *Light List, Notice to Mariners* (NTM or NM), and the *Local Notice to Mariners* (LNM). These three publications supplement the nautical chart. Additionally, commercially produced cruising guides and boating almanacs often contain valuable information and are worthwhile additions to the ship's library. Finally, in this information age, there is a great deal of useful information posted on the Internet. Important Internet addresses are provided.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ❏ *Additional sources of chart-related information*
- ❏ *Overview of contents of the United States Coast Pilot and Light List*
- ❏ *Purpose and utility of Notice to Mariners and Local Notice to Mariners*
- ❏ *Important web site addresses*
- ❏ *How to estimate the visible range of a light*

COAST PILOT

The *United States Coast Pilot*, to use its formal title, is published periodically by the *National Ocean Service* (NOS), *Charting and Geodetic Services* (C&GS), *National Oceanic and Atmospheric Administration* (NOAA), United States Department of Commerce. It is published in nine volumes covering the Atlantic and Pacific coasts (including Alaska and Hawaii), and the Great Lakes and their connecting waterways. (The area covered by the 1210-Tr chart, for example, is contained in the *Coast Pilot, Vol. 2, Atlantic Coast: Cape Cod to Sandy Hook.)* Coverage diagrams and dates of latest editions of the USCP are available from the NOAA web site (http://chartmaker.ncd.noaa.gov/).

The USCP supplements the navigational information depicted on the nautical chart. This information is developed in several ways, including field inspections conducted by NOAA, excerpts from the NTM (discussed below), and information furnished by other federal agencies and state and local governments, maritime and pilotage associations. Mariners are also encouraged to recommend corrections and additions to the USCP. These changes can be sent to NOAA on Form 77-6 (Coast Pilot Report), copies of which can be found at the back of each USCP. These corrections can also be filed electronically.

Topics covered in the USCP include:

- ❑ Coast and channel descriptions,
- ❑ Designated anchorages,
- ❑ Communication frequencies,
- ❑ Drawbridge schedules and signals (which differ from bridge to bridge),
- ❑ Bridge and cable clearances,
- ❑ Currents,
- ❑ Tide and water levels,
- ❑ Prominent features,
- ❑ Availability of pilotage,
- ❑ Availability of towage,
- ❑ Weather,
- ❑ Ice conditions,
- ❑ Wharf descriptions,
- ❑ Dangers,
- ❑ Routes, traffic separation schemes,
- ❑ Small craft facilities, and
- ❑ Federal regulations applicable to navigation.

In short, the USCP provides a virtual encyclopedia of local knowledge. Some topics in the above list, such as the availability of pilotage, towage, and wharf descriptions, are of particular interest to commercial shipping. However, the USCP provides useful information to the operators of recreational vessels (see below). As of this writing, NOAA is searching for ways to make the USCP more useful to operators of small craft.

Corrections to the USCP since the date of publication are published in the NTM (see below). *Critical corrections* (both important and time sensitive) to the USCP are published on the following web site (http://critcorr.ncd.noaa.gov/critcorr2.htm). Critical corrections provide advance notice of critical chart and USCP identified and orig-

Charts 13233, 13230, 13229.-Robinsons Hole is a narrow buoyed passage from Vineyard Sound to Buzzards Bay between the western end of Naushon Island and the eastern end of Pasque Island. *It has numerous rocks and ledges, and strong tidal currents. The buoys often tow under, and the passage should never be attempted by strangers; it is used occasionally by local fishermen. It has been reported that currents sometimes reach a velocity of 5 knots in the passage.* The velocity in the narrow part is about 3 knots. The flood sets southeastward and the ebb northwestward into Buzzards Bay. (See the Tidal Current Tables for predictions, and the Tidal Current Charts, Narragansett Bay to Nantucket Island, for the hourly velocities and directions of the current.)

Canapitsit Channel, between the east end of Cuttyhunk Island and Nashawena Island, is used by small boats and is partially marked by buoys. In November 1980, the channel had a controlling depth of 5 1/2 feet. *The buoys at this entrance are often dragged off station by strong currents and heavy seas. The channel should never be used during a heavy ground swell. With southerly winds, heavy seas will break across the entrance.*

FIG. 10-1–Excerpt from the *U. S. Coast Pilot*, 30th Ed. (Emphasis Added) inated corrections by NOS cartographers. These corrections include information on hazards to navigation or other information considered essential for safe navigation, such as channel conditions, bridge and cable clearances, and regulatory changes. Information provided on the critical corrections web site do not include all corrections provided in the NM or LNM. These publications (see below) must also be consulted.

Use of the Coast Pilot: An Example

Examples, rather than lengthy discourse, best indicate the value of the USCP. Suppose, therefore, that you are in a 32-ft. sailboat with a 3.5-ft. draft located in the basin at Menemsha, on Martha's Vineyard, and wish to travel to Fairhaven, on the east side of New Bedford Harbor. The auxiliary engine has been acting up, but you have replaced the plugs and feel that the problem is solved. Winds are out of the south at 10 to 15 knots. The current is setting eastward through Vineyard Sound.

As can be seen by referring to the 1210-Tr chart, there are two broad options for this voyage: try to make passage through one of three channels (termed holes in that part of the country) between the Elizabeth Islands (Canapitsit Channel, Quicks Hole, or Robinsons Hole) or detour west and pass clear to the west of Cuttyhunk Island. The distance "the long way around" is at least 28 miles, equivalent to 5.6 hours at 5 knots, but it could be longer considering the eastward set of the current in Vineyard Sound. Alternatively, if you go through Quicks Hole (which appears fairly broad and deep on the chart) the distance is only about 19 miles (3.8 hours at 5 knots). What should you do?

A glance at the USCP (30th edition) descriptions for either Canapitsit Channel or Robinsons Hole (refer to Figure 10-1) suggests that either of these options would be a "white knuckle special," best left either to those with local knowledge or the foolhardy. Quicks Hole (see Figure 10-2 for the USCP excerpt) looks to be a better option—in particular, the remark about avoiding possibly heavy seas in the entrance to Vineyard Sound is tantalizing. However, the advice that sailing vessels should not attempt to pass through Quicks Hole unless there are favorable winds and a favorable current is potentially unsettling because, with an eastward current in Vineyard Sound, foul currents in Quicks Hole are to be expected. (Perhaps the engine cannot be relied upon.) Hmmm, looks like the long way around is not such a bad idea after all. If the seas are ugly at the entrance to Vineyard Sound, you can turn around and try to use the engine, or run east to some location like Tarpaulin Cove. The USCP would be a good place to look to identify possible alternatives. Of course, you could always remain where you are and await more favorable conditions.

The point of this example is not to recommend a particular course of action or to offer a discourse on voyage decision making, but, rather, to illustrate the value of the USCP. It puts a wealth of information and local knowledge in your

CHANGES TO COAST PILOT

Mariners who enjoy the benefits of the USCP have a responsibility to identify any errors and recommend changes so that others can benefit from your experience. NOAA Form 77-6 provides a convenient way to submit these changes. On the back of the form, space is provided for the mariner to request additional surveys or chart changes and/or to provide additional information. The "request for surveys or chart change" instructs mariners to list the area(s) for which surveys and/or changes in chart format, scale, or layout are needed. Additional information requested by NOAA includes information about unusually strong currents; prominent landmarks; objects which provide particularly good radar returns; sheltered anchorages (including direction of weather and type of bottom observed); drawbridge operation changes (e.g., drawbridge remains permanently in open position); changes in pilot pickup points; and changes in radio frequencies monitored by pilots, marine exchanges, harbor masters, or drawbridges.

hands that cannot be provided by the chart alone. *United States Coast Guard* (USCG) and *United States Coast Guard Auxiliary* (USCGAUX) vessels (in some Districts) are required to have the latest editions of these aboard, and the above example shows you why.

Organization of the Coast Pilot

All volumes of the USCP share a common organization. Familiarity with this organization makes it much easier to use. At the beginning of each volume is a chart that depicts the areas covered by this and other volumes. Following this chart is a graphic chapter index that identifies the geographic areas covered in each chapter of the specific volume consulted. The first two chapters of the USCP provide (1) general information and (2) navigation regulations. As the name implies, general information is not region-specific. It includes definitions of terms, an identification of U.S. government agencies providing maritime services, distress signals and communications, distress assistance and coordination procedures, radio navigation warnings and weather, information about nautical charts and aids to navigation, and related information. The chapter on navigation regulations contains some general information, but focuses on regulations applicable to the areas covered in this volume. Navigation regulations include the location of COLREGS demarcation lines (the boundaries

Quicks Hole, between Pasque Island and Nashawena Island is the only passage between Vineyard Sound and Buzzards Bay eastward of Cuttyhunk available for vessels of over 10-foot draft. The clearly defined entrance from Vineyard Sound, about 0.6 mile wide, is about 4 miles southwestward of Tarpaulin Cove and about 5 miles north of Gay Head. *The passage is used considerably by tows, especially during westerly or southerly winds, to avoid the very heavy sea in the entrance to Vineyard Sound,* and also because a secure anchorage from these winds can be had, if necessary, on the north side of Nashawena Island. The passage is considered unsafe for a long tow at night, but otherwise it may be used by steamers either night or day.

Vessels should follow a midchannel course through the passage. The channel is nearly straight with a width of about 0.2 mile. General depths are 30 feet or more, but there are several spots of 16 to 18 feet and others of 21 to 27 feet. Because of the broken nature of the bottom, the passage is not recommended for a stranger drawing more than 21 feet. Buoys marks the channel.

The aids in Quicks Hole are colored and numbered for passage from Vineyard Sound to Buzzards Bay.

The eastern side of Quicks Hole is foul, and no attempt should be made to pass eastward of the lighted buoy. Felix Ledge, 0.2 mile off the eastern shore of Nashawena Island, is covered 16 feet and marked by a buoy.

In November 1985, a sunken wreck was reported on the west side of the passage in about 41° 26.5' N., 70° 51.0' W.

Lone Rock, covered 4 feet and marked by a lighted buoy, is off the northern entrance, about 0.7 mile northward of North Point, the northeastern extremity of Nashawena Island.

Tides and currents.—The mean range of tide is 2.5 feet at the south end and 3.5 feet at the north end of Quicks Hole. *The tidal currents have considerable velocity in Quicks Hole, about 2 to 2.5 knots, and a sailing vessel should not attempt to pass through unless with a strong favorable wind on a favorable current.* Deep-draft vessels should be careful not to be set off their courses. With a strong westward current through Vineyard South, there is a northward current through Quicks Hole; *with a strong eastward current in Vineyard Sound, the current sets southward through Quicks Hole.* Strong winds affect the regularity of the currents. (See the Tidal Current, Tables for predictions, and the Tidal Current Charts, Narragansett Bay to Nantucket Sound, for the hourly velocities and directions of the current.)

FIG. 10-2–Excerpt from the U. S. Coast Pilot, 30th Ed. (Emphasis Added)

(1) No.	(2) Name and location	(3) Position	(4) Characteristic	(5) Height	(6) Range	(7) Structure	(8) Remarks
	SEACOAST (Massachusetts) – First District						
	GEORGES BANK AND NANTUCKET SHOALS (Chart 13200)	N/W					
565	*Boston Approach Lighted Whistle Buoy BA*	40 49.1 69 00.0	Fl Y 10s		7	Yellow.	
570	*Asia Rip Lighted Bell Buoy AR*	40 44.3 69 19.2	Fl Y 2.5s		6	Yellow.	
575	*Davis South Shoal Lighted Whistle Buoy DS*	40 43.2 70 00.5	Fl Y 4s		6	Yellow.	
580	*Nantucket Shoals Lighted Horn Buoy N*	40 30.0 69 25.5	Mo (A) W		6	Red and white stripes.	HORN: 1 blast ev 30s (3s bl). RACON: N (–•). Equipped with a Fl 4s strobe. Lighted throughout 24 hours.
	APPROACHES TO NEW YORK - NANTUCKET SHOALS TO FIVE FATHOM BANK (Chart 12300)						
590	*Squibnocket Lighted Bell Buoy 1*	41 15.7 70 46.3	Fl G 4s		4	Green.	
595	Squibnocket Shoal Buoy 2 On west side of shoal.					Red nun.	
600	Old Man Ledge Buoy 3 On north end of Rocky Shoal.					Green can.	
605	Lone Rock Buoy 5					Green can.	
606	*No Man's Land Shellfish Area Lighted Buoy NW*		Fl Y 4s			Yellow.	Private aid.
607	*No Man's Land Shellfish Area Lighted Buoy SW*		Fl Y 4s			Yellow.	Private aid.
608	*No Man's Land Shellfish Area Lighted Buoy SE*		Fl Y 4s			Yellow.	Private aid.
610	*Nomans Land Lighted Whistle Buoy 2*	41 12.2 70 50.0	Fl R 4s		4	Red.	
615	Nomans Land Gong Buoy 4					Red.	
620 15610	**Gay Head Light**	41 20.9 70 50.1	Al W R 15s 0.2 Wfl 7.3s ec. 0.2 Rfl 7.3s ec.	170	W 24 R 20	Red brick tower. 51	Obscured from 342° to 359° by Nomans Land; light occasionally visible through notches in hilltop. Emergency light (Fl W 6s) of reduced intensity when main light is extinguished. Lighted throughout 24 hours.
	SEACOAST (Rhode Island) – First District						
	APPROACHES TO NEW YORK - NANTUCKET SHOALS TO FIVE FATHOM BANK (CHART 12300)						
625 15980	*Narragansett-Buzzards Bay Approach Lighted Whistle Buoy A*	41 06.0 71 23.4	Mo (A) W		6	Red and white stripes with red spherical topmark.	RACON: N (–•).
	SEACOAST (Massachusetts) – First District						
	APPROACHES TO NEW YORK - NANTUCKET SHOALS TO FIVE FATHOM BANK (Chart 12300)						
630 15985	BUZZARDS BAY ENTRANCE LIGHT	41 23.8 71 02.0	Fl W 2.5s	67	17	Tower on red square on 3 red piles with large tube in center, worded BUZZARDS on sides.	Emergency light of reduced intensity when main light is extinguished. HORN: 2 blasts ev 30s (2s bl-2s si-2s bl-24s si). RACON: B(–•••). Lighted throughout 24 hours.

FIG. 10-3–Excerpt from the Main Tables of *Light List*

separating areas subject to International and Inland Rules), anchorage regulations, drawbridge operation regulations, ports and waterways regulations, vessel traffic management regulations, inland waterways regulations, regulated navigation areas and limited access areas, shipping safety fairways, danger zones and restricted area regulations, and other applicable regulations. Following the chapter on navigation regulations is a chapter that provides an overview of the areas covered. In turn, this chapter is followed by others that provide information on specific areas. The USCP volume concludes with a series of useful tables and an index.

Read the USCP carefully as you prepare for your trip. Take the time to annotate your charts with particularly relevant information and/or put adhesive tabs on relevant pages in the text.

LIGHT LIST

First published in 1838, the *Light List* is now published annually by the USCG. Seven volumes cover the United States. The area covered by the 1210-Tr chart, for example, is contained in Volume 1, Atlantic Coast, St. Croix River, Maine to Shrewsbury River, New Jersey. Briefly stated, the purpose of the *Light List* is to provide more complete information concerning aids to navigation than can be shown on nautical charts. In addition to specific information, the *Light List* contains useful general information on such topics as buoyage, bridge markings, and electronic aids to navigation (including radar, *Loran-C, Global Positioning System* (GPS), and *Differential GPS* (DGPS)).

The "heart" of the *Light List* is a massive series of tables that describe nearly every aid to navigation in the area covered by the specific volume. Entries in the table include the name and location of the ATON, position (latitude and longitude); light color and characteristic, height and nominal range (see discussion below), nature of structure, and a catchall category titled "remarks." Figure 10-3, for example, provides an excerpt from the 1998 *Light List* relevant to the 1210-Tr chart. The last entry shown in this figure (No. 630) provides information on the Buzzards Bay Entrance Light. Although some of this information can be read from the nautical chart, the *Light List* provides additional details, for example, on the location, description of the structure, existence of an emergency light, and the pattern of sound signals. Other useful information could include, for example, the note that the ATON is seasonal, or that it might be removed if threatened by ice, the true bearings of range lights, and limits to visibility.

The *Light List* employs a number of abbreviations that may be unfamiliar to the mariner. These abbreviations include:

A1	-	Alternating
bl	-	blast
C	-	Canadian
ec	-	eclipse
ev	-	every
F	-	Fixed
fl	-	flash
F1	-	Flashing
FS	-	Fog Signal
Fl(2)	-	Group flashing
G	-	Green
I	-	Interrupted
Iso	-	Isophase (Equal interval)
kHz	-	Kilohertz
LFl	-	Long Flash
Lt	-	Lighted
LNB	-	Large Navigational Buoy
MHz	-	Megahertz
Mo	-	Morse Code
Oc	-	Occulting
ODAS	-	Anchored Oceanographic Data Buoy
Q	-	Quick (Flashing)
Ra ref	-	Radar reflector
R	-	Red
RBN	-	Radiobeacon
s	-	seconds
si	-	silent
SPM	-	Single Point Mooring Buoy
W	-	White
Y	-	Yellow

Visibility of Lights

The *Light List* provides a useful graph for estimating the distance of visibility of lights at night. This is reproduced in the logarithmic chart of Figure 10-4. The abscissa, or x axis, shows the nominal range of the light in nautical miles. *The nominal range of the light is the maximum distance a light can be seen in clear weather (meteorological visibility of 10 nautical miles)*. This value is listed for all lighted aids to navigation except range lights, directional lights, and private aids to navigation. Referring to Figure 10-3, the nominal range of the Buzzards Bay Entrance Light is 17 nautical miles.

The ordinate, or y-axis of Figure 10-4, shows the *luminous range* of the light in nautical miles. *The luminous range of the light is the greatest distance a light can be seen given its nominal range and the prevailing meteorological visibility.* Figure 10-4 shows the relationship

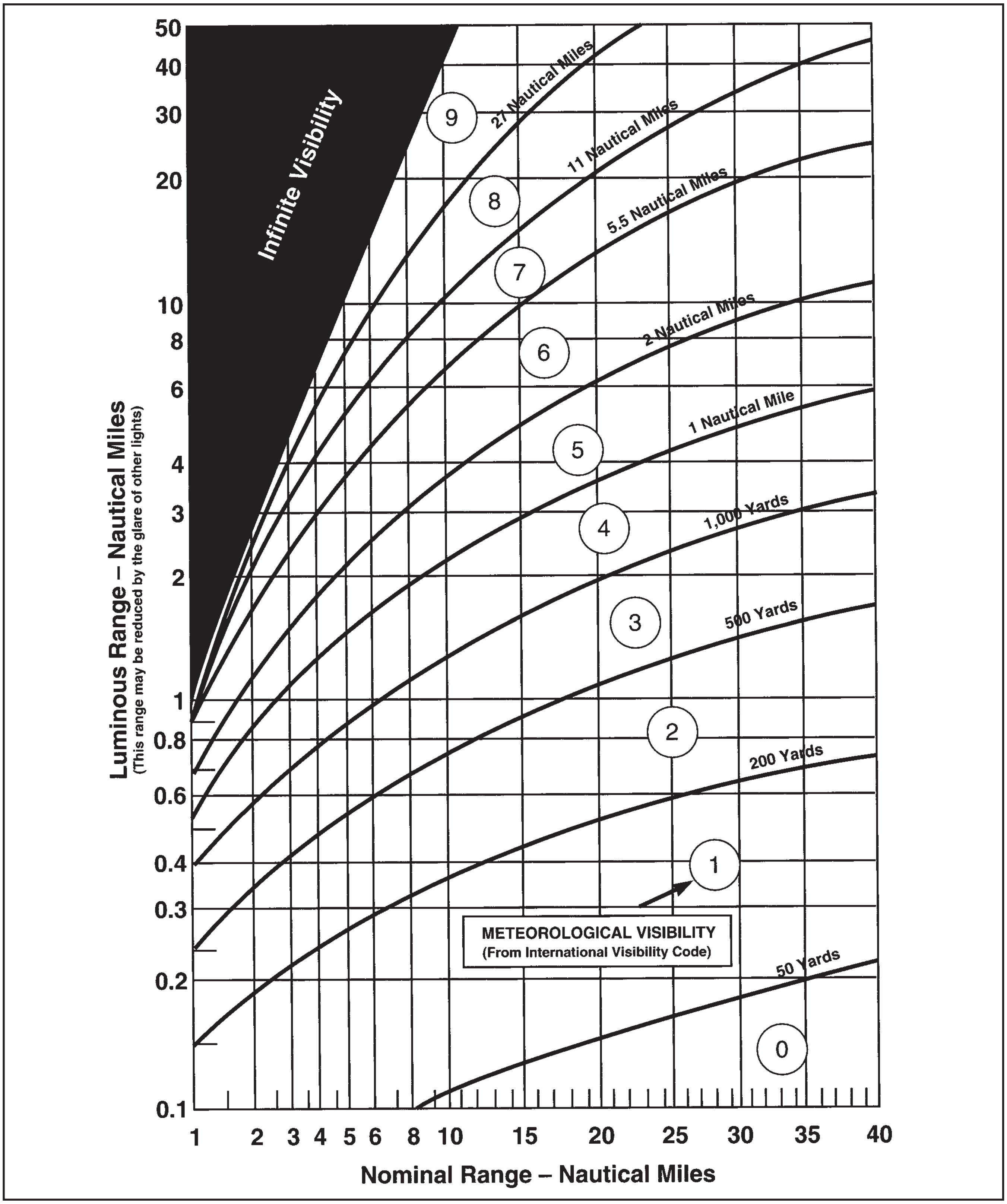


FIG. 10-4–Luminous Range Diagram from *Light List*

between the nominal and luminous range of the light. To convert from the nominal to the luminous range, enter the figure with the nominal range and read upwards to the line that best describes the prevailing visibility. For example, in looking for the Buzzards Bay Entrance Light (nominal range 17 nautical miles, read from the *Light List*) when the prevailing visibility could be classified as "haze" (category 5 on the chart, visibility 1 to 2 nautical miles), the luminous range would be between 3 and 5 nautical miles (the smaller figure corresponding to a visibility of 1 nautical mile, and the larger to a visibility of 2 nautical miles). To be more precise, if the visibility were 2 nautical miles, the luminous range would be approximately 5 nautical miles.

CHART ANNOTATIONS

As noted in other chapters, it is a good idea to make numerous annotations on the nautical chart to avoid having to refer to other publications. Many mariners make it a habit to draw circles on charts around major lights to indicate the approximate distance at which these should be visible at night. Other relevant information might include drawbridge operating schedules, prominent landmarks, sound characteristics of aids to navigation, and related data.

Neither the nominal range nor the luminous range makes any allowance for the curvature of the earth, distance to the horizon, or *geographic range*. In other words, the luminous range captures only the effects of the power of the light and the attenuation of the atmosphere.

The geographic range is the greatest distance the curvature of the earth permits an object of a given height to be seen from a particular height of eye without regard to luminous intensity or visibility conditions (synonym: distance to the optical horizon). This concept is discussed in Chapters 6 and 9. In particular, Table 6-2 provides a convenient basis for estimating geographic ranges. For example, if the height of eye were 10 ft. on a vessel, and the height of the object were 70 ft. (note from Figure 10-3 that the height of the Buzzards Bay Entrance Light is 67 ft.), then the geographic range would be approximately 13.5 nautical miles.

The procedure for estimation of the distance at which the light can be seen is as follows:

- ❑ First, read the nominal range of the light from the *Light List* and note the prevailing visibility. The nominal range from the *Light List* is 17 miles and the prevailing visibility is 2 miles in this example.
- ❑ Second, use Figure 10-4 to convert the nominal range to a luminous range, lr, considering the prevailing visibility. In this example, the luminous range is approximately 5 nautical miles.
- ❑ Third, using estimates of the height of eye aboard the vessel and the height of the object from the *Light List*, calculate the geographic range, gr. In this example, the geographic range is approximately 13.5 nautical miles.
- ❑ Finally, calculate the actual range as the smaller of the luminous range or the geographic range.

In the above example, the luminous range (5 miles) is smaller than the geographic range (13.5 miles), so the luminous range would be the best estimate of the distance at which the Buzzards Bay Entrance Light could be seen.

As an aside, David Burch writing in the book *Emergency Navigation* offers the following simple approximation to the luminous range,

$$lr = 1 + 0.1 \text{ v } N,$$

where lr = luminous range (nautical miles),
v = visibility (nautical miles), and
N = nominal range (nautical miles).

Using this formula, the approximate luminous range in the above example would be 1 + 0.1 (2)(17) = 4.4 nautical miles, approximately the same as that found from Figure 10-4. This equation is believed to be correct to within approximately +/- 20 percent.

Other useful information contained in the *Light List* applicable to radio navigation is discussed in Chapter 9. *Light List* corrections can be found on the *National Imagery & Mapping Agency* (NIMA) website(http://www.nima.mil/) and, also, the USCG's *Navigation Center* (navcen) web site (http://www.navcen.uscg.gov/).

NOTICE TO MARINERS

Nautical charts and publications are kept up-to-date through use of the NTM, prepared jointly by the National Ocean Service and the U.S. Coast Guard. The NTM is published weekly, and is available from NIMA in Washington, DC. This pamphlet contains the latest information on navigational safety, changes in aids to navigation, channels, and chart information over a broad area useful to the oceangoing and coastal vessel alike. The USCPs are kept current by updating them from information contained in the weekly NTMs.

The NTM can also be downloaded from the Internet. Start with the web site (http://www.nima.mil), click on the "About NIMA" button and then the "Marine Navigation Home Page." Follow directions to the NTM. Once the NTM database is located, it can be searched by chart number, NTM (week and year), or by a *minimum bounding rectangle* (MBR). The MBR is specified by the northwest and southeast corners of the rectangle using latitude and longitude. All changes that fall within this rectangle are displayed and can be downloaded.

Other agencies of the U.S. government provide NTM for specific areas in electronic form. For example, the *National Park Service* (NPS) provides NTM for Lake Powell as part of the Glen Canyon National Recreational Area (http://www.nps.gov/glca/notice.htm).

Several other countries of the world have established Internet web sites containing NTM information. For example, *Canadian Notices to Mariners* are posted on the web site (http://www.notmar.com/). Other countries that provide Internet access to the NTM include Australia, Hong Kong, Malaysia, New Zealand, Singapore, and the United Kingdom.

ANMS

ANMS is an acronym that stands for *Automated Notices to Mariners System*. Anyone having a personal computer with a modem can dial up this system (contact NIMA for details and the latest access numbers) and, after entering a user identification number (available on request from NIMA), access the system. The system is very easy to use and can print out chart corrections, *Light List* revisions, Broadcast Warnings, and other important corrections. Ultimately, ANMS is likely to be superceded by the NIMA web site.

One very nice feature of ANMS is that it can provide all of the corrections to each chart from the date of issue. This eliminates the possibility of missing an important correction because you neglected to enter a given mailing. Additionally, changes/corrections are first input to ANMS before the NTM is printed; so, with ANMS you can get information sooner.

LOCAL NOTICE TO MARINERS

The Commander of each local USCG District issues the *Local Notice to Mariners* (LNM)—also on a weekly basis. There is no charge for this publication, which may be obtained upon request from the local USCG District Commander. The LNM contains the very latest navigational safety information pertinent to all craft within the area of the district. Notices of marine regattas and other important marine events are also announced through the LNM. The basic difference between the NTM and the LNM is that the NTM focuses on information relevant to areas frequented by oceangoing vessels, whereas the LNM includes information relevant to all (including smaller) vessels. The LNM is more comprehensive than the NTM.

Information contained in the LNM includes special notices, discrepancies in *Aids to Navigation* (ATONs), temporary changes to ATONs, chart corrections, advance notice of pending changes, *Light List* corrections, military operations (e.g., helicopter airborne mine-countermeasure operations, sonobuoy operations, firing exercises), shoaling, construction/dredging, bridge information (e.g., closures, painting, and repairs), and other relevant information. Perhaps the easiest way to obtain a copy of the LNM is to access the navcen web site (http://www.navcen.uscg.gov/). Follow the directions to access the LNM for the applicable USCG District.

Key to Abbreviaitons Used in LNM

One of the most important purposes of the LNM is the dissemination of information on changes to aids to navigation. In this process, most Districts use abbreviations to save space. Although the meanings of many of these are self-evident (e.g., LT EXT means light extinguished, HAZ NAV means hazardous to navigation, DEST means destroyed, DISC means discontinued, W/P means watching properly), the following list may be helpful:

ANCH	Anchorage
APP	Approach
ART	Articulated
BB	Bell buoy
BKHD	Bulkhead
BKW	Breakwater
BNM	Broadcast Notice to Mariners
BY	Buoy
CH	Channel
DMGD	Damaged
DAYBD	Dayboard
DBN	Daybeacon
E	East/easterly
ENT	Entrance
EMERGY LT	Emergency light
F/S	Fog signal
GB	Gong buoy
HBR	Harbor
IMPCHA	Improper characteristic
IN	Inlet
INOP	Inoperative
IS	Island
JCT	Junction
LB	Lighted buoy
LBB	Lighted bell buoy
LGB	Lighted gong buoy
LHB	Lighted horn buoy
LIB	Lighted ice buoy
LLNR	*Light List* Number
LWB	Lighted whistle buoy
LNB	Large navigational buoy
MSLD SIG	Misleading signal
N	North/northerly
OFF STA	Off station
PT	Point
PVT	Private aid
RACON	Radar beacon
RBN	Radiobeacon
REDINT	Operating at reduced intensity
RF	Range front
RIV	River
RR	Range rear
RPTD	Reported
S	South/southerly
SHL	Shoal
TRDBN	Temporary daybeacon
TRLB	Temporary lighted buoy
TRUB	Temporary unlighted buoy
TEMP	Temporary
TERM	Terminal
UIB	Unlighted ice buoy
W	West/westerly
WRK	Wreck
WW	Waterway

BROADCAST WARNINGS

Finally, the Coast Guard transmits broadcast warnings (monitor channel 16) or *broadcast notice to mariners* (BNM) that provide information otherwise contained in the LNM that is too urgent to be left to a weekly publication

ADVICE YOU SHOULD HEED

Although most commercial vessels regularly receive NTMs (and LNMs), the number of subscriptions to these publications is very much smaller than the number of registered vessels. This proves the sad truth that many mariners are either unaware of these publications or believe that the information provided in these valuable publications isn't worth the effort required to read and update charts and other publications.

Failure to pay attention to these important changes is akin to playing the marine equivalent of Russian Roulette. You may be lucky; the post on which the daymark was secured that was knocked down by a tow (and duly reported by the USCG in a Broadcast Warning) may not penetrate your hull. And the entrance buoy that you depend on for navigation may not have been blown off station by last week's storm. (In fact, the Brenton Reef Light on which you have taken bearings throughout the course is now no longer in existence.) But to assume that everything is as represented in any of these charts or publications, particularly when operating in unfamiliar waters is to take an uncalculated risk. The imprudent mariner is always surprised by events, while the prudent mariner is always prepared.

NONGOVERNMENT SOURCES

In addition to the publications discussed above, a number of commercial firms publish cruising guides and related materials that are useful to take along. The commercial guides often emphasize services available at various marinas and provide interesting historical information about the areas covered. For example, commercial guides provide information on marinas such as brands of gasoline/diesel fuel available, types of credit cards accepted, available services, and amenities. Some guides contain small charts that identify particular marinas.

Many cruising areas are interesting from the perspective of the tourist, and it is handy to have a guide that includes this information. For example, Penikese Island (located in Buzzards Bay and referred to elsewhere in this text) was at one time a leper colony, gunnery and bombing range for military aircraft, and a type of reform school for troubled youths. Although this information is not essential for navigation, it does provide interesting reading.

Some of these guides also contain information on tidal and other currents, tide tables, a Nautical Almanac, or other material available from the government.

Additionally, other governments, such as Canada or Great Britain, publish guides that are useful. The English publication, *Ocean Passages of the World,* is viewed as a compact classic. A trip to your nearest source of nautical publications is definitely in order.

Finally, there are several web sites that provide useful information, as shown on Table 10-1.

Nautical Internet Addresses of Interest

as of April, 2002

USCP – Coverage diagrams and edition dates: http://chartmaker.ncd.noaa.gov

USCP – Critical and/or time sensitive corrections: http://critcorr.ncd.noaa.gov/critcorr2.htm

NIMA List of Lights: http://pollux.nss.nima.mil/pubs/NIMALOL/pubs_j_nimalol_list.html

NIMA Light List Corrections: http://pollux.nss.nima.mil/pubs/NIMALOL/pubs_j_nimalol_list.html
Click the link at the bottom of the page for the current Light List Corrections

US Notice to Mariners information: http://www.nima.mil
Click on “About NIMA” button and then the “Marine Navigation Home Page”

USCG Local Notice to Mariners information: http://www.navcen.uscg.gov/lnm/default.htm

USCG Navigation Center: http://www.navcen.uscg.gov

Canadian Notices to Mariners: http://www.notmar.com/eng/index.asp

Nautical Chart User’s Manual: http://chartmaker.ncd.noaa.gov/staff/NCUM/ncum.htm

Online Nautical Charts: http://anchor.ncd.noaa.gov/noaa/noaa.html

Dates of latest Nautical Charts: http://chartmaker.ncd.noaa.gov/mcd/dole.htm

These addresses are subject to change at the need and desire of the originating agency.

TABLE 10-1–Useful Web Sites

SELECTED REFERENCES

Borton, M. C. et al., (1989). *The Complete Boating Guide to Rhode Island & Massachusetts,* Embassy Marine Publishing, Essex, CT.

Burch, D., (1986). *Emergency Navigation,* International Marine Publishing Co., Camden, ME, p 205.

Holland, F. R., (1988). *America's Lighthouses, An Illustrated History,* Dover Publications Inc., New York, NY.

CHAPTER 11

FUEL AND VOYAGE PLANNING

"Excuses for failure attributed to shortness of coal will be closely scrutinized; and justly."

–Mahan: Naval Strategy, 1911

INTRODUCTION

Few things are as frustrating as hearing the familiar rhythmic hum of the vessel's engine(s) interrupted by a deafening silence and realizing that the vessel has run out of fuel. Add some other elements to the scenario, such as deteriorating weather and an adverse current setting the vessel towards shoal waters or a busy shipping channel, and inconvenience quickly turns to potential disaster. Perhaps most disturbing is the fact that, in most cases of fuel exhaustion, the assignable cause is operator error rather than mechanical malfunction. Neglecting to verify the amount of fuel in the tanks before setting out for a demonstration ride around the harbor, a decision not to buy fuel at the last marina visited because of high prices or lack of the proper credit card, a failure to allow for foul currents or poor weather, neglecting to fill the tanks in order to avoid a long waiting line at the fuel dock, etc., all sound like feeble excuses while drifting under a hot sun and waiting for an expensive tow. Running fuel tanks dry may create additional problems. Water (which has a greater density than fuel) and dirt typically settle to the bottom of the fuel tank. Drawing a water-dirt mixture into the engine risks damage to injectors and other components.

Accurate statistics on the frequency of fuel exhaustion for pleasure craft are not available—in part, because out-of-fuel vessels are often towed in by friends or Good Samaritans and not reported to the *United States Coast Guard* (USCG) or state law enforcement officials. But, in the opinion of most experts, incidents of fuel exhaustion are surprisingly common.

Aircraft also run out of fuel, despite explicit regulations on the amount of fuel to be carried. According to available statistics, in an average year more than 200 aircraft are destroyed and 30 people are lost in fuel exhaustion accidents. In 1977, one of the worst years for this type of accident, 55 persons were killed, and 60 seriously injured. These accidents are not

PHOTO COURTESY OF POST YACHT COMPANY

limited to recreational pilots. Commercial aircraft and airliners also are involved in fuel exhaustion accidents, albeit less frequently. On 25 January 1990, Avianca Flight 52 inbound to New York from Bogota, Colombia, crashed, killing 72 persons. The *National Transportation Safety Board* (NTSB) concluded that fuel exhaustion was the probable cause of this accident. Earlier in 1978, a United Airlines DC-8 crashed near Portland, Oregon, after running out of fuel, killing 10 of 189 persons on board.

One of the reasons for discussing aircraft-related fuel incidents in a text on marine navigation is that aircraft manufacturers, airline operators, and pilots have developed systematic approaches to fuel planning and management that are equally useful to the mariner. Several of these techniques are discussed in this chapter and illustrated with actual fuel consumption data for recreational boats.

The material in this chapter presents a systematic view of fuel planning and management for vessel operators. Practical tips on this important subject complement development of fuel consumption curves and related material.

WHAT YOU WILL LEARN IN THIS CHAPTER

- ***How to construct and interpret a fuel consumption chart***
- ***How to make efficiency, range and endurance calculations***
- ***How fuel efficiency varies with speed for displacement and planing hull vessels***
- ***Sources of fuel consumption information***
- ***How to make time-fuel efficiency tradeoffs***
- ***How to make a "howgozit" chart***

BEGINNINGS: A FUEL CONSUMPTION CHART

Careful fuel planning and management should be an integral part of powerboat navigation. A basic input to the fuel planning process is the vessel's fuel consumption chart or curve. This curve ties together the vessel's speed curve with engine fuel consumption information.

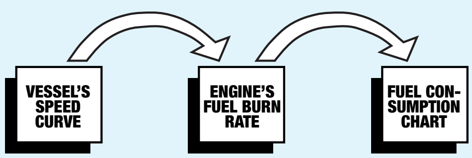
- ❑ First, the fuel consumption chart includes the relationship between the engine throttle setting in *revolutions per minute* (RPM) and the vessel's *speed through the water* (STW) in knots, the familiar *speed curve* for the vessel discussed in Chapter 5. An illustrative speed curve for a semi-displacement hull vessel, *Aventura,* is shown in Table 11-1 (Laudeman, 1986). RPMs to be used in the development of this curve vary from the lowest attainable (clutch speed) to the maximum recommended continuous power setting. According to the data given in Table 11-1, the vessel's clutch speed is only 1 knot. For many boats, clutch speeds are significantly higher.
- ❑ Second, the fuel consumption chart includes data on the relationship between engine RPM and fuel consumption rate, measured in *gallons per hour* (GPH). Table 11-2 shows these data for the same vessel. Possible sources of these data are discussed below.
- ❑ Third, data from these two sources are combined into a fuel planning worksheet, shown in Table 11-3. (Sources and methods for obtaining these data are discussed later in this chapter.) The fuel-planning worksheet presents basic data on the throttle setting (RPM), speed through the water (STW), and the fuel consumption rate (GPH). In Table 11-3, no current (either fair or foul) is assumed; so the *speed of advance* (SOA) is numerically equal to the STW at any throttle setting. The other columns are discussed below.

To facilitate following the calculations in this chapter, several significant figures are retained for each entry in the tables. However, the reader should bear in mind that fuel consumption data are seldom exact—error margins of ±10 percent, or even more, should be attached to these figures. This injunction is particularly applicable to manufacturer's test data—not because of any deliberate attempt to inflate performance statistics, but rather because these data are often developed under ideal test conditions. Therefore, it is appropriate to round off actual fuel–planning calculations to within this margin.

THROTTLE SETTING (RPM)	SPEED THRU THE WATER STW (KNOTS)	VESSEL: AVENTURA TEST CONDITIONS
1000	1.0	DATA ARE FOR VESSEL AT "CRUISE
1250	2.0	WEIGHT," FULL FUEL AND WATER TANKS.
1500	3.5	THE HULL CONDITION IS CLEAN AND
1750	5.0	JUST REPAINTED. OTHER LOADING DATA
2000	7.0	ARE AS FOLLOWS: 4 ADULTS, 150 LBS.
2250	8.0	BAGGAGE. WIND AT TIME OF TEST WAS
2500	9.0	LESS THAN 15 KNOTS, AND SEAS LESS
2750	9.5	THAN 2 FEET.
3000	10.0	

TABLE 11-1–Illustrative Speed Curve for Vessel *Aventura*

The Fuel Consumption Chart Combines the Vessel's Speed Curve with Engine Fuel Consumption Data



THROTTLE SETTING (RPM)	FUEL CONSUMPTION RATE (GPH)
1000	0.33
1250	0.80
1500	1.80
1750	3.30
2000	5.00
2250	6.70
2500	9.00
2750	11.90
3000	16.00

TABLE 11-2–Relationship Between RPM and Fuel Consumption

SINGLE-ENGINE OPERATION WITH TWIN ENGINE BOATS

For twin engine vessels, it is useful to develop speed curves and fuel consumption estimates for both single- and twin-engine operations. In this way, you can be prepared with relevant data in case of engine failure. Check with the manufacturer before attempting to develop a single-engine speed curve, however. Typically, manufacturers impose limits on the maximum RPM to be used for single-engine opera-

FUEL EFFICIENCY, RANGE, AND ENDURANCE

Before discussing the sources of these data, it is instructive to examine the uses of this information. From these basic data, it is possible to calculate other quantities that are important in fuel planning. One important measure is the *fuel efficiency, defined as the distance the vessel can travel on each gallon of fuel*. It is measured in *nautical miles per gallon* (MPG) and is calculated as the speed of advance (knots) divided by the fuel consumption rate in GPH. Thus, for example, referring to Table 11-3, at 2000 RPM the SOA is 7 knots and the fuel consumption is 5 GPH. Therefore, the fuel efficiency is 7 nautical miles per hour/5 gallons per hour = 1.4 MPG. Fuel efficiency figures at this and other throttle settings are given in the fifth column of Table 11-3.

Another important fuel planning factor is the *range* of the vessel. *The range is the distance in nautical miles that a vessel can travel with the fuel available*. The range depends, *inter alia* (among other things), upon the throttle setting. In Table 11-3, the fuel capacity of the vessel is given as 200 gallons, and this capacity could be used for range estimates. More typically, a contingency factor of 10 percent, 20 percent, or more is assumed to allow for unusable and reserve fuel as discussed below. Thus, if a 10 percent fuel reserve is assumed, the fuel capacity is reduced by this amount [0.1 (200) or 20 gallons in this example], leaving 180 gallons "voyage" or "en route" fuel. The estimated range is calculated by multiplying the en route fuel (gallons) by the fuel efficiency (MPG). To continue the above example, the range of this vessel at a throttle setting of 2000 RPM is the en route fuel (180 gallons) times the fuel efficiency (1.4 MPG) or 252 nautical miles, assuming a 10 percent fuel reserve.

The vessel's fuel endurance is the length of time in hours that the ves-

VESSEL: AVENTURA FUEL CAPACITY: 200 GALLONS
FOUL CURRENT: 0 KNOTS

THROTTLE SETTING (RPM)	SPEED THRU THE WATER STW (KNOTS)	SPEED OF ADVANCE SOA (KNOTS)	FUEL CONSUMPTION RATE (GPH)	FUEL EFFICIENCY (MPG)	ESTIMATED RANGE IN NAUTICAL MILES WITH FUEL RESERVE		ESTIMATED ENDURANCE IN HOURS WITH FUEL RESERVE	
					10%	20%	10%	20%
1000	1.0	1.00	0.33	3.03	545	485	545	485
1250	2.0	2.00	0.80	2.50	450	400	225	200
1500	3.5	3.50	1.80	1.94	350	311	100	89
1750	5.0	5.00	3.30	1.52	273	242	55	48
2000	7.0	7.00	5.00	1.40	252	224	36	32
2250	8.0	8.00	6.70	1.19	215	191	27	24
2500	9.0	9.00	9.00	1.00	180	160	20	18
2750	9.5	9.50	11.90	0.80	144	128	15	13
3000	10.0	10.00	16.00	0.63	113	100	11	10

TABLE 11-3–Illustrative Fuel Planning Worksheet

sel can be operated at a given throttle setting until the en route fuel is exhausted. The endurance is given by the en route fuel (total fuel less reserve) divided by the fuel consumption rate. For example, the endurance of this vessel at a throttle setting of 2,000 RPM is the en route fuel (180 gallons) divided by the fuel consumption rate (5 GPH), which is equal to 36 hours (10 percent fuel reserve). Table 11-3 displays these calculations for both a 10 percent and 20 percent fuel reserve at various power settings. The reader should repeat the calculations shown in Table 11-3 to ensure familiarity with the various quantities and how they are calculated.

WHY FUEL RESERVES?

In the above numerical examples, the term *fuel reserve* is used. The fuel reserve is just that—a reserve or set-aside to allow for contingencies or unforeseen circumstances that could arise in a voyage. Possible contingencies could include greater fuel-burn rates than assumed in the fuel consumption curve, the necessity to divert to an alternate destination due to adverse weather, an unanticipated request to tow another vessel, unanticipated adverse currents, and the need to stand off a potentially dangerous inlet until conditions improve. There are no hard-and-fast rules for deciding on the appropriate fuel reserve. For a voyage in familiar waters where currents are generally predictable, en route fueling opportunities are abundant, seas are calm, and the weather outlook is good, a reserve of only 10 percent might be adequate. In less ideal conditions, a larger reserve would be prudent. Reserve margins of 20, 30, or even 50 percent might be justified in more adverse circumstances.

Many mariners are taught a simple “one-third” rule for fuel planning: plan to use one-third of the fuel on the outbound voyage, one-third for the return, and keep one-third in reserve.

Aircraft pilots operating under Part 91 of the *Federal Aviation Regulations* (FARs) under *instrument flight rules* (IFR) are required under FAR 91.23 to carry sufficient fuel (considering weather reports and forecasts, and actual weather conditions) to complete the flight to the airport of intended landing, fly from that airport to an alternate airport, and fly after that for 45 minutes at normal cruising speed.

The above rules or guidelines are offered for illustration only; the navigator is responsible for selecting the most appropriate fuel reserve, considering the circumstances of the voyage.

FUEL EFFICIENCY VERSUS SPEED

The simple calculations displayed in Table 11-3 provide useful information for fuel planning decisions. In particular, these calculations show that (for this vessel) increases in the throttle setting (and, hence, speed) are associated with decreases in fuel efficiency and range. In this example, depend-

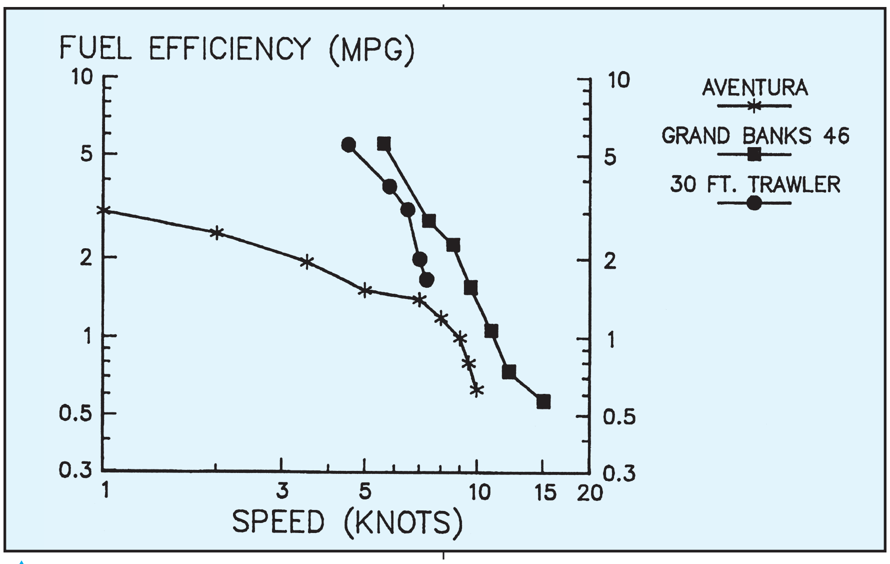


FIG. 11-1–For displacement or semi-displacement hulls, fuel efficiency is highest at low speeds.

ing upon the throttle setting and, therefore, how fast the vessel is operated, the range (assuming a 10 percent reserve) can vary by nearly a factor of five from only 113 nautical miles at a speed of 10 knots to 545 nautical miles at a speed of 1 knot! For the example given in Table 11-3, a throttle setting of 1,000 RPM maximizes both range and endurance. That is, there is no other throttle setting for which *Aventura's* range or endurance is higher.

Typically, however, *the throttle settings for maximum range and maximum endurance are not the same*. The relationship between fuel efficiency and throttle setting shown in Table 11-3 is broadly characteristic of *displacement* or *semi-displacement* hull vessels. Figure 11-1 shows fuel efficiency versus speed curves for a small, but representative, sample of displacement hull or semi-displacement hull vessels including trawlers or trawler-yachts. (The data for the Grand Banks 46 are taken from an article in *Boating* magazine [Berrien, 1987].) Recall that a vessel with a displacement hull achieves its buoyancy by displacing a volume of water equal to the vessel weight (as loaded). The maximum speed, or *hull speed*, for a true displacement vessel in knots is approximately equal to 1.35 times (the theoretical number is 1.34) the square root of the water line length in feet. For example, the hull speed of a vessel with a 25-foot length at the water line would be approximately 1.35 times 5, or 6.8 knots. Examples of displacement hull vessels include sailboats, motorsailers, many trawlers, and most merchant vessels. The constant, 1.35, is only approximate and depends upon the hull design. Values between 1.25 and 1.5 are reported for displacement hull vessels. As can be seen in Figure 11-1, in each case, extra speed is attained only at the expense of decreased fuel efficiency (and range) for displacement or semi-displacement vessels.

Hull speed serves as a physical limit in the case of a true displacement-hull vessel. Installation of a more powerful engine, or adding a second engine, to vessels with this hull design will not result in speeds appreciably greater than the hull speed. The additional power simply creates a larger bow wave, causes

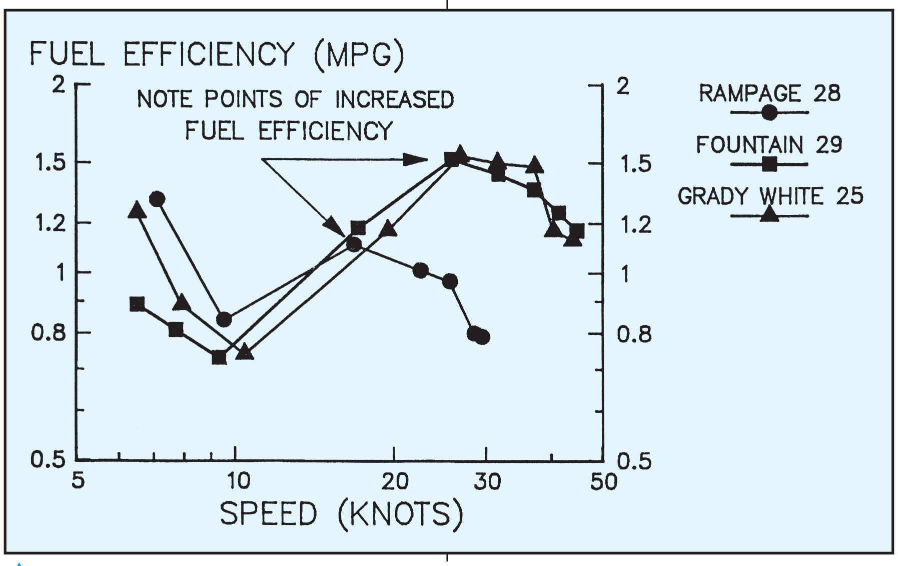


FIG. 11-2–Vessels with planing hulls may increase fuel efficiency when "on plane". Boat-specific differences are important.

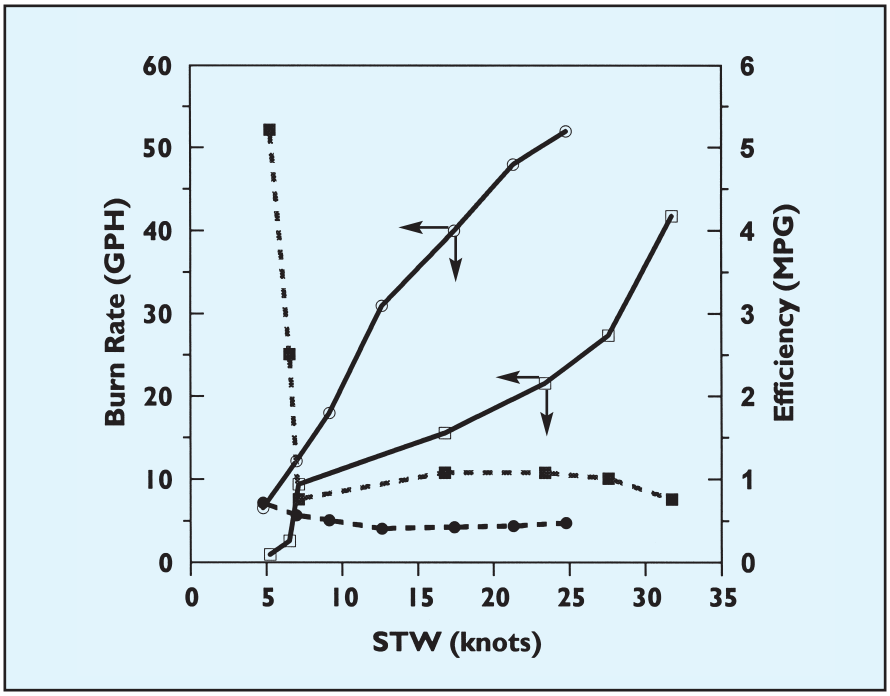


FIG. 11-3–Fuel burn rate and efficiency for the same boat with two power plants.

the stern to sink deeper in its wake, and sharply increases fuel consumption. Typically, the normal cruising speed for a displacement-hull vessel is slightly lower (say, 10 percent or so) than the theoretical hull speed.

Adding a second engine to a displacement-hull vessel confers many benefits (chiefly, increased reliability and maneuverability), but neither speed nor fuel efficiency is improved. Typically, the twin-engine version of a displacement-hull vessel will burn almost twice the fuel of the single-engine version and be only slightly faster. Range, therefore, is lower compared to the single-screw version. Trawlers designed for long distance voyages are typically equipped with a single-screw diesel engine.

For vessels with hulls that can get on plane, it is often found that fuel efficiency first decreases as speeds are increased within the displacement range and then increases at speeds above hull speed when the vessel comes "unstuck" and water drag is reduced. In these cases there is more than one speed with increased range. Figure 11-2 shows fuel efficiency curves for a sample of vessels with planing hulls as taken from various issues of *Boating* magazine given in the references at the end of this chapter. In each case, there is a secondary power setting for increased fuel economy that is above hull speed. But substantial boat-to-boat differences are evident—even in this small sample—so that it is difficult to provide useful rules of thumb. Nonetheless, it is common for fuel efficiency to increase above planing speeds. As speed is increased still further, drag forces again increase and fuel efficiency falls off.

The top speed of a planing vessel is determined by the hull design, propulsion, and planing angle. Installation of larger engines in a planing vessel will increase the top speed (for a fixed hull design), but not in direct proportion to the increase in horsepower. Several theoretical and empirical equations have been proposed for the speed-horsepower relationship (see the references at the end of the chapter). Although these differ somewhat, most indicate that the top speed varies with horsepower raised to an exponent between approximately 0.33 to 0.55—that is, if the engine horsepower were to double, the top speed would increase by only 25 to 50 percent. The attainment of significantly faster speeds for planing hulls depends upon hull design and powerplant selection jointly. Nonetheless, unlike the situation with displacement-hull vessels, adding power to a planing-hull vessel can increase the top speed.

At the other end of the speed range, planing-hull vessels can be operated at displacement speeds. Operation at these lower speeds often (but not always, see Figure 11-2) results in increased fuel efficiency. Advocates of planing hull cruisers for long distance voyages are quick to point this out. However, for vessels of comparable length and overall size, a vessel with a planing hull will generally be less fuel-efficient than a "similar" one with a displacement hull. The difference in fuel efficiency between the two vessels, which could range from 20 to 40 percent or more, is the penalty paid for the flexibility of being able to get on plane and attain higher speeds. There is little doubt that the full displacement vessel is optimal for long distance cruising.

Incidentally, skippers who habitually run turbo-charged engine equipped vessels at displacement speeds should check with the vessel or engine manufacturer to determine the proper procedures to ensure long engine life at these speeds. One source recommends that turbo-charged engines should be run up to 1800 RPM periodically during a voyage to avoid engine damage.

References given at the end of this chapter provide a theoretical discussion of fuel consumption for displacement- and planing-hull vessels.

GAS VERSUS DIESEL

The speed curve and the fuel consumption curve for a vessel depend upon the type of engine installed. Typically, diesel engines are more fuel-efficient than gasoline engines and diesel fuel costs less than gasoline. Modern turbocharged diesels are often faster, as well. Diesels are typically heavier and substantially more expensive than gasoline engines. Whether diesels are a cost-effective choice (i.e., whether the annual savings in fuel cost is greater than the annualized capital cost increment for the diesel) depends upon the estimated usage. Several references (e.g., Moss, 1981; Kreisler, 1995; and West, 1975) provide relevant data and economic analyses applicable to initial purchase or repowering. Discussion of the merits of alternative powerplant selection and/or repowering is beyond the scope of a text on navigation.

What is clear and relevant, however, is that the fuel efficiency of a diesel engine is typically greater than that for a comparable gasoline engine. (The word "typically" is used here. Not all diesels are more fuel-efficient. Some turbocharged diesels have comparable fuel efficiency to gasoline engines.) Figure 11-3 shows relevant comparisons based on data presented by Kreisler (1995). The two solid curves show the relation between STW and fuel burn rate for a Bertram 33 powered by twin gasoline inboards (markers are the open circles) or twin diesels (markers are the open squares). The two dashed curves show the corresponding fuel efficiencies. The dashed line marked by the closed circles represents the gasoline-powered version, that with the closed squares, the diesel-powered version. As can be seen, the fuel efficiency of the diesels is greater—and dramatically so for low speeds. Powered with these diesels, this vessel has very "long legs" (can travel much farther).

Figure 11-4 shows fuel efficiency estimates (Gorant, 1995) for a Luhrs T-320 open sportfish available with three twin-engine inboard powerplants. The solid black line (filled square markers) shows the fuel efficiency with a gasoline inboard and the dashed lines the fuel efficiency of the same vessel as powered with two different diesels. Again, the fuel efficiency of the diesels is greater at all speeds, but dramatically so at low speeds.

SOURCES OF FUEL CONSUMPTION INFORMATION

Sources of fuel consumption data include published test results and measurements on the actual vessel.

Published Test Results

There are numerous sources of fuel consumption information of the kind displayed in Table 11-3. Vessel owner's manuals sometimes provide these data. Additionally, several periodicals, such as *Boating* and *Power & Motoryacht* magazines, offer compilations of test data for newer vessels. Such boat tests are often an excellent source of data. However, the reader should note the conditions of the test, particularly the loading and reported sea conditions. As noted below, these can have an important effect on fuel efficiency. These data offer guidance, but should not be used unless validated to estimate fuel consumption for your vessel, even if similarly equipped.

Measured Data

Measurement of fuel consumption can be accomplished in a variety of ways. Commercial *fuel flow meters,* sometimes integrated into microprocessor-based *fuel management systems,* are probably best for this purpose. Another advantage of a fuel flow meter is that instantaneous measurements are available, which means that the most efficient power setting can be determined while underway and adjusted as circumstances dictate. These systems (particularly for diesel-powered twin-engine boats) are expensive, however.

A simpler, although less accurate, method is to fill the tank, run the vessel at a constant RPM for, say, half an hour, and then measure the amount of fuel it takes to refill the tank to its original level. This

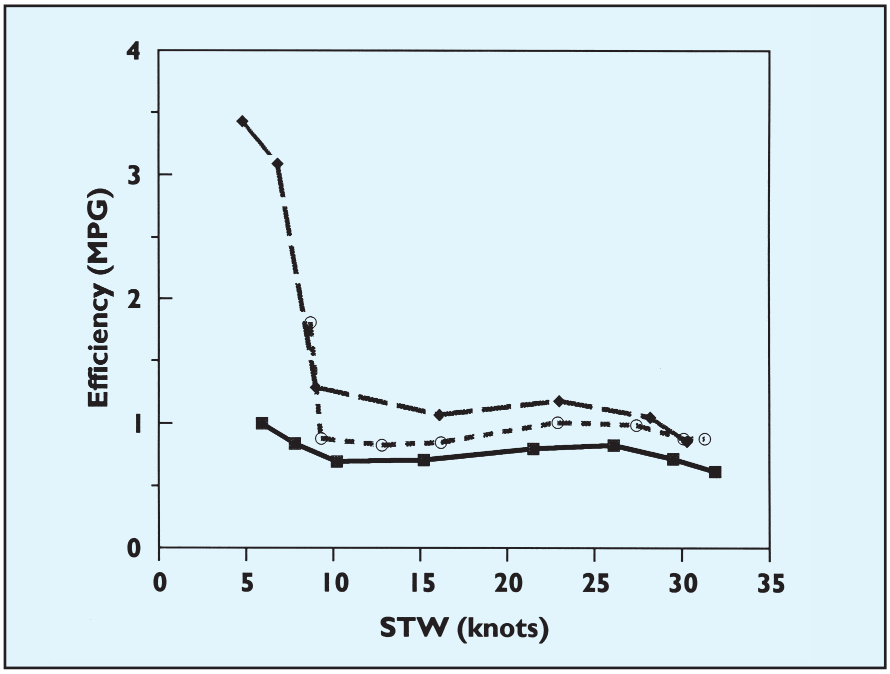


FIG. 11-4–Fuel burn rate and efficiency for the same boat with three different power plants.

process can be repeated at other throttle settings to produce data such as are shown in Table 11-2.

Even if data are available from manufacturer's literature or periodicals, it makes sense to check (audit) some of the data points to ensure that these are appropriate for the vessel. The accuracy of this audit is one of the factors that should be used in determining a safe reserve. If, for example, the fuel consumption for a vessel was 10 percent higher than published data indicate, the curve should be adjusted by this amount and/or an adequate reserve included.

Unless the vessel is equipped with a fuel flow meter, it is tedious and time consuming to check fuel consumption data for each possible throttle setting. A practical compromise would be to check only key points in the chart, such as the maximum range RPM, the normal cruise RPM, and the maximum continuous-duty RPM.

FACTORS THAT AFFECT FUEL EFFICIENCY

Hull design, powerplants, and throttle setting are important determinants of fuel efficiency and range. Table 11-4 shows several other factors that are also important. Some of these are discussed below. Many of these factors are self-evident, such as vessel hull design, condition of hull, throttle setting (RPM), engine tuning, and engine horsepower.

The diameter and pitch of the propellers can affect both speed and fuel consumption, as can the balance of the propellers.

The condition of the hull can affect the relationship between RPM and speed (and, hence, fuel efficiency) quite significantly.

A rough and time-honored rule of thumb recommended in older texts is to reduce the speed corresponding to any RPM by approximately 1 percent for each month since the vessel was out of dry dock. Rather than use this approximation, it is preferable to recalibrate the speed curve and update the fuel consumption table periodically.

The weight of the vessel (and how this weight is distributed) can also affect the speed curve. Devotees of so-called predicted log races (where even seconds matter) make corrections to the speed curve to account for the change in the vessel's weight as fuel is burned. Adjustments to the speed curve to reflect fuel burn are generally not significant for most fuel planning purposes, however.

The installation and positioning of *trim tabs* also affects the vessel's speed curve and fuel economy. Data on the effectiveness of trim tabs can be found in Moss (1981). Ensure that the trim tabs (if installed) are set to the correct position when the speed curve is determined.

Engine ventilation and engine-compartment temperature (West (1975)) are also important determinants of fuel efficiency.

Some of the factors listed in Table 11-4 are subtle, such as vessel trim and the ability of the person at the helm to maintain a constant course. Environmental conditions such as wind and sea conditions or currents are also important. The effect of currents is discussed below. Winds affect powerboats as well as sailing craft—in part, by direct action (e.g., increased drag or leeway) and, also, because winds can induce fair or foul currents. Finally, sea conditions are important. It is found for large and small craft alike that SOAs decrease as wave heights increase–even if the same throttle setting is maintained. Additionally, it is often necessary to reduce engine RPMs or alter course when wave heights increase in order to ensure a more comfortable ride. Some of these effects—such as RPM, hull design, and engine variables—are considered explicitly in the fuel-consumption chart. But other factors, such as trim, sea state, and prevailing winds, are not. For this and other reasons noted above, a prudent planner makes allowance for these contingencies and maintains an adequate fuel reserve.

- ✓ Vessel Hull Design
- ✓ Condition of Hull
- ✓ Engine Type, Horsepower, and Condition
- ✓ Engine Throttle Setting (RPM)
- ✓ Pitch and diameter of propellors
- ✓ Weight (Load) and Weight Distribution (Balance)
- ✓ Trim Settings
- ✓ Fair or Foul Currents
- ✓ Wind and Sea Conditions
- ✓ Ability of Helmsman to Maintain Course

TABLE 11-4–Factors that Affect Fuel Efficiency

EN ROUTE TIME-THROTTLE SETTING TRADE-OFFS

Returning to the example given in Table 11-3, this section shows how these data can be used in a practical manner for improved fuel management and voyage planning. The fact that, with displacement-hull vessels, high cruising ranges can only be achieved at low speeds does not mean that low speeds are always desirable. Not all voyages are long enough to require great range, and sometimes fuel stops can be found even on long voyages. The fuel consumption chart provides essential information for speed-range tradeoff analysis.

One way to make use of the information given in the fuel consumption chart is to reformat it as shown in Table 11-5. In this example, a trip of 120 nautical miles is being planned. For purposes of this illustration, the possibility of intermediate fuel stops is not considered. Table 11-5 repeats the data in Table 11-3 to show the time required to reach the destination and the estimated fuel, time, and cruising distance remaining when the destination is reached. This fuel remaining must include fuel for entry into the harbor, additional maneuvering, and a contingency for foul currents, adverse weather or sea conditions, waiting outside an inlet for favorable passage conditions, diversion en route, etc. Note, first, that at a throttle setting of 1000 RPM the fuel remaining at the destination is maximized—only approximately 40 gallons en route fuel is consumed. To see this, note that the SOA (assuming no current) is 1 knot, so it would take 120 hours (120 M/1 MPH) for the trip as shown in column 5 of Table 11-5. The fuel required for this trip equals the trip time (120 hours) multiplied by the fuel consumption rate (0.33 GPH) or approximately 40 gallons as shown in column 6 of Table 11-5. Assuming full tanks (200 gallons) at the start of the trip, this would leave 200 - 40 = 160 gallons remaining in the tanks, as shown in column 7 of Table 11-5. This remaining fuel (160 gallons) would allow the vessel to cruise at 1000 RPM for 160/0.33 or approximately 486 hours, and to travel an additional 486 hrs x 1 MPH = 486 nautical miles as shown in columns 8 and 9 of Table 11-5.

But the speed (1 knot) of advance at this throttle setting is so slow that 120 hours would be required for the trip! Alternatively, at a throttle setting of 3000 RPM corresponding to a STW of 10 knots, the 120 M trip will take only 12 hours; but fuel consumption is so high (192 gallons) that the tanks would be virtually dry upon arrival, leaving no margin for error. Compared to this plan, a compromise throttle setting of, say, 2250 RPM would add only 3 hours to the trip but would increase the estimated fuel on board at the destination

VESSEL: AVENTURA
FUEL: 200 GALLONS ON BOARD
DISTANCE: 120 NAUTICAL MILES
CURRENT 0 FOUL CURRENTS ARE NEGATIVE

THROTTLE SETTINGS (RPM)	STW (KNOTS)	SOA (KNOTS)	FUEL CONSUMPTION RATE (GPH)	REQUIRED TRIP DURATION (HOURS)	TRIP FUEL REQUIRED (GALLONS)	FUEL REMAINING AT DESTINATION (GALLONS)	TIME TO FUEL EXHAUSTION AT DESTINATION (HOURS)	RESERVE RANGE AT DESTINATION (MILES)
1000	1.0	1.00	0.33	120.0	40	160	486.1	486
1250	2.0	2.00	0.80	60.0	48	152	190.0	380
1500	3.5	3.50	1.80	34.3	62	138	76.8	269
1750	5.0	5.00	3.30	24.0	79	121	36.6	183
2000	7.0	7.00	5.00	17.1	86	114	22.9	160
2250	8.0	8.00	6.70	15.0	101	100	14.9	119
2500	9.0	9.00	9.00	13.3	120	80	8.9	80
2750	9.5	9.50	11.90	12.6	150	50	4.2	40
3000	10.0	10.00	16.00	12.0	192	8	0.5	5

Note: Effects of current not considered in this run

TABLE 11-5–Time-Throttle Setting Tradeoffs Illustrated

to nearly 100 gallons—enough to travel nearly 120 additional miles at this throttle setting.

The choice between throttle settings of 2250 RPM and 3000 RPM is, in reality, no choice at all. It would be sheer folly to attempt this voyage at 3000 RPM without a fuel stop. And, even if a fuel stop were feasible along the route of this voyage, the additional time required for the fuel diversion (queuing at the fuel dock, fueling, and returning to the original track) would have to be added to the voyage time at a throttle setting at 3000 RPM for a valid portal-to-portal time comparison. If the delay occasioned by the fuel stop were, for example, 1-1/2 hours, the total time difference would shrink to 1-1/2 hours (13.5 hours compared to 15 hours). As this example clearly shows, there is generally little purpose in running displacement-hull vessels at maximum speed.

The appropriate choice of RPM depends upon many factors (e.g., how much reserve is deemed prudent, time schedules, etc.), but the value of a systematic analysis of time/throttle setting trade-offs should be clear. All that is required for this analysis is the vessel's basic fuel consumption chart and a few additional computations.

EFFECT OF CURRENT

Currents can be very important to fuel planning, and information on current set and drift should be considered, if available. As is noted in Chapters 5 and 7, currents may alter the required course to maintain a desired track, and the fair or foul component of the current can either increase or decrease the estimated SOA relative to the STW.

Currents are important to fuel planning for two principal reasons:

- ❏ Currents can increase or decrease the range attainable at any throttle setting (RPM). Fair (i.e., following) currents

PHOTO COURTESY OF UNITED STATES COAST GUARD

The only time there is too much fuel on board is when the vessel is on fire.

[1]*Data used in this illustration are taken from the original source. Generally, however, the STW at the lowest feasible throttle setting (the so-called "clutch speed") is greater than 1 knot—often 5 or 6 knots.*

VESSEL: AVENTURA
FUEL CAPACITY: 200 GALLONS
FOUL CURRENT: 2 KNOTS

THROTTLE SETTING (RPM)	SPEED THRU THE WATER STW (KNOTS)	SPEED OF ADVANCE SOA (KNOTS)	FUEL CONSUMPTION RATE (GPH)	FUEL EFFICIENCY (MPG)	ESTIMATED RANGE IN NAUTICAL MILES WITH FUEL RESERVE 10%	20%	ESTIMATED ENDURANCE IN HOURS WITH FUEL RESERVE 10%	20%
1000	1.0	-1.00	0.33	UNDEFINED	INFEASIBLE	INFEASIBLE	545	485
1250	2.0	0.00	0.80	0.00	INFEASIBLE	INFEASIBLE	225	200
1500	3.5	1.50	1.80	0.83	150	133	100	89
1750	5.0	3.00	3.30	0.91	164	145	55	48
2000	7.0	5.00	5.00	1.00	180	160	36	32
2250	8.0	6.00	6.70	0.90	161	143	27	24
2500	9.0	7.00	9.00	0.78	140	124	20	18
2750	9.5	7.50	11.90	0.63	113	101	15	13
3000	10.0	8.00	16.00	0.50	90	80	11	10

TABLE 11-6–Illustrative Fuel Planning Worksheet

increase the range, foul (head) currents decrease the range.

- ❑ Currents can alter the optimal throttle setting for maximum range. Foul currents increase the optimal power setting.

These points are illustrated in Table 11-6, which builds upon the data given in Table 11-3 except that a 2-knot foul current is assumed. The SOA is 2 knots less than the STW in this instance, but the calculations are otherwise identical to those in Table 11-3.

For example, consider a throttle setting of 1750 RPM. The STW at this RPM is 5 knots but, because a 2-knot foul current is assumed, the SOA is only 3 knots. Fuel consumption at this RPM is 3.3 GPH; so the fuel efficiency at this throttle setting is 3/3.3 = 0.91 MPG (shown in Table 11-6) rather than the 5/3.3 = 1.52 MPG shown in Table 11-3. The range with 10 percent fuel reserve is 180 times 0.91 or 164 miles, rather than 273 miles, nearly a 40 percent reduction. Obviously, a 2-knot foul current rules out operation at throttle settings less than 1500 RPM (2-knot STW) if a positive SOA is desired. But, in this instance, unlike that for the zero current calculations, the maximum range does not occur at the lowest feasible RPM, nor are the throttle settings identical for maximum range and maximum endurance. As shown in Table 11-6, the throttle setting that maximizes the range is 2000 RPM. In general, it can be shown in fuel consumption curves typical of displacement vessels, foul currents increase the RPM for maximum range. Table 11-7 and Figure 11-5 show how the optimal throttle setting and resulting fuel efficiency vary with the strength (drift) of the foul current.

Table 11-7 shows the results of varying the current from 5 knots

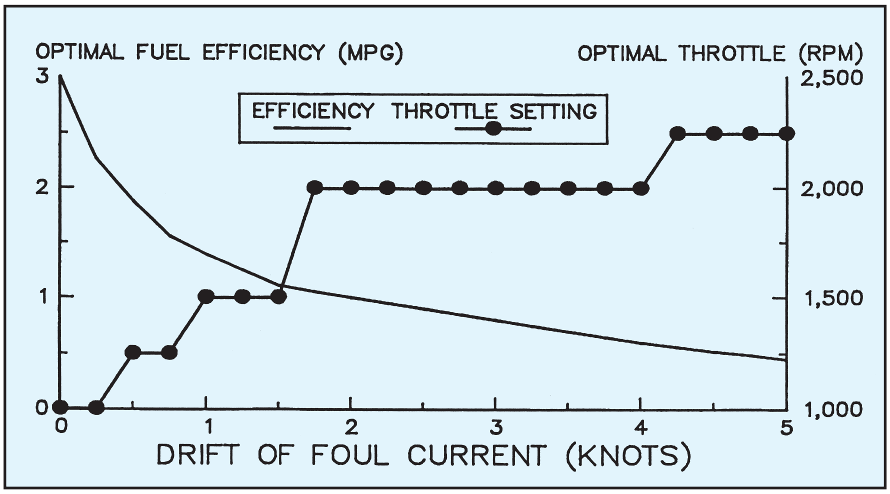


FIG. 11-5–How optimal throttle setting and resulting fuel efficiency vary with foul currents for vessels with displacement hulls.

CURRENT DESCRIPTION	DRIFT (KNOTS)	OPTIMAL THROTTLE SETTING (RPM)	OPTIMAL STW (KNOTS)	OPTIMAL SOA (KNOTS)	OPTIMAL FUEL EFFICIENCY (MPG)	OPTIMAL RANGE WITH 10% RESERVE (MILES)
Fair	5.00	1000	1.0	6.00	18.18	3273
Fair	4.00	1000	1.0	5.00	15.15	2727
Fair	3.00	1000	1.0	4.00	12.12	2182
Fair	2.00	1000	1.0	3.00	9.09	1636
Fair	1.00	1000	1.0	2.00	6.06	1091
None	0.00	1000	1.0	1.00	3.03	545
Foul	-0.25	1000	1.0	0.75	2.27	409
Foul	-0.50	1250	2.0	1.50	1.88	338
Foul	-0.75	1250	2.0	1.25	1.56	281
Foul	-1.00	1500	3.5	2.50	1.39	250
Foul	-1.25	1500	3.5	2.25	1.25	225
Foul	-1.50	1500	3.5	2.00	1.11	200
Foul	-1.75	2000	7.0	5.25	1.05	189
Foul	-2.00	2000	7.0	5.00	1.00	180
Foul	-2.25	2000	7.0	4.75	0.95	171
Foul	-2.50	2000	7.0	4.50	0.90	162
Foul	-2.75	2000	7.0	4.25	0.85	153
Foul	-3.00	2000	7.0	4.00	0.80	144
Foul	-3.25	2000	7.0	3.75	0.75	135
Foul	-3.50	2000	7.0	3.50	0.70	126
Foul	-3.75	2000	7.0	3.25	0.65	117
Foul	-4.00	2000	7.0	3.00	0.60	108
Foul	-4.25	2250	8.0	3.75	0.56	101
Foul	-4.50	2250	8.0	3.50	0.52	94
Foul	-4.75	2250	8.0	3.25	0.49	87
Foul	-5.00	2250	8.0	3.00	0.45	81

TABLE 11-7–Optimal Power settings and Associated Information, as a Function of the Drift of the Assumed Current

fair to 5 knots foul. For each case, the optimal RPM is determined as well as the resulting fuel efficiency and range. Although these calculations are tedious, they are not complex and are readily programmed into scientific calculators or *personal computers* (PCs). Once completed, the results of these calculations are easy to interpret and use.

Note that, in this example, even a small adverse current can substantially decrease the maximum range; a 1-knot adverse current reduces the maximum range by more than 50 percent! It is useful to make these calculations for each vessel to be operated because the results will differ from vessel-to-vessel. This example however, shows that current affects can be substantial—particularly for displacement vessels. Many mariners have a qualitative idea of the affect of an adverse current on the vessel's range, but have not made the types of calculations shown above and, so, lack a quantitative understanding. In one *Search and Rescue* (SAR) case, for example, a small cabin cruiser ran out of fuel in the middle of the channel of the Delaware River, near Philadelphia, Pennsylvania. Fortunately, a *United States Coast Guard Auxiliary* (USCGAUX) patrol vessel was in the immediate vicinity and managed to get a line on and towed the disabled cabin cruiser out of the path of an oncoming tanker. When asked how it came to be that the cabin cruiser had run out of fuel, the distraught skipper responded, "I don't understand it. I filled the tanks yesterday morning and traveled down to the Delaware Bay and back—a trip I've made before without needing fuel en route." Reconstruction of the details

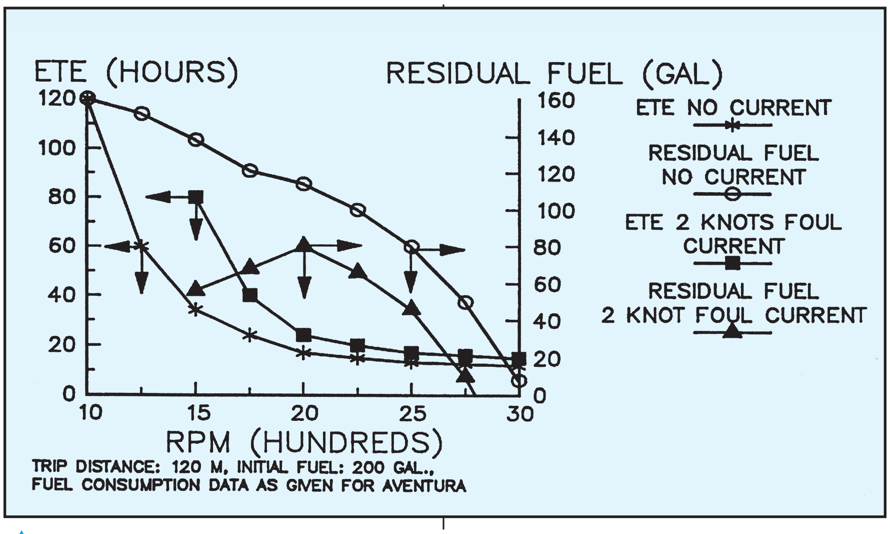


FIG. 11-6–Assumed currents can substantially affect speed–fuel consumption trade-offs for displacement or semi-displacement hull vessels.

of the voyage showed that, on this occasion, the run down and back on the river was timed unfortunately—the cruiser had foul currents on both legs. (See Chapter 8 for a discussion of how to select starting times to avoid this situation.) After-the-fact range calculations for this vessel indicated that the effective range given a 2-knot foul current was reduced by 50 percent in comparison to the no-current condition. Additionally, because the trip was longer, the skipper ran at a higher than customary throttle setting to complete the voyage during the daylight hours. As it was, the skipper nearly made it, the cruiser was only a few miles from homeport when the engine quit. This skipper now has fuel consumption charts (of the type shown in Tables 11-3 and 11-6) pasted into the vessel's log!

Current considerations are also important to the kinds of trade-offs considered in Table 11-6. Table 11-8, for example, shows similar calculations to those displayed in Table 11-5, except that a foul current of 2 knots is assumed. The range of throttle-setting options is more restricted—1000 RPM and 1250 RPM are not feasible, and a 3000-RPM throttle setting guarantees fuel exhaustion before the destination is reached. The attractiveness of operation at 2250 RPM (a possible compromise) is reduced; en route time has been increased from 15 hours to 20 hours and the cruising reserve decreased from nearly 120 miles to 60 miles—a substantial effect from what is arguably a modest current. Figure 11-6 shows this graphically.

RADIUS OF ACTION AND RELATED CONCEPTS

(This section is more technical and can be omitted without any loss of continuity. This material is not covered in the final examination.)

Aircraft pilots employ two other fuel-planning concepts that are also relevant to the mariner, the radius of action and the point of no return. Before defining these terms, it is useful to imagine an "out and back" voyage from a port of origin without the possibility of refueling en route—for example, on an offshore fishing trip from the coast of New Jersey to the Hudson Canyon.

The radius of action is the greatest distance (out) that may be traveled and still leave sufficient fuel aboard to return to the port of origin without touching the fuel reserve. The point of no return is the point beyond which there is insufficient fuel to return using the entire fuel reserve. Mathematically, the radius of action, RA, is given by the equation,

$$RA = F(1-R)/G([1/SOAo] + [1/SOAr])$$

where,

RA = radius of action (nautical miles),
F = fuel capacity (gallons),
R = fuel reserve (fraction),
G = fuel consumption rate (gallons per hour),
SOAo = speed of advance out (knots), and
SOAr = speed of advance on return leg (knots).

The distance to the point of no return, Dponr, is calculated using the same equation given above, except that the reserve, R, is set equal to zero for this computation. In the special case where there is no current and the SOAo and SOAr are each equal to the STW, the radius of action is equal to the range divided by two.

To illustrate, suppose that the vessel *Aventura* (for which fuel consumption and capacity data are given in Table 11-3) is taken on a trip and a throttle setting of 2250 RPM is selected. The STW corresponding to this throttle setting is 8.0 knots (see Table 11-3). Suppose also that current sailing calculations (discussed in Chapter 7) employing estimated set and drift (discussed in

VESSEL:	AVENTURA
FUEL:	200 GALLONS ON BOARD
DISTANCE:	120 NAUTICAL MILES
CURRENT	2.00

THROTTLE SETTINGS (RPM)	STW (KNOTS)	SOA (KNOTS)	FUEL CONSUMPTION RATE (GPH)	REQUIRED TRIP DURATION (HOURS)	TRIP FUEL REQUIRED (GALLONS)	FUEL REMAINING AT DESTINATION (GALLONS)	TIME TO FUEL EXHAUSTION AT DESTINATION (HOURS)	RESERVE RANGE AT DESTINATION (MILES)
1000	1.0	-1.00	0.33	N/A	N/A	N/A	N/A	N/A
1250	2.0	0.00	0.80	N/A	N/A	N/A	N/A	N/A
1500	3.5	1.50	1.80	80.0	144	56	31.1	47
1750	5.0	3.00	3.30	40.0	132	68	20.6	62
2000	7.0	5.00	5.00	24.0	120	80	16.0	80
2250	8.0	6.00	6.70	20.0	134	66	9.9	59
2500	9.0	7.00	9.00	17.1	154	46	5.1	36
2750	9.5	7.50	11.90	16.0	190	10	0.8	6
3000	10.0	8.00	16.00	15.0	240	-40	-2.5	-20

TABLE 11-8–Time-Throttle Setting Trade-offs Illustrated

Chapter 8) indicate that the best estimate of the SOA on the "out" leg is 7.1 knots, and on the "back" leg is 7.3 knots. (Both would be beneath the STW in the case of a beam current.) The fuel consumption rate at this throttle setting, G, is 6.7 GPH (see Table 11-3). Assume that a 20 percent fuel reserve (R = 0.2) is desired. The radius of action at this throttle setting calculated from the above equation is,

$$RA = 200(1-0.2)/6.7([1/7.1] + [1/7.3]),$$

equal to approximately 86 nautical miles. The point of no return in this numerical example would be 20 percent larger, or equal to approximately 119 nautical miles.

Both the radius of action and the point of no return vary with the throttle setting. This is because G and STW (hence, SOAo and SOAr) vary with the throttle setting.

Computations of the radius of action and point of no return are also useful for trips where the origin and destination differ—for example, on a trip from Florida to the Bahamas. For any distance out less than the point of no return, the vessel has sufficient fuel to return to Florida if a diversion is required. Beyond the point of no return, the vessel is committed (at least in terms of available fuel) to continue to the Bahamas. This voyage to the Bahamas also serves as an example where the SOAo and SOAr would both be less than the STW, because the Gulf Stream would be a beam current on both the out and return legs. Normally, the point of no return would be calculated in advance as part of the prevoyage planning. It serves as a convenient memory aid to enter the point of no return into the Loran-C or *Global Positioning System* (GPS) receiver as one of the en route waypoints. Obviously, if the estimated set and drift differ appreciably from those assumed in the plan, it is appropriate to recompute the point of no return.

INTEGRATION OF FUEL PLANNING INTO VOYAGE PLANNING

The above concepts are readily integrated into general voyage planning. Table 11-9, for example, shows a voyage planning worksheet that contains entries relevant to fuel planning (e.g., RPM, STW, SOA, fuel consumption rate, and fuel required and remaining for each leg) as well as the TVMDC course entries and current sailing entries. Checkpoints (the ends of the trip legs) can be defined, not only for navigational convenience (e.g., where courses change), but also as "option points" where diversions for additional fuel stops can be considered. Remember the old adage that the only time there is too much fuel aboard is when the vessel is on fire!

IS ALL THIS REALLY NECESSARY?

The above fuel planning examples may seem unnecessarily elabo-

VOYAGE PLANNING WORKSHEET

REMARKS ON VOYAGE PLAN:

GENERAL INFORMATION:

	CHECK ITEMS			
DATE:__________	CHARTS REQD:______	CURRENT TABLES:__________	NAV. GEAR:________	
NAVIGATOR: ________	COAST PILOT:______	DEVIATION TABLE: __________	TIMEPIECE:________	
VESSEL: __________	LIGHT LIST:______	FUEL/RPM TABLE: __________		TIME START:________ FOB (GAL.):______
	TIDE TABLES: ______	PILOT CHARTS: __________		

DETAILED LEG PLAN:

LEG	FROM	TO	INTENDED TRACK (TRUE)	LEG DISTANCE (M)	POWER SETTING (RPM)	ESTIMATED STW (KNOTS)	CURRENT SET	CURRENT DRIFT	TRUE COURSE	VARIATION	MAGNETIC COURSE	DEVIATION	COMPASS COURSE	ESTIMATED SOA (KNOTS)	ETE HH:MM	ETA HH:MM	EST. FUEL CONSUMPTION (GAL.)	EST. FUEL REMAINING (GAL.)

TABLE 11-9–Voyage Planning Worksheet

CATEGORY	DESCRIPTION
General Planning	– Develop a fuel use versus throttle settings (RPM) curve for your vessel. – Consider voyage routing or timing options to minimize exposure to foul currents or adverse weather conditions. – Study publications to learn the locations along a proposed route where fuel is available. – Use formal fuel planning and allow adequate reserve margins. – Consider speed versus fuel consumption trade-offs.
While Underway	– Do not trust fuel guages–verify fuel levels before and during voyage. – Maintain a “Howgozit” chart, or – Maintain a fuel log and be prepared to divert to alternate destinations.
Maintenance and Related	– Keep engines tuned. – Clean bottom periodically. – Fill up tanks after each trip to minimize condensation problems.
Vessel Equipment	– Consider installation of cross-feeds in multiple tank/engine setups. – Consider installation of fuel management system. – Consider installation of vessel trim tabs.

TABLE 11-10–Tips for Improved Fuel Management

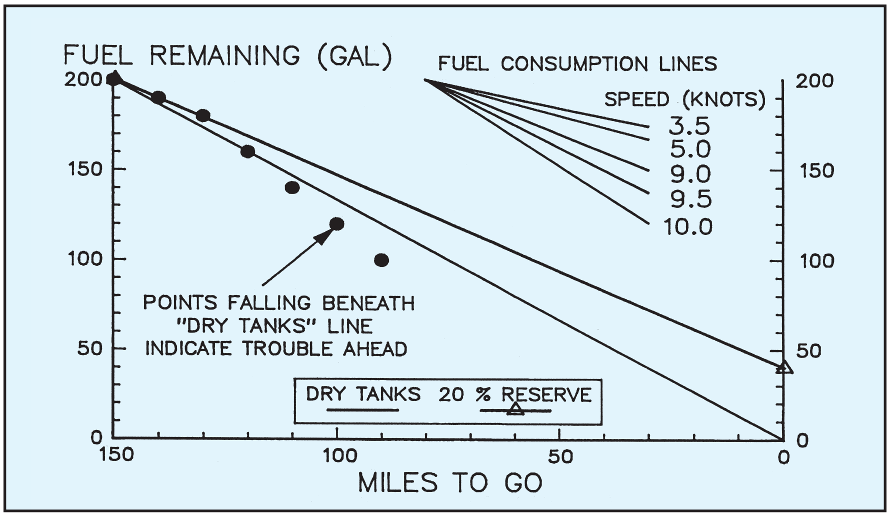


FIG. 11-7–"Howgozit" Chart for Example Voyage

rate. It is important to note that for short voyages with frequent opportunities to refuel, some computational shortcuts can be taken. Just as the detail of DR plots, frequency of fixes, etc., can be adjusted to circumstances, so, too, can the detail of the fuel planning calculations. At a minimum, however, the vessel operator should determine that the fuel on board is sufficient for the voyage and provide a reasonable reserve.

ADDITIONAL TIPS FOR IMPROVED FUEL MANAGEMENT

Table 11-10 lists 14 experience-proven suggestions for improved fuel management that should be considered by the prudent mariner. These are grouped under four broad headings: general planning, while underway, maintenance and related, and vessel equipment.

General planning

Those suggestions in the "general planning" category summarize the material presented in this chapter and are not discussed further.

While underway

The "while underway" category includes the suggestion to verify fuel gauges before and during a voyage. Gauges (and other components of the system) can fail and, moreover, the complex (rounded) shape of some fuel tanks may make the gauge calibration inaccurate, particularly at low fuel levels. Many tanks can be checked by inserting a stick in the fuel-filler hose. Calibrate the reading on this dipstick by adding measured quantities of fuel and marking the stick accordingly. These measurements are most valid while the vessel is stationary; so it is necessary to stop the vessel briefly during a voyage to ensure maximum accuracy. Keep an accurate log showing RPM and length of time the vessel is operated at each RPM as an additional check on fuel burn.

Incidentally, the capacity of the fuel tanks should be verified—on new as well as used boats. There have been instances where the manufacturer inadvertently installed the wrong fuel tank. Moreover, manufacturers sometimes offer different capacity tanks as options.

A simple means for keeping track of the vessel's fuel status is to maintain a "Howgozit" (a corruption of "How goes it") chart. Figure 11-7 illustrates such a chart. It is constructed as follows.

- ❑ First, do conventional fuel planning for the intended voyage to ascertain the appropriate throttle setting, etc. Suppose, for example, that a trip of 150 miles is planned and a fuel load of 200 gallons is available at the start of the voyage. In this example, it is assumed that the vessel *Aventura* is used, for which basic fuel consumption data are given in Table 11-3.
- ❑ Second, construct a graph with total gallons remaining plotted on the y or vertical axis, and miles to go on the x or horizontal axis, as shown in Figure 11-7. Using a straight edge or plotter, draw a line starting in the upper left hand corner (200 gallons on board, 150 miles to go) of the graph to the lower right hand corner of the graph (0 gallons on board, 0 miles to go). Identify this as the "dry tanks" line.
- ❑ Third, specify the desired fuel reserve, say 20 percent, and calculate the remaining fuel on board at the end of the trip if this reserve is maintained. In this example, the reserve fuel is (0.2) (200) or 40 gallons. Draw another straight line on the

"Howgozit" graph from the upper left-hand corner (200 gallons on board, 150 miles to go) to the reserve fuel (40 gallons) at the destination (0 miles to go). Label this the "20% reserve" line.

Once the "Howgozit" chart is prepared, keep track of the remaining fuel and distance to go while underway. For example, you might note the fuel remaining from inspection of the gauges or from a *fuel totalizer* (an instrument that is coupled to the fuel flow meter and notes the total fuel consumed on the voyage) at selected DR positions, fixes (even better), and/or at the end of the various legs of the journey. Plot these data as you go. In order to ensure that you have sufficient fuel to complete the voyage, it is clear that the plotted points must always lie above the "dry tanks" line; and to ensure the desired fuel reserve at the destination, these points must stay above the "20 percent reserve" line. If all points plotted remain above both lines, the fuel will be adequate to reach the destination.

However, if the plotted points dip beneath these lines (as shown in Figure 11-7), you have the makings of a problem because, at the fuel consumption rates experienced thus far in the journey, the vessel will run out of fuel before reaching the destination. Now, early in the voyage when options remain, something needs to be done. One solution might be to divert to an alternate marina where fuel is available. (Identification of suitable alternates where fuel is available is an important part of the preplanning process.) Another solution is to change the throttle setting so as to increase fuel efficiency. (Generally, with a displacement-hull vessel, this amounts to slowing down.) In the example shown, the fuel remaining is 100 gallons with 90 miles to go. If it is desired to regain the 20 percent fuel reserve (40 gallons remaining at the destination), then no more than 60 gallons of fuel can be consumed during the remaining 90 miles, a fuel efficiency of 90/60 or 1.5 MPG. Reference to Table 11-3 shows that, theoretically at least, operating at a throttle setting of 1750 RPM (equivalent to a STW of 5 knots) or lower should leave you sitting at the dock with a 20 percent fuel reserve. If this solution were chosen, you would continue to maintain the "Howgozit" chart and monitor the vessel's fuel status. If the plotted points did not rise closer to the "dry tanks" line or, even better, the "20% reserve" line, it's time to rethink options. (The calculations, for example, might be in error because of the presence of an unanticipated foul current.)

As an alternative to having to calculate a feasible throttle setting as you go, it is relatively easy to superimpose the vessel's fuel consumption data on the "Howgozit" chart directly. This idea can be implemented if a series of *fuel consumption lines* are drawn, as shown in the upper right hand corner of Figure 11-7. Separate lines are drawn for each throttle setting, with the slope of the line equal to the fuel consumed per mile (reciprocal of the fuel efficiency) at that throttle setting or STW.

For example, at a throttle setting of 1750 RPM, the vessel's STW (Table 11-3) is 5 knots, and the fuel consumption rate is 3.3 GPH. Therefore, the vessel will consume approximately 3.3/5, or 0.66 gallons per mile. To draw this "5-knot line," pick an uncluttered part of the chart and draw a line with this slope. Suppose that you start, as shown on Figure 11-7, at the point 200 gallons, 80 miles to go. Pick a distance, say 50 miles, sufficient to provide a clear indication of the slope. If a vessel traversed 50 miles at this throttle setting, it would consume 0.66 gallons per mile times 50 miles, or 33 gallons. Starting with 200 gallons, the fuel remaining would be 200 - 33, or 167 gallons. Draw the fuel consumption line from the original point (200 gallons, 80 miles to go) to the point (167 gallons, 30 miles to go), and label this with the speed (5 knots). Repeat this procedure for each of the other throttle settings to produce the fuel consumption lines shown in Figure 11-7. Although this might sound like a tedious effort, in practice it is quick to do. Moreover, once done, it radically simplifies en route decision making. Whether or not you go to the trouble of drawing in the fuel consumption lines, it is important to use the "Howgozit" chart en route.

Once drawn, the fuel consumption lines are very simple to use. Just take a paraline plotter and align one end with the last solid dot in Figure 11-7, corresponding to the vessel's actual fuel state and distance to go. Next, take the other end of the paraline plotter and align it with the desired reserve at the destination. Now roll the paraline plotter up to the speed lines above, taking care not to change the alignment, and read directly the speed necessary to reach the final destination.

Maintenance and related

The suggestions listed under the "maintenance and related" heading are self-evident for the most part. Filling the tanks after each trip minimizes the chance that moisture in the airspace above the fuel in the tank condenses and (since water is heavier than fuel) settles at the bottom of the tank where it could be drawn into the engine. Avoid topping off the tanks, however, as this leads to spills.

Vessel equipment

The suggestions listed under the "vessel equipment" heading are also self-explanatory, but some remarks are appropriate for vessels equipped with more than one fuel tank. Installation of cross-feeds (i.e., interconnections among fuel tanks and the engines) enable the vessel to be kept in better trim. They also enable any tank with bad fuel or a clogged line to be bypassed to maintain fuel flow to the engine(s). Some especially careful mariners will not take on an entire load of fuel from one source to minimize the possibility of contaminated fuel in all tanks. This consideration is particularly important at some foreign ports of call.

ADDITIONAL PERSPECTIVE: THE SEAMAN'S EYE

When the mariner has learned navigation skills thoroughly, he or she will know when use of the formal techniques (such as plotting, making detailed float plans such as are shown in Table 11-9, or detailed fuel projections) is necessary and when departures from these formal processes are appropriate and can be made safely. In familiar areas, such as on a particularly frequented embayment or sound, river or coastal area, where the charted hazards, aids to navigation, currents, tides, and other essential navigational information are well known, it may be sufficient only to keep the chart handy for marking positions when desired (at the approach of a fog bank or other period of restricted visibility, for example) but not carry on a DR plot or take frequent fixes.

Informal navigation is appropriate under these circumstances and is termed navigation by seaman's eye. Its proper and safe use comes only after the mariner has learned the navigation skills and techniques sufficiently and has gained sufficient experience to make sound judgments regarding the use of the various techniques available for navigation of the vessel.

Thus, seaman's eye navigation is used after sufficient knowledge of the area is obtained through study of the available charts, *Tide Tables, Tidal Current Tables, Coast Pilots,* and other navigation publications and combined with local knowledge of the area. A thorough mastery of the navigational skills and techniques offered in the material in this textbook should provide a firm foundation for the navigator to know when to apply seaman's eye.

SELECTED REFERENCES

Beebe, R., (1984). *Voyaging Under Power,* Seven Seas Press Inc., Newport, RI.

Berrien, A. D., (1987). Boat Test No. 437: Grand Banks Motor Yacht, *Boating,* February, pp. 93 et seq.

Collins, R. L. (1985). Out of Gas; Accidents Caused By Running the Tanks Dry are Among the Most Avoidable of Mishaps, *Flying,* Vol. 112, No. 9, September, pp. 25, et seq.

Gorant, J., (1995). Three for One; We not only tested the Luhrs T-320, we tested her with three different engine packages, *Power & Motoryacht,* January.

Kinney, F. S., (1981). *Skene's Elements of Yacht Design,* Eighth Edition, Dodd, Mead & Company, New York, NY.

Kreisler, K., (1995). To Repower Or Not To Repower? Seaplane, a 1988 Bertram 33, confronts the eternal question and offers some answers, *Power & Motoryacht,* January, pp 70 et seq.

Laudeman, W. J., (1986). The Speed/RPM chart revisited, *The Navigator,* Fall, p 16.

Lord, L., (1963). *Naval Architecture of Planing Hulls,* Third Edition, Cornell Maritime Press Inc., Cambridge, MD.

Lydecker, R. (undated). Reducing Fuel Costs: A Guide for Recreational Boating, University of Maryland Sea Grant Extension Program.

Lyon, T. C., (1972). *Practical Air Navigation,* Eleventh Edition, Jeppesen, Denver, CO., pp. 136 et seq.

McFadden, R. D., (1990). Toll at 72 in L. I. Air Crash; 89 Survive, Investigators Say the Colombian Plane May Have Run Out of Fuel, *The New York Times,* Vol CXXXIX, No. 48,128, 27 January, p 1, continued on p 30.

Moss, F.T., (1981). *Modern Sportfishing Boats,* International Marine Publishing Co., Camden, ME.

Pike, D., (1976). *Motor Sailors,* David McKay Company, Inc., New York, NY.

Rains, J., and P. Miller, (1989). *Passagemaking Handbook: A Guide for Delivery Skippers and Boat Owners,* Seven Seas Press, Camden, ME.

Shufeldt, H. H. and K. E. Newcomer (1980). *The Calculator Afloat,* Naval Institute Press, Annapolis, MD, pp 188 et seq.

Stapleton, S., (1989). *Stapleton's Powerboat Bible,* Hearst Marine Books, New York, NY.

Stearns, B., (1986). Boat Test No. 423: Rampage 28 Sportsman, *Boating,* September, p 94.

Stearns, B., (1987). Boat Test No. 443: Grady-White Trophy Pro 25, *Boating,* February, p 132.

Stearns, B., (1987). Boat Test No. 458: Fountain 8.8 Meter Center Console, *Boating,* May, p 110.

Teale, J., (1977). *Designing Small Craft,* David McKay Company, Inc., New York, NY.

Weems, P. V. H., (1940). *Marine Navigation,* D. Van Nostrand Company, Inc., New York, NY.

West, J., (1975). *Modern Powerboats,* Second Edition, International Marine Publishing Co., Camden, ME.

CHAPTER 12

REFLECTIONS

"Vision is the art of seeing things invisible"

–Jonathan Swift, Thoughts on Various Subjects; from Miscellanies

"The sea is at its best in London, near midnight, when you are within the arms of a capacious chair, before a glowing fire, selecting phases of the voyages you will never make"

–Henry Tomlinson, The Sea and The Jungle [1912]

INTRODUCTION

Having reached this point in the text, you should have a working knowledge of the essential tools, techniques, and theory of coastal navigation. This chapter is written to go beyond technique to share insights on the practice and/or art of navigation. It presents ten experience-proven principles of navigation practice for your consideration. This chapter has no homework questions or problems to slave over, simply points to ponder. Nonetheless, this is one of the most important chapters in the *Advanced Coastal Navigation* (ACN) text.

Each of the principles discussed below is illustrated with examples—many taken from the vast literature on accidents with commercial ships, some from personal experience of the writer and other members of the *United States Coast Guard Auxiliary* (USCGAUX). The examples all involve navigational errors, some with disastrous consequences, most with happy endings. These examples are not intended to frighten, but rather to instruct. George Santayana's famous remark that "Those who cannot remember the past are condemned to repeat it" is equally applicable to the practice of navigation.

It has been said that the sea is a cruel mistress, totally unforgiving of error. However, careful study of marine mishaps indicates that *isolated* navigation errors are seldom the sole probable cause of an accident. Typically, many adverse factors are required before error turns from mere embarrassment to disaster. It may be prudent to believe otherwise, but an isolated navigational error is often recoverable. In the open ocean, far removed from navigational hazards, an error may be virtually inconsequential. Even in more restricted waters, an error may not be critical if promptly detected and corrected. An error in taking or plotting a fix, for example, can be revealed by a comparison of a fix with the *dead reckoning* (DR) position, or from consistency checks with collateral information (e.g., depth soundings, additional bearings). Even if the fix error is not immediately discovered and causes the navigator to change course towards potentially dangerous waters, such as reefs, there is the possibility that the reefs can be detected and course altered to safer waters, unless night or storms also conspire to reduce visibility or mask the noise of breaking waves. In the famous case of the *Titanic*, for example, it has been argued that only an unfortunate conspiracy of timing was responsible for the disaster. Had the iceberg been seen just a few minutes earlier, the vessel could have turned to avoid collision. Had the iceberg been seen a few minutes later, the *Titanic* would have hit head on, and emerged with a bashed-in bow—seriously damaged—but with most of the watertight compartments intact and the majority of the passengers and crew would have survived.

So it is that boating is a generally safe activity. Moreover, available statistics indicate that fatality rates (per 100,000 recreational vessels) have declined in recent years. To note these trends lends valuable perspective, but it is also important to stress that any accidents or fatalities are, in some sense, intolerable. Statistics show that, for most boating and aircraft accidents as a group, *human error rather than equipment failure* is the probable cause. For example, according to recent *United States Coast Guard* (USCG) estimates published in *Boating Statistics*, operator error was a contributing factor in nearly three-quarters of the boating fatalities where fault could be determined. This statement is not intended as an indictment—rather as a challenge to increase professionalism.

Navigation errors, *per se,* generally account for only a small percentage of the recreational boating accidents in the United States. For example, according to recent issues of *Boating Statistics*, navigation error was judged to be the principal cause for reported accidents involving only about 2 percent of recreational vessels. Again, this statistic is furnished to lend useful perspective, and not to suggest that such a low rate is acceptable.

WHAT YOU WILL LEARN IN THIS CHAPTER

Ten key principles of professional navigation, including:

- ❑ ***Pay attention to detail***
- ❑ ***Practice is essential and can also be fun***
- ❑ ***Do not rely on any one technique for determining the vessel's position***
- ❑ ***Be alert to anomalies***
- ❑ ***Emphasize routine in times of stress***
- ❑ ***Slow down or stop the vessel if necessary and circumstances permit***
- ❑ ***Preplan as much as possible***
- ❑ ***Be open to data or information at variance with your understanding of the situation***
- ❑ ***Know and operate within your limits***
- ❑ ***Maintain a DR plot***

This chapter is organized into a series of maxims or principles that are useful to study and explore in search of wisdom. Space constraints limit the detail that can be included in each of the examples. References are included for those seeking more detail.

PRINCIPLE 1:
PAY ATTENTION TO DETAIL

Professional navigation is as much an attitude of mind as an art or science. In this regard, it is important to heed the advice of the late Frances W. Wright to practice "constant vigilance." This is particularly true with respect to the everyday details or computations that many mariners take for granted. A casual attitude can lead otherwise competent navigators to commit the most amazing blunders. Consider the following examples.

- ❑ A navigator tuned in the Brenton Reef (RBn 295) *radiodirection finding* (RDF) station but dialed in 291 kilohertz (the frequency for Nobska Point) by mistake (an error in the last digit only) and failed to verify the Morse code identifier or to plot the bearing and discover the error. Misled by the false bearing, the navigator altered course and nearly grounded the vessel on the rocks.

- ❑ A navigator using a *Global Positioning System* (GPS) receiver with provision for waypoints and a *course deviation indicator* (CDI) allowed the vessel to drift off course to the left. On realizing that the CDI indicated a course correction to the right, the navigator put the helm over to return the ship to the intended track to reach the waypoint without plotting the vessel's position or realizing that a direct return to track put the vessel in shoal waters.
- ❑ Captain John M. Waters, Jr., in his book, *Rescue at Sea* (Walters, 1989), writes of a B-29 that was forced to ditch 200 miles away from its intended island destination because the navigator, in adjusting the true course for magnetic variation had subtracted, rather than added. This simple arithmetic mistake cost the lives of several people and an aircraft.
- ❑ Cameron Bright, writing in the magazine *Ocean Navigator* (Bright, 1987), describes a routine delivery of the cutter *Acadia* from West Palm Beach to New York. One storm-tossed night on this voyage near Cape Hatteras, the navigator finally realized that the reason for the increasing discrepancy between DR and Loran-C positions was accounted for by essentially the same arithmetic error noted above in adjusting for variation. In this episode, fate took a kinder hand, and the only damage was a bruised ego.
- ❑ In another story from the pages of *Ocean Navigator* (Anon, 1990) the third mate on the bulk freighter *Mavro Vetranick* sighted Pulaski Light in the Dry Tortugas too close on the starboard beam. The mate adjusted the course on the autopilot to compensate but, unfortunately, turned the autopilot dial in the wrong direction before immediately retiring to the chart table to check the navigation receiver. The mate did not stay on deck to verify that the correct course change resulted and, instead of turning away from the reef, the vessel turned towards the reef and subsequently grounded!
- ❑ The late Sir Francis Chichester (a superb navigator of both aircraft and vessels) was most candid in his book, *Gypsy Moth Circles the World* (Chichester, 1967), to reveal that, on occasion, he consulted the wrong page of the Nautical Almanac, and that he had left behind the required tables for celestial navigation when he originally set out on a round-the-world voyage!
- ❑ John Milligan, in his book, *The Amateur Pilot* (Milligan, 1974), recounts the story of a participant in the Transpac race who made an error in misidentifying the Molokai Light as the Makapuu Light, a navigation error that caused the yacht to lose the race. The navigator had carefully timed the 10-sec light but failed to note that the Molokai Light is flashing while the Makapuu Light is occulting!
- ❑ While cruising near the Newfoundland port of Grand Bank, a navigator prepared to enter *Additional Secondary Factor* (ASF) corrections to a Loran-C, as published in the *Canadian Coast Guard* publication, *Radio Aids to Marine Navigation* (Hall, 1989). The instructions indicated that the tabulated correction was to be subtracted. For example, if the published entry were -0.9 µsec and the navigator incorrectly entered -0.9 µsec, rather than -(-0.9)= +0.9 µsec, in the Loran-C with the result that the corrected loran position was less accurate than the original position.
- ❑ Richard Cahill, in his excellent book, *Strandings and Their Causes* (Cahill, 1985), describes a 1979 accident to the tanker *Messiniaki Frontis* near the island of Crete. En route to a planned anchorage, the mate took a visual bearing on Megalonisi Light and completed the fix with a radar range on this same light. The *variable range marker* (VRM) was not used for this purpose. Instead, the range was interpolated from the *fixed range markers* (FRMs). Unfortunately, the range setting on the radar had inadvertently been switched to a 3-mile range from a 6-mile range, with the result that the estimated range was in error by a factor of two and, therefore, the fix was in error. No attempt was made to obtain another visual bearing on other lights in the area, and so the position error went undetected. Shortly thereafter, the vessel went aground.
- ❑ Leonard (1998) relates the story of a yacht, *Silk*, which nearly went aground off New Caledonia because the wrong

GPS datum was set into the receiver. As noted in Chapter 9, the datum used in the GPS receiver must match that used for the chart.

- ❑ Hoffer and Hoffer (1989) relate the story of Air Canada flight 143 from Montreal to Ottawa on 23 July 1989. The Boeing 767 ran out of fuel and had to make an emergency landing. Fortunately, all were saved as a result of the remarkable skills of the pilot. There were several reasons for this incident. One of the major reasons was a failure to correctly convert between English and metric units in calculating fuel quantities.

None of these errors are profound—all appear quite foolish in hindsight. All were preventable by the simple expedient of rechecking calculations, seeking to validate estimates by other means, or taking a little more time to think. The key quality necessary to prevent, or at least reduce, the likelihood of these errors is to realize that small details are important and deserve attention. The USCG uses the phrase *sweat chart* to describe a conning chart used for harbor approaches. This is a particularly apt term because it reinforces the concept of constant vigilance.

Another relevant aspect of the constant vigilance theme is the need to maintain a proper lookout. Every year, "improper lookout" is found to be a major cause of recreational boating accidents, according to *Boating Statistics*. A proper lookout is required by the Navigation Rules and good common sense besides.

PRINCIPLE 2: *PRACTICE IS ESSENTIAL AND CAN BE FUN*

Upon completion of this course, the average student is well equipped to begin to learn the art of coastal navigation. However, experience, though essential, is not necessarily the best teacher. Twenty years of subsequent experience may simply amount to one year, repeated twenty times. Many students first eagerly begin to apply the tools and techniques taught in the course. In familiar waters and during periods of good visibility and calm seas (which the beginning navigator wisely insists on), the techniques are diligently practiced, at first. Soon, it becomes apparent that formal techniques are not always necessary—at least, under the circumstances of these relatively simple voyages. Fuel reserves, first laboriously calculated, are found to be more than adequate in home waters. DR plots, originally laid out in meticulous fashion, are also found to be "unnecessary." Lights are first carefully timed for positive identification, but then the local lights become familiar and the stopwatch left ashore. Other potentially unsafe habits evolve, justified first as expedient shortcuts, then later dignified with the appellation, seaman's eye.

The delivery captain of the 137-foot offshore clamboat *Little Gull* (Anon, 1993a) ran the vessel aground on what should have been a routine trip from Atlantic City, New Jersey, to New York City. Among other problems, the vessel had no fixed compass and no charts. The captain reportedly said (Anon 1993a) that "My brain is so impregnated with loran bearings that I can figure out where to go without charts" and "I don't have to plot; I just know it all by heart." In short, experience in a benign environment misleads beginner and expert alike. Moreover, without practice, skills are lost.

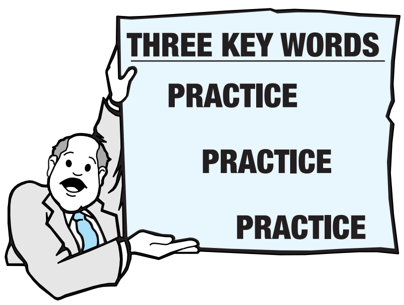
Studies by the *Federal Aviation Administration* (FAA) indicate that many aircraft pilots go through the same process. Knowledge (at least, that knowledge required to pass the pilot's written examination) is actually lost at a fairly rapid rate. Unless the aviator works to gain additional ratings, there is a real need to stay in practice to maintain/regain knowledge. For this reason, among others, the FAA insists on periodic retraining for all licensed pilots.

In a benign environment (e.g., no equipment failure, operations in good visibility and in familiar waters), this loss of skills and/or knowledge may not be critical. However, lack of practice and diligence can take its toll; isolated thunderstorms may break out during the "dog days" of late summer, shutting down visibility and kicking up substantial waves. Or a pleasant fishing trip off the coast of Maine, or portions of California, turns into a real challenge as fog sets in, along with the realization that the bottom is not the familiar soft mud of the Chesapeake Bay, but rather sharp rocks, interrupted with pinnacles. Grounding in these waters does not simply call for volunteers to get wet pushing the vessel off a muddy bottom, but may lead to a nasty gash in the hull and thoughts of "Mayday."

The gradual attrition of skills is not limited to amateur navigators and other casual boaters. Full-time paid navigators also need to work to ensure that skills do not go rusty. An article in the pages of *Ocean Navigator* (Walsh, 1987) tells of the 672-foot Venezuelan tanker, *Lagoven Caripe*, that went aground 60 miles outside the vessel's proper shipping channel on Cultivator Shoal while en route to Boston, Massachusetts. This vessel departed Venezuela in early February of 1987 with a full load of 14.5 million gallons of No. 6 fuel oil. After some early difficulties, including the loss of a navigation receiver off Savannah and the loss of one of two radar sets, the problems began in earnest. Bad weather and an inability to obtain RDF fixes forced the vessel to rely on DR throughout most of the voyage. However (Walsh, 1987), the ship should have passed a range of the Highland Light RDF beacon and the Nantucket LNB beacon. Moreover, prior to grounding, there was an interval of clear weather when celestial sights should have been taken to fix the ship's position. Some celestial sights were attempted, but the celestial worksheets were later described by the ship's agent as a "joke." The captain was relieved of duty upon entry to Boston Harbor. Although a definitive investigation was not conducted, the provisional explanation for this near-disaster (the vessel was able to be refloated without a spill) is that the captain and officers were simply out of practice with the appropriate navigational techniques (here, celestial as a backup) necessary for the voyage. "Use it or lose it," is an apt expression.

The requirement to stay current with navigational techniques applies to all aboard who will handle the vessel, not simply the primary navigator. Captain John O. Coote (Coote, 1988) recounts the following anecdote in his interesting and well-written book, *Yacht Navigation–My Way*:

> "Sailing *Roundabout* back from Copenhagen after the One-Ton Cup in 1961, I left a guest artist on the tiller after clearing the roads off Copenhagen. Around 0500 I awoke to realize that we were hard aground and in thick fog. There had not been a single entry in the log or on the chart for four hours, so it was anyone's guess where we had fetched up. We backed off and sailed a reciprocal course until we picked up an identifiable navigational landmark, but it was a creepy feeling."



The principle here is summarized in three keywords: practice, practice, and practice. Practice these techniques even if the voyage does not require the extensive use of formal navigation techniques. This is not an exhortation to unremitting drudgery, donning the nautical equivalent of a hair shirt. Try making a game of it. For example, divide the voyage into legs and have various crewmembers act as navigators for each of the legs. Each navigator uses all available information to calculate an *estimated time of arrival* (ETA) at the checkpoint that marks the end of his or her leg. The navigator closest to the actual time past the checkpoint wins dinner, or is excused from cleaning the dishes or washing down the vessel.

Another game (in vessels appropriately equipped and configured) is for the navigator to con the vessel from the navigator's station only, without being able to come on deck for visual observations. Fog or other limitation to visibility is simulated in excellent weather by having the lookouts report sightings only within a fixed distance of the vessel, e.g., one mile or one-half mile. The navigator's task is to reach an identifiable object, such as a buoy, from these limited data. The measure of success is the actual distance away from the buoy when the navigator indicates that the buoy should be alongside. (Assign a lookout to ensure that the vessel does not pass too close to the buoy, however.)

Variations on these ideas are literally endless. For example, certain electronic aids can be presumed inoperative and the display covered by cardboard or rubber inset. (Aircraft pilots, at least those with instrument ratings, are well familiar with this idea, called *partial panel work*.) Or, perhaps all the electronics can be presumed disabled and navigation conducted only by DR and visual fixes.

In the USCGAUX boat crew program, vessel coxswains-in-training must pass a task called "night ops." Here, one participating vessel (the notional victim) ventures out at night and simulates a distress transmission. (The word "Mayday" is never used in this simulation and the phrase "this is a drill" begins and ends each transmission.) The *search and rescue unit* (SRU), conned by the apprentice coxswain, tries to find the "lost" vessel. The operator of the SRU asks a series of questions of the lost vessel by radio to narrow down the area to be searched. "Can you see any bridge over the river?" "What color is the light on the buoy?" "When did you leave your home port, and in what direction?" are illustrative questions. (USCGAUX *Qualification Examiners* (QEs), those entrusted with examining and certifying the skills of the prospective coxswain, can tell a great deal about the applicant's navigational skills merely from the questions asked.) This training exercise provides invaluable experience in night navigation and decision making, and is regarded as the highlight of the *on-the-water* training program by many Auxiliarists.

The obvious point of this practice in ideal conditions is to prepare the navigator to cope with less than ideal conditions when these arise. Good habits are formed and, equally important, the navigator becomes more alert to the possibility of error.

Boating is supposed to be fun, and it is not suggested here that every portion of every voyage be the topic of a training exercise. Nonetheless, every voyage offers some opportunity to learn something worthwhile, and the navigator should strive to perfect skills for at least a part of the voyage and, in particular, attempt to learn from his or her inevitable mistakes. For example, when a fix and DR position do not coincide, the navigator can attempt to rationalize this difference. Calculate the apparent current set and drift (using the methods of Chapter 7) and test the plausibility of this estimate from the data in the *Tidal Current Tables* or *Charts* (Chapter 8). Perhaps the DR was in error, or the navigator made the mistake of drawing the current vector from the fix to the DR (rather than the reverse). Perhaps the navigator failed to calculate the DR position corresponding to the exact time of the fix, or made an error in the 60D = ST formula. Tracking down the error is itself a learning opportunity.

Navigators should stay within the proven limits of their skills and the capabilities and equipment of their vessels—a point addressed below. But voyages could also be planned with the idea of pushing and stretching these limits. An excellent way to do this is to crew with more experienced navigators to learn their tricks of the trade. Even crewing with less experienced navigators can be instructive.

It's appropriate to close this section with the apocryphal story of a famous navigator once asked the secret of his success: "Not making mistakes" was the tongue-in-cheek reply. This led to the inevitable follow-up question: "How did you learn to avoid making mistakes?" The truthful answer was: "By making mistakes!"

PRINCIPLE 3:
DO NOT RELY ON ANY ONE TECHNIQUE FOR DETERMINING THE VESSEL'S POSITION

Many navigators would consider this the one cardinal rule of successful navigation. Indeed, there are scattered reminders of this point throughout the text. Simply stated, this principle urges the navigator to use all available information in fixing the vessel's position, rather than to rely on any one measurement, method, or technique. For example, radar, GPS, or visual bearings can be used to check a Loran-C fix. Even depth information can be useful in assessing the plausibility of the fix.

The essential idea here is to use the various methods as cross-checks on each other to increase the confidence of the navigator in the vessel's position. Excluding power failures, which can prevent any electrical system from functioning properly, the possible errors among the principal methods of fixing position are largely independent. Therefore, having several pieces of evidence all pointing to the same conclusion increases its reliability. Professor R. V. Jones, one of the key figures in British scientific intelligence during World War II, writing on the use of deception in hoaxes, explains the principle as follows (Jones, 1967):

> "The ease of detecting counterfeits is much greater when different channels of examination are used simultaneously. This is why telephonic hoaxes are so easy—there is no accompanying visual appearance to be counterfeited. Metal strips (*chaff* or *window*) were most successful when only radar, and that of one frequency, was employed. Conversely, the most successful naval mines were those which would only detonate when several different kinds of signal,

magnetic, hydrodynamic, and acoustic, were received simultaneously. A decoy, which simulates all these signals, is getting very like a ship. From these considerations, incidentally, we can draw a rather important conclusion about the detection of targets in defense and attack: that as many different physical means of detection as possible should be used in parallel. It may, therefore, be better in some circumstances to develop two or three independent means of detection, instead of putting the same total effort into the development of one alone."

Though obviously ventured in a different context than the practice of navigation, the point is equally valid here. The navigator is not necessarily the victim of intentional deception by another, but rather of self-deception.

The advice to use as many systems of position fixing as possible is particularly apt in the electronic era. The nautical literature abounds with examples of problems caused by over-reliance on one method of navigation. Here are a few examples:

- RDF (now largely obsolete in U.S. waters) provides bearing information only. If used for homing, it is essential to include some additional means (perhaps an RDF cross bearing from a different station) to determine the distance of the vessel from the RDF station. The case of the collision of the liner, *Olympic*, with the Nantucket Lightship in 1934 is relevant. The *Olympic* homed in on the lightship's radio signal, without regard for the distance to the lightship, with disastrous results (McClench and Millar, 1979).

  Nor is this an isolated example. A relief lightship to the Ambrose Lightship (on the approaches to New York Harbor) was rammed in 1960 by the freighter *Green Bay*. Closer to the waters covered by the 1210-Tr chart, the Texaco tanker *Lightburne* ran aground on rocks just beneath the Block Island Southeast Lighthouse on 10 February 1939. The tanker had been using the RDF station, then located at this light, for navigation and misjudged the distance off. The wreck remains today, another memorial to the dangers of homing without position fixing. The wreck of the *Lightburne* is not shown on the 1210-Tr chart, but can be found on chart number 13218 at L: 41° 04.3' N, Lo: 71° 32.3' W. Similar stories of sinkings and near misses abound, all prompted by the same mental error.

- The 568-foot cruise ship *Royal Majesty* ran aground near Rose & Crown shoal, 10 miles east of Nantucket Island in 1995. According to one account (Anon, 1995a), a loose antenna connection on the GPS receiver caused it to fail and default to a dead reckoning mode; but the ship's officers did not detect this and failed to make comparisons of the GPS position with those determined by Loran-C, radar, or depth sounder. The ship's captain, called to the bridge to handle a problem with the autopilot, detected the problem and attempted to return the ship to safe water. However, the ship went aground before this corrective action took effect. Passengers reported that the captain claimed earlier that same evening that his ship "could never run aground because of space-age navigation equipment installed on the bridge."

- The Cypriot-registered grain ship *Katya V* ran aground in fog the Chesapeake Bay (Anon, 1993b) after the pilot had misidentified a fishing vessel as the Morse A "CR" fairway buoy off Tilghman Island. The ship was reportedly equipped with three operating radar sets, some with ARPA, as well as GPS, but the pilot did not properly fix the vessel's position using all available means.

Relying on one method of navigation can actually create two types of problems. Perhaps the worst outcome is if the method chosen is flawed in some respect and the navigator remains unaware of the problem. Again, the pages of *Ocean Navigator, Professional Mariner,* and other nautical magazines are filled with examples of this type of error. One correspondent (Howell, 1985) writes of undetected loran problems that led to the grounding of the 48-foot sloop *Victory,* near Conception Island in Exhuma Sound, in the 1985 race from Miami to Montego Bay, Jamaica. Although lights in this area are few and far between, visual LOPs apparently were not attempted and the crew sailed on unaware of the problem until striking the reef.

There is also another difficulty caused by overreliance on one method of navigation. This happens when the one method chosen fails catastrophically, e.g., a Loran-C or GPS receiver outage caused by a power failure or surge as an engine is started. Losing the one tool in use creates chaos, as neglected DR tracks are hastily reconstructed.

It is particularly important to seek confirmatory evidence in connection with the location of floating aids to navigation. Buoys in U.S. waters are, in fact, on station the vast majority of the time. But collisions, storms, and, particularly, ice can lead to buoys being sunk, damaged, or off station. Major as well as minor buoys can be off station. In early October of 1986, for example, the Nantucket *Large Navigation Buoy* (LNB), which is an important aid located south of the Nantucket Shoals, broke free of its mooring chain and drifted out to sea still flashing its light, transmitting its RDF broadcast, and returning a racon signal. Thus, RDF and radar navigation, as well as visual observations, could have been in error over the time period from the buoy's escape until it was located and towed back by the USCG buoy tender *Evergreen*. Fortunately in this case, alert navigators of commercial vessels noted the discrepancy and reported it to the USCG.

In earlier chapters, mention has been made of the utility of the depth sounder in checking positions determined by other methods. Although there are circumstances (e.g., areas where the depth is nearly constant over a broad area, or where dangerous reefs rise abruptly off the ocean floor) where a depth sounder cannot be used directly to fix the vessel's position, depth information can sometimes be quite useful in confirming a fix determined by other methods. Mention of the text, *Strandings and Their Causes,* has already been made. This invaluable compilation of case studies of large ship groundings lists numerous examples that were either caused by negligence in the use of, or failure to use, the depth sounder. Specific accidents cited in this text involve the tanker *Argo Merchant* in December 1976, the tanker *Messiniaki Frontis* in February 1979, the liberty ship *Valiant Effort* in January 1959, the tanker *Hindsia* in January 1965, the liberty ship *Bobara* in January 1955, the steamship *Cornwood* in November 1957, the tanker *Cristos Bitas* in October 1978, the tanker *Transhuron* in September 1974, and the freighter *Bel Hudson* in May 1970. A careful study of these cases shows conclusively the value of the depth sounder.

A professional navigator should use all available means—radar, Loran-C, GPS, depth information, and maintain a DR plot to fix and navigate the vessel. In truth, these means are complementary and mutually reinforcing, rather than competitive.

PRINCIPLE 4:
BE ALERT TO ANOMALIES

Many professional navigators seem to develop a sixth sense about the well-being of the vessel. An experienced navigator asleep in a comfortable bunk may awaken if the vessel's motion changes. Changes in the motion could come about from wind shifts, changes in sea conditions, or an inattentive helmsman who allows the vessel to slowly drift off course.

The clues to changed conditions or problems may be quite subtle. The famous Sherlock Holmes story of the dog that did not bark in the night reminds us that negative information can also be important. A marine VHF radio that is silent, when normally abuzz with clatter, may indicate that someone has altered the squelch setting, the vessel has departed normally crowded sea lanes, or a power failure has occurred. A light that is not seen may be the first indication that the vessel is not where it is supposed to be or that the visibility is deteriorating.

In addition to being concerned about the failure to observe something expected, the sight or sound of something unexpected could be cause for alarm. For example, John Rousmaniere quotes Hewitt Schlereth as noting that the naked eye has sufficient resolving power to enable the mariner to count individual trees on a shoreline from a distance off of 1 M., count windows in waterfront houses at 2 M., and see the junction line between land and water at 3 M. Using these rules of thumb, if a vessel's intended track were to pass no closer than 4 M to shore but windows could be counted on waterfront houses, the alert navigator should investigate further.

In the days before inertial navigation systems became common, an aviator broke out "on top" of the clouds after flying some distance over the ocean by reference to instruments alone to find that the sun was on the right, rather than on the left where it should have been if the aircraft were on course. This was the first indication of a compass failure. Because the failure was gradual in this case, the pilot had kept resetting the directional gyro to the compass, and the directional gyro was similarly useless.

To the uninitiated, such a sixth sense may seem almost mystical. In truth, this sixth sense has more pedestrian origins and, with a little care and planning, can be developed by any navigator. The "unseen light" provided a clue only because the navigator took the trouble to estimate the range at which the light should be seen (using methods discussed in Chapter 10) and either drew a circle of visibility on the chart or made a note to look for the light when the vessel was supposedly within this arc of visibility. The pilot who identified the compass error simply exploited the common knowledge that the sun rises in the east and sets in the west. The navigator who counted windows and wisely fixed the vessel's position and altered course also exploited elementary knowledge.

Good weather and sea conditions and abundant *Aids to Navigation* (ATONs) lower the level of cockpit tension and lull the navigator into a state of complacency. For example, after completing a difficult landfall a navigator left the helmsman at the wheel of a trawler with instructions to maintain course so as to keep the bow pointed at a distant lighthouse visible on the bow with the vessel's heading 270 degrees. After going below for coffee, a well-thumbed copy of the appropriate *Light List*, and a few minutes of conversation, the navigator returned topside to bring coffee to the helmsman. A quick glance showed the lighthouse, apparently larger now over the bow. To the casual navigator all was well, an occasion to swap lies with the helmsman over coffee. A more alert navigator would check the vessel's compass heading upon returning topside. A heading significantly more (less) than 270 degrees would indicate a current is setting the vessel to the south (north) of the original track. In effect, this vessel is homing (using visual means) rather than tracking. Perhaps this distinction is of no great consequence, but it could be if there was unsafe water to the south (north). In any event, an alert navigator gains potentially valuable information from a simple glance at the compass.

Sound and kinesthesia (motion sense) can also furnish important clues to the mariner. After many hours operating the same vessel, the navigator develops a clear, although intuitive, sense of the relation between speed, power setting, and trim that goes beyond the mere ability to identify a rough-running engine. Slight changes in trim and/or bottom condition affect the speed curve (Chapter 5) and (absent a speedometer) may be a clue to the reason for a discrepancy between the DR position and a fix that cannot be accounted for by current alone. In operating powerboats in conditions of restricted visibility, it is often useful to slow down or stop the vessel periodically and shut off the engine. In the silence that follows it is sometimes possible to hear the sound of diaphones or other sound clues (let's hope not the sound of breaking surf!) that would otherwise be masked by the noise of the engine. (As noted below, slowing down may be important for other reasons as well.)

PRINCIPLE 5:
EMPHASIZE ROUTINE IN TIMES OF STRESS

Now and again, the tapes or transcripts of communications between commercial aircraft pilots and air traffic controllers are made public after an accident or near-accident. The startling thing to most nonpilots is the high degree of professionalism and cool decision-making revealed in these communications. To most of us this appears almost heroic, and well it may be. But it is also the product of extensive conditioning. Pilots are systematically trained (in actual aircraft and sophisticated simulators) to cope with all manner of emergencies. This training alone lends an element of the routine to emergencies. Equally important, however, is the programmed method of instruction for dealing with emergencies. Pilots are taught early and often in their careers to use checklists. There are checklists used in the preflight inspection, checklists used in starting engines, pre-takeoff checklists, cruise checklists, etc. There are also various emergency checklists, often neatly categorized as fire, engine out, landing gear inoperative, etc. Reading out the items in this checklist, and following the concise instructions, is not only an orderly way of problem solving that lowers the likelihood of omission of critical items, but also serves to lower the likelihood of panic among the aircrew. In short, these checklists act to make emergencies routine, to place these in the context of the familiar.

Mariners can benefit from this same approach. For example, Marvin Creamer (an accomplished "bare bones" blue-water navigator), writing in *Ocean Navigator* (Creamer, 1986), makes the point that DR is both possible and necessary during storms. He cites several positive aspects to attempts at storm navigation: it assists in prompt post-storm location, helps focus minds of personnel and combats lethargy, increases the confidence of crew in navigator/skipper, provides practice in heavy-weather navigation, and helps to pass the time. All too frequently, the drama of a crisis event distracts the navigator from necessary tasks. In storms, particularly severe storms, seamanship, rather than navigation, may be the most immediate priority. However, assuming that the vessel survives the storm, it is essential to know the vessel's position and proximity to dangerous waters. This task will be vastly simplified if a simple record of estimated speeds and courses was maintained. Such a record may not be exact for a variety of reasons; speeds may be very approximate (particularly for a sailing vessel running in a storm under bare poles) and leeway only a guess. But even an approximate DR record is better than no information.

Get in the habit of using checklists. Start out with obvious checklists, such as the pre-underway checks, cruise checks, approaching rough weather checks, and the like. Put experience to work by gradually developing and revising these checklists for maximum utility on your vessel. And remember that checklists are particularly useful in emergency situations because it is precisely in time of emergency that important items are most likely to be overlooked.

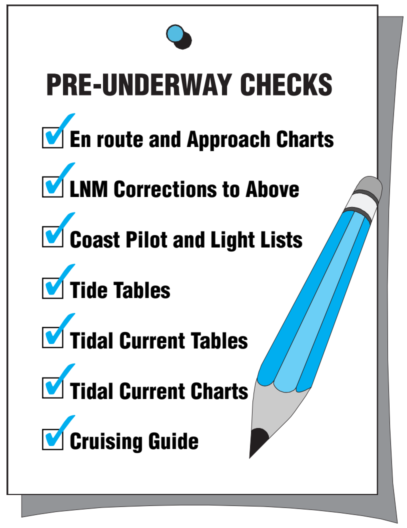
PRINCIPLE 6:

SLOW DOWN OR STOP THE VESSEL IF NECESSARY AND CIRCUMSTANCES PERMIT

Sometimes a crisis is self-induced. It may be a crisis to be unsure of your position when approaching a reef-strewn harbor at 20 knots. At this speed the vessel will travel over 333 yards in 30 seconds, roughly the length of time that it has taken you to read two or three paragraphs of this text. But part of this crisis is self-induced and can be removed by the simple expedient of slowing down or stopping. This is why the anchor is listed among the navigator's tools in Chapter 4. (Obviously, there are circumstances where stopping is ill-advised, such as in the middle of running a tough inlet.)

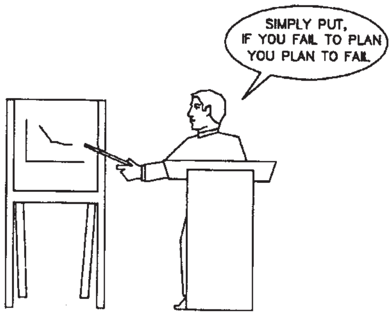
Chapter 9 makes the point that any confusion in interpreting a *relative motion plot* (RMP) from radar observations can be eliminated if you stop. After stopping, aside from the effects of possible drift, the radar plot appears much the same as if a true-motion device were used. This comment is not intended to relieve the mariner of any obligation under the navigation rules, such as the responsibility of the stand-on vessel (if defined) to maintain course and speed.

Slowing down or stopping may be prudent or necessary in circumstances of reduced visibility. And it should be considered whenever the vessel is in hazardous waters and you are unsure of your position. Leaving the vessel running will just get you to the scene of the accident faster!



Slowing down may be prudent even if you know approximately where you are. You can use extra time to think, identify buoys or lights, and/or take more frequent position fixes. In a harbor with a complex and/or unfamiliar approach, for example, proceeding at a slower speed provides the navigator time to "catch up" with the physical progress of a vessel. It is not unusual for three or more minutes to be required to take bearings and plot a fix. At 20 knots the vessel will be 1 M, or approximately 2,000 yards, beyond the fix by the time it is plotted, at 5 knots only 500 yards. The "maritime casualties" section of *Professional Mariner* provides numerous examples that show the benefits of slowing down. For example (Anon 1995b), the tanker *Kentucky* went aground and ripped a 10-foot-long gash in its hull by running over a rocky bottom in the Delaware River south of the Commodore Barry bridge. Rain squalls and a malfunctioning radar set created difficulties for the pilot. However, Coast

Guard officials concluded that the pilot was negligent because he continued ahead without slowing the ship. Before grounding, the *Kentucky* passed the Marcus Hook anchorage, an area where it could easily have pulled aside to await better visibility.



If you elect to drift or anchor, remember that, while this gives you valuable time to assess your situation, it confers no immunity from accidents. It is still important to stay alert and maintain a proper lookout. The majority of recreational boating accidents (nearly three-quarters) occur while vessels are cruising, engaged in special operations (e.g., water-skiing, towing, being towed), or maneuvering, but an appreciable fraction (15 percent) occur while drifting or at anchor. If circumstances permit (e.g., absence of rocks, shoals, bars, crab or lobster pots), it may be advisable to move a shallow-draft vessel out of the main channel to avoid traffic conflicts with deep-draft vessels.

When it comes to stopping, vessels have an extraordinary advantage over aircraft. A boat can be allowed to drift or the anchor can be set to provide ample time for careful consideration of options. An aircraft can be stopped only when it lands or crashes. The maximum possible flight duration can be calculated in advance.

Stopping gives you time to think and to use other means of fixing the vessel's position. Stopping gives you silence to listen. Stopping allows you time to regain command.

PRINCIPLE 7:

PREPLAN AS MUCH AS POSSIBLE

George S. Morrison, in discussing the planning for the so-called Culebra Cut, one of the most difficult parts of the Panama Canal, is quoted as saying:

> "It was a piece of work that reminds me of what a teacher said to me when I was at Exeter over forty years ago, that if he had five minutes in which to solve a problem he would spend three deciding the best way to do it."

So it is with the practice of navigation. Time spent in planning the details of a voyage is time well spent. Simply put, if you fail to plan, you plan to fail.

Search and rescue experience indicates that too many mariners neglect to plan fuel needs adequately. They behave as though they were driving automobiles in easy range of the next service station. On the water, refueling opportunities are often more limited. Moreover, other factors combine to make fuel consumption per nautical mile quite variable: unanticipated currents, a diversion to assist a disabled vessel, etc. For these reasons, formal fuel planning, as discussed in Chapter 11, is important. Fuel planning should not be limited to before-the-fact calculations. A mariner needs to know the vessel's fuel state and safe cruising radius at all times, together with feasible alternate destinations where fuel is available. A few minutes time spent with the *U.S. Coast Pilot* (USCP), or equivalent cruising guide, are all that is required to identify these alternates.

Preplanning is particularly important for approaches to unfamiliar harbors. Of course, the relevant charts and reference publications should be aboard, but it is even easier if the navigator summarizes this information as extra chart annotations or as separate lists. (For example, a list of which ATONs have horns, gongs, or other sound-producing devices would be a handy reference in circumstances of reduced visibility.) The mere act of writing this information down increases the navigator's retention. Precalculated turning bearings (even if buoys are available) on what are expected to be prominent visual landmarks save work during the actual approach when time may be at a premium.

Preplanning is also very important for operators of fast boats. This is one of the key points made by authors who write about fast boat navigation (e.g., Bartlett, 1992; Kettlewell and Kettlewell, 1993; Pike, 1990). Fast boats, typically, have smaller helm areas (which renders plotting more difficult) and are lively (which also makes plotting a chore). Moreover, there is less time to take and plot bearings. Waypoints should be carefully entered (and checked) into navigation receivers before the trip, plausibility checks on visual fixes should be preplanned to reduce the time required for taking and interpreting these, and routes should be

FIG. 12-1–The destroyers *S. P. Lee* (right) and *Nicholas* (left) seen against the rock-strewn coast. Photograph originally appeared in *Tragedy at Honda,* and is reproduced with the kind permission of the Lockwood family.

selected to maximize the number of navigation marks along the way (the distance penalty is of less consequence on a fast boat).

The mariner should devote some time to thinking through possible contingencies during the voyage planning process. For example, the mariner might plan to make a landfall by offsetting the intended aim point so as to arrive definitely either north or south of the harbor entrance (a trick of long-ago and present-day navigators alike) and to turn one way or the other to follow a particular depth contour to the main channel. However, this plan is certain to need revision if the depth sounder becomes inoperative en route. Time spent in the comfort of your den or office thinking about how to handle this contingency and the precalculation of alternate check points based upon visual fixes is likely to be much more productive than the same time spent at the helm of a pitching vessel.

As noted in other chapters of this text, it is impossible to plan out everything in advance; unanticipated events can and do arise. However, planning can go a long way towards reducing the likelihood and/or consequences of an unpleasant surprise. Arrival at the proper time to take advantage of a slack or favorable current (Chapter 8), the onboard availability of the appropriate large-scale nautical charts for alternate destinations, adequate fuel margins (Chapter 11), distance of visibility arcs (Chapter 10) scribed on charts, and an array of prominent pre-identified fix objects, for example, will not be happenstance events if a little care is exercised in the planning phase of a voyage. Moreover, the development of contingency plans gives the navigator a real edge in the battle with panic when trouble develops. It's much more calming (to the navigator and crew alike) to be able to say "Let's put plan B into operation," rather than "This sure doesn't look like Kansas, Toto; any ideas?" Planning, like checklists, serves to make contingencies routine.

PRINCIPLE 8:
BE OPEN TO DATA OR INFORMATION AT VARIANCE WITH YOUR UNDERSTANDING OF THE SITUATION

Robert Jervis, a political scientist writing on misperception in international politics, writes, "actors tend to perceive what they expect." Humans often tend to form fixed ideas based upon limited information. Once formed, these

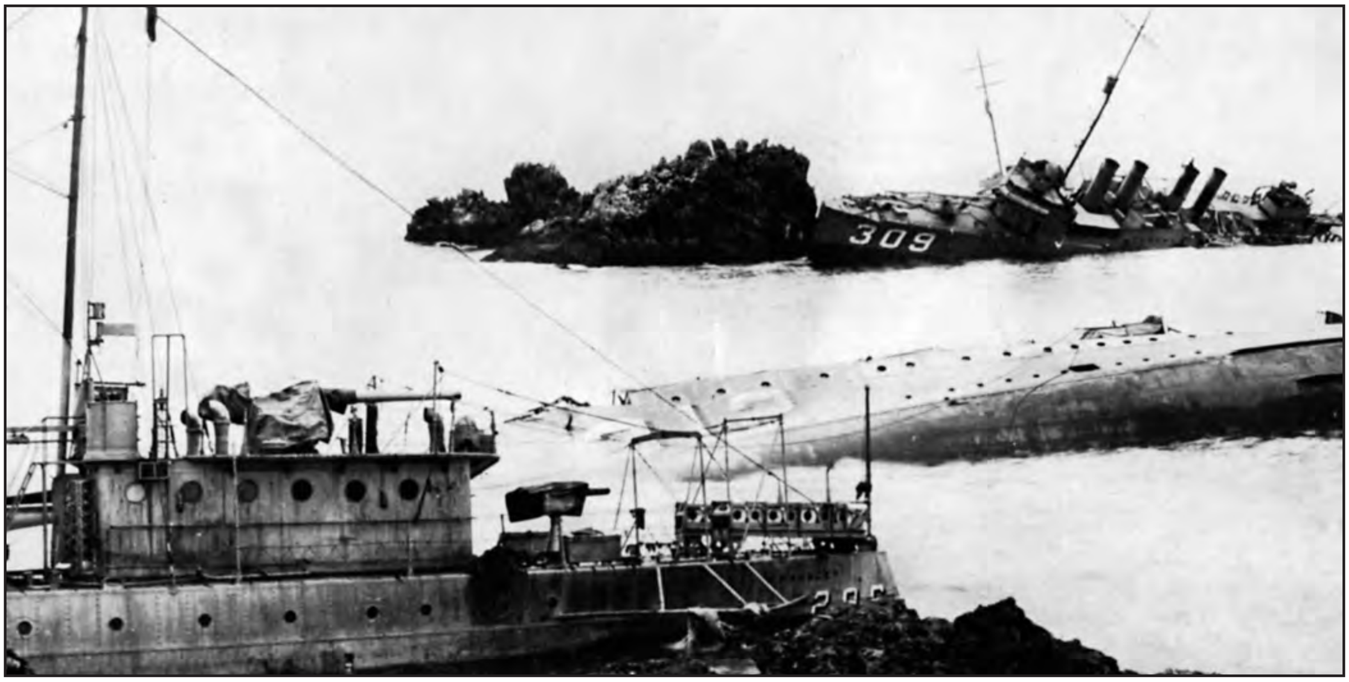


FIG. 12-2–Port side of the destroyers *Young* (middle distance) and *Chauncey* (foreground). The *Woodbury* (309) can be seen in the distance. Photograph originally appeared in *Tragedy at Honda,* and is reproduced with the kind permission of the Lockwood family.

ideas are often difficult to displace and contrary evidence may be dismissed as incorrect or overlooked entirely.

The same phenomenon also occurs with navigators. In this context, the fixed idea might be the appropriateness of a particular method of navigation (compared to alternatives), or even the accuracy of a particular position estimate developed by this method. Often these ideas are soundly based; for example, a visual fix taken on positively identified fixed ATONs is likely to be more accurate than one based solely on buoys. The danger arises when conflicting information from other sources is simply rejected out-of-hand without more careful examination.

Misperception errors have occurred on numerous occasions in the history of navigation. Perhaps the most dramatic example of this error occurred on the night of 8 September 1923 when nine navy destroyers ran aground and seven were stranded/sunk off the coast of California.

In brief, the story is as follows. (See Alden, 1965; Hadaway, 1957; Lockwood and Adamson, 1960; Mueller, 1980, for details.) The destroyers were part of a navy training exercise involving a high-speed endurance test run down the coast of California from San Francisco to San Diego. The lead destroyer had three experienced navigators aboard, one fresh from teaching navigation at the U.S. Naval Academy.

During the run, a careful DR track was maintained, predicated on the assumption of a 20-knot speed. RDF was then a new system and, in the opinion of the many mariners, unproven. Nonetheless, RDF bearings were obtained from a shore station. These bearings gave LOPs that were inconsistent with the lead destroyer's (the *Delphy*) DR plot, indicating that the squadron was not making good the estimated *speed of advance* (SOA) and/or the squadron was closer to the shore than planned.

An anticipated sighting of a light at Point Arguello was not observed, and so no visual LOPs or running fixes were obtained from this source. Visibility was sharply reduced by fog. Given this situation, a prudent mariner should have reduced speed to try to sort things out and, in this

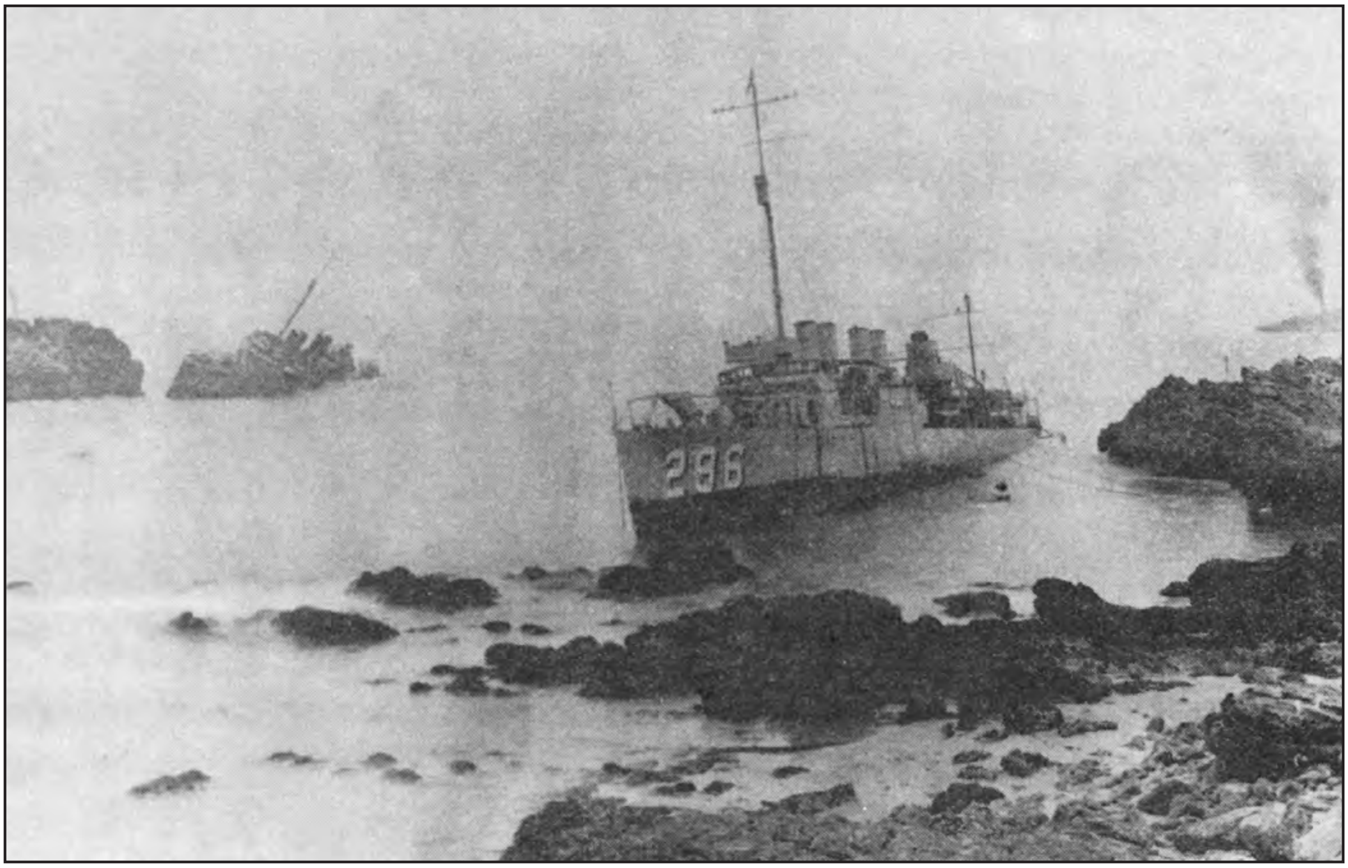
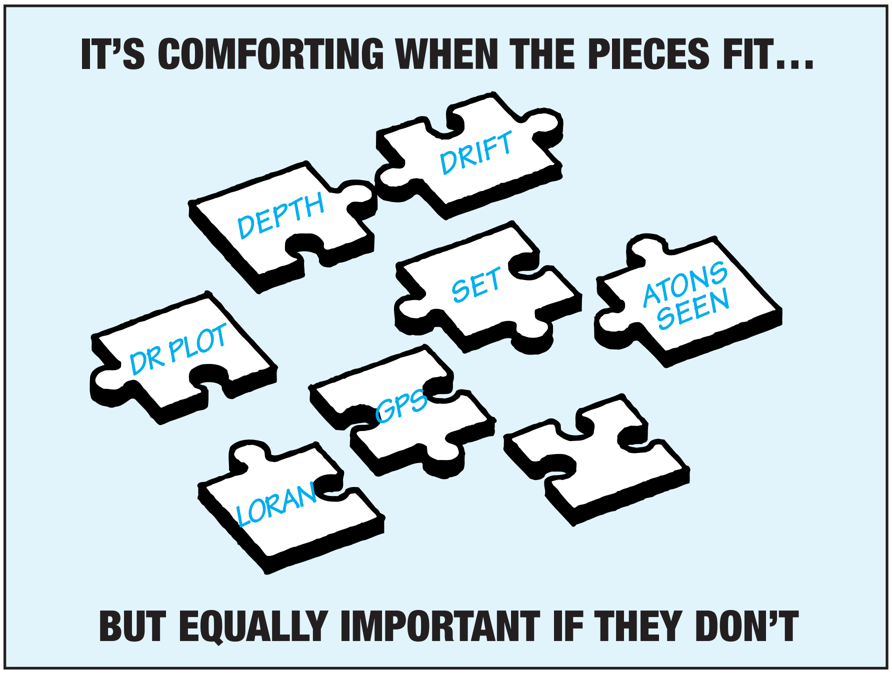


FIG. 12-3–Another photograph of *Chauncey* (296) at right and *Woodbury* (309) at left on what is now known as Woodbury Rock. The mast of the *Fuller* (297) can be seen projecting above Woodbury Rock. Photograph courtesy of the Lockwood family.

case, to obtain soundings that might confirm or reject the DR position. (One of the destroyers, the *Thompson*, did just that but, as this was the last destroyer in the column, this did not help the others.) This action was not taken by the lead ship, in part because of the demands of the training exercise to maintain speed. In any event, a further RDF bearing was taken which also indicated that the squadron was well north of its DR position at the entrance to the Santa Barbara channel. Despite this evidence, the navigators in the lead destroyer clung to the idea that the DR was correct and that the RDF bearings were erroneous. Indeed, it was assumed that a reciprocal bearing was obtained. The squadron altered course to an easterly heading and, one-by-one in sequence, crashed onto the rocks appropriately named "the Devil's Jaw" well north of the DR position. Figures 12-1, 12-2, and 12-3 show photographs taken after the disaster. Remarkably, although nine vessels were sunk or damaged, only 23 sailors of the 800 at risk were killed. The full version of this abbreviated story can be found in the excellent (but, unfortunately, out-of-print) book, *Tragedy at Honda,* listed among the references.

There are many lessons to be learned from this tragedy—e.g., some navigators on the following destroyers had a very different appreciation of the situation, yet did not question the order to alter course to the east, etc. But the errors that stand out in this context are the reluctance and, ultimately, failure of the lead navigation team to consider information at variance with their preconceived DR-based estimate of position (Principle 8), their unwillingness to seek additional depth information (Principle 3), or their failure to slow down to sort things out (Principle 6).

Many observers have drawn the analogy between navigation and



solving a puzzle. The pieces of the puzzle are the various bits of information, or misinformation, and the navigator has to assemble these into a coherent picture. It's comforting when the pieces fit—but this principle reminds us that it is equally important if they don't.

PRINCIPLE 9:
KNOW AND OPERATE WITHIN YOUR LIMITS

In commercial aviation, the concept of limits and standards for safe operation are well-developed and codified. For example, there are explicit regulatory limits on:

- ❏ **The aircraft:** Commercial aircraft have *minimum equipment lists* (MELs) which determine exactly what equipment must be on board and operational before a flight is permitted.
- ❏ **The pilot:** Pilots are, likewise, subject to a variety of explicit limits/requirements. Pilots without an instrument rating, for example, cannot legally undertake a flight unless the weather conditions along the route of flight satisfy certain constraints in terms of ceiling and visibility. Additionally, the pilot must satisfy recent experience and retraining requirements.
- ❏ **Destination weather:** In addition to requirements on the demonstrated proficiency of the pilot, each type of instrument approach to a destination airport has unique weather minimums. So-called precision approaches to an airport enable the pilot to descend lower and operate in lower visibility than do nonprecision approaches to the same airport. And even for the same type of instrument approach (e.g., ADF), the weather minimums may vary from airport to airport depending upon terrain and obstructions. Finally, the legal weather minimums for a particular instrument approach become more stringent if components of the landing system are inoperative.

Recreational boaters are not federally licensed and have much greater flexibility of operation. Nonetheless, the idea of self-imposed limits is valuable. It is obviously foolish, for example, to deliberately undertake an ocean voyage without, at least, a working knowledge of celestial navigation and the appropriate tools, reference publications, and nautical charts. (This notwithstanding, the story published in one of the, otherwise fine, boating magazines tells of a major ocean crossing in which the navigator brought books and embarked on a "crash", on-the-job self-training program in celestial navigation!)

Some harbors may require extensive local knowledge for safe operation, while others have easy and well-marked approaches. Some harbors may be easy to enter during conditions of daylight and good visibility, but tricky at night or in fog. In this latter example, a prudent mariner would plan to arrive at the harbor during times of good visibility and either divert to an alternate destination or anchor out if this proved impossible.

A prudent navigator gives thought to these and other factors in deciding whether or when to attempt a particular voyage. Table 12-1 provides a candidate list of factors to consider in establishing personal limits to operation. There is no attempt to spell out detailed go-no-go rules. This is left to the discretion of the navigator. However, it is suggested that the navigator think carefully about establishing personal limits for these and other relevant factors. Over time, these limits are likely to change. As the navigator gains experience, local knowledge, and/or operates a better-equipped vessel, these personal limits can be modified or stretched.

One of the "personal minimums" often overlooked by mariners and aircraft pilots alike are limits related to fatigue. Mariners and aircraft pilots can suffer two overlapping types of fatigue, acute skill fatigue and chronic fatigue. Acute skill fatigue is that diminution of acuity resulting from task repetition during an extended voyage. Symptoms include lassitude, an inability to concentrate, and an aversion to further activity. Fatigue leads to degradation of skills, increased reaction time, and impaired judgment. Fatigue is not often explicitly cited as a cause of vessel or aircraft accidents, in part because data may be lacking and/or the effects of fatigue are difficult to quantify. Nonetheless, it is generally recognized that a well-rested crew is essential to safe operations. Here are a few examples of the consequences of fatigue:

- ❑ Fatigue was one of the causes listed in the crash of a Learjet on final approach to Byrd Field in Richmond, Virginia, on 6 May 1980. At the time of the accident, the pilot had been awake for 20 hours, and the copilot for 18 hours. The crash came after the pilots misjudged the approach.

Dement and Vaughn (1999) relate several other examples of accidents attributed to sleep deprivation, including the *Exxon Valdez* (the third mate had slept only 6 hours in the previous 48), space shuttle *Challenger* (officials of the National Aeronautics and Space Administration (NASA) suffered from severe sleep deprivation, according to the Human Factors Subcommittee), and 1995 crash of an American Airlines flight in Colombia.

- ❑ The *Golden Gate*, a San Francisco pilot boat, ran into the bridge of the same name and suffered hull and engine damage (Anon, 1994a). It was alleged that the pilot fell asleep or was daydreaming when the accident occurred. The vessel was being guided by an autopilot at the time of the accident.

1. General knowledge and recent experience of navigator and crew
2. Local knowledge of navigator and crew
3. Navigation equipment (including up-to-date and corrected nautical charts and navigation reference publications) and communications gear aboard
4. En route and destination weather (visibility and sea conditions) and daylight/darkness at ETA
5. Features of destination harbor and en route:
   –hazards to navigation
   –availability of ATONs
6. Availability and characteristics of nearby alternate destinations
7. Health and fatigue status of navigator/crew
8, General seaworthiness and type/size/speed of vessel

TABLE 12-1–A suggested list of factors to consider for setting personal limits.

- ❑ The 642-foot freighter *Pacific Breeze* ran aground at 16 knots in the Chesapeake Bay near Sharps Island Light. The pilot is alleged to have fallen asleep and did not make a necessary course correction. The chief mate was "just too polite to wake the pilot; I don't think he realized how fast asleep the pilot was," observed a Coast Guard investigating officer. When the pilot fell asleep he reportedly had had only six hours of sleep in the previous 24 hours.

Mariners should establish personal fatigue standards as part of their rules for go-no-go decisions.

PRINCIPLE 10:
MAINTAIN A DR PLOT

Arguably, the need to maintain an accurate DR plot falls under several principles enumerated above. But, to lend emphasis to this important point, it is made a separate principle. Were this text written a few years ago, it would probably not have been necessary to underscore the need for DR plotting. However, the "electronic revolution", with its proliferation of ever more lightweight, lower cost, and more powerful navigation tools (such as GPS, radar, electronic charting, and integrated navigation packages), has rendered DR all but obsolete in the minds of many navigators.

Electronic navigation is fast, accurate, convenient, and powerful. The system reliability of the principal electronic navigation aids that require external signals (e.g., Loran-C, GPS) is very high. Yet, for these systems to function, the shipboard components must also work correctly. As noted in many places in this text, the marine environment is notoriously hostile (or, at least, unkind) to electronics and power supplies alike. Barely a month goes by without one or more articles appearing in the boating press reporting instances of shipboard failures of electronic components on recreational, commercial, and naval vessels. Fuses blow, antennas are knocked down, green water breaks over the bow and saturates the supposedly waterproof loran, and batteries or alternators fail. G. R. Kane, for example, in his interesting book, *Instant Navigation* (Kane, 1984), writes of a racing yacht lost on a Cuban shoal after a loran failure which occurred after starting the engine to recharge the batteries. This was an unpleasant event, to be sure, and one with critical consequences because the navigator apparently did not maintain a DR track or record of fixes.

There are numerous instances where well-equipped ships have run aground and failure to maintain a DR plot was cited as a reason for loss of situational awareness. Here is a small sample of cases:

- ❑ The 207-foot cruise ship *Nantucket Clipper* grounded on the rocks in Penobscot Bay, Maine, in 1992 (Anon, 1993c). Coast Guard investigators pressed charges against the first mate after determining that he had referred solely to the radar for navigation and did not plot positions or maintain a DR plot on the chart.
- ❑ The mate on the tug *Janice Ann Reinauer* drove a loaded fuel barge up onto rocks outside of New London Harbor in 1993 (Anon, 1993d) after becoming confused over the identity of buoys in calm weather and clear visibility. Coast Guard investigators said he had not fixed his position on a chart but was proceeding entirely by seaman's eye.
- ❑ The third mate of the 989-foot freighter *Indiana Harbor* was blamed after the ship drove directly into the Lansing Shoals Light on Lake Michigan. Coast Guard investigators believed that the mate was navigating solely by radar without plotting positions and "just failed to notice the lighthouse ahead of the ship."
- ❑ The 525-foot cruise ship *Starward* ran aground on the island of St. John (U.S. Virgin Islands) in 1994 (Anon, 1994c). In this case, GPS positions were plotted on a semiregular basis, but no radar ranges or bearings were taken. No DR positions were plotted and no determination of the current set and drift were made. The ship drifted onto rocks in the vicinity of Dittlif Point, a spit on the south coast of the island. The ship could be backed off the coral, but only after leaving parts of its starboard propeller at the scene of the grounding.

If these accidents can happen to experienced mariners, they can happen to you.

Redundancy is a partial solution to the availability/reliability problems of electronic systems. Carry extra fuses, bulbs, batteries, an emergency antenna, and even complete systems, such as a portable GPS. But this solution is expensive and, in any event, still imperfect. A cheaper and ultimately more satisfactory solution to the problem is to maintain a DR plot and update this by frequent visual fixes as discussed in Chapters 5 and 6 of this text. Unless the mariner is voyaging near homeport in well-known waters and the actual and forecast weather is benign, a DR plot should be maintained and updated, as new data become available.

As the story of the tragedy at Honda illustrates, DR positions can still be in error. But these are undoubtedly superior to no position at all. Remember the proverb that in the land of the blind, the one-eyed man is king.

KEEP READING

Numerous sea stories are included in this chapter to illustrate the points made in the text. These are taken from the literature illustrated in the references at the end of this chapter.

Another very useful source of information is provided in a series of accident reports written by the *National Transportation Safety Board* (NTSB), an independent agency of the U.S. Government that investigates aircraft, marine, highway, railroad, and pipeline accidents. NTSB maintains a Web Site (http://www.ntsb.gov/) which contains copies of these accident reports. Periodically, access this site and download copies of recent reports for later study. NTSB marine accident (click on the *Marine* or *Publications* icons) reports include both commercial ship and recreational boat mishaps. This site also contains copies of other relevant reports. For example, the report *Evaluation of U.S. Department of Transportation Efforts in the 1990s to Address Operator Fatigue* provides an interesting summary of the operator fatigue problem.

CONCLUDING COMMENTS

Probably most readers of this text will never elect to make navigation a profession, in the sense of a paying occupation. But all readers of this text have the opportunity to become a professional navigator in the sense of developing a professional attitude and professional caliber skills and judgment. Graduation from high school, college, or university is often called commencement, because this marks the point when the graduate commences to gain experience, maturity, and insight—in a word wisdom. Go forth, learn, enjoy, stay humble (remember, it is arrogant to sail to a destination and appropriately humble to sail *towards* a destination), continue to study (the chapter references are a good starting point), and write to tell us of your experiences. Better still, join the USCGAUX and consider writing the next edition of this book!

SELECTED REFERENCES

Alden, J. D., (1965). *Flush Decks and Four Pipes,* United States Naval Institute, Annapolis, MD.

Anon, (1990). A Spin of the Dial, *Ocean Navigator,* No. 30, January/February, pp. 67-68.

Anon, (1993a). Fishing Vessel Hits Beach in Navigational Blunder, *Professional Mariner,* No. 1, p. 29.

Anon, (1993b). Navigation Lapse Sent Chesapeake Freighter Aground, *Professional Mariner,* No. 3, Oct/Nov, p. 31.

Anon., (1993c). First Mate Defends License After Grounding Cruise Ship, *Professional Mariner,* No. 1, p. 28.

Anon., (1993d). Navigational Lapse Caused Grounding off New London, *Professional Mariner,* No. 1, p. 24.

Anon., (1994a). New San Francisco Pilot Boat Crashed into Golden Gate Bridge, *Professional Mariner,* No. 8, Aug/Sept, p. 48.

Anon., (1994b). Third Mate Charged With Negligence after Piloting Ship into Lighthouse, *Professional Mariner,* No. 6, p. 49.

Anon., (1994c). What Did Happen That Morning Aboard the Starward?, *Professional Mariner,* No. 7, p. 52.

Anon, (1995a). Space-age Cruise Ship Goes Aground, *Ocean Navigator,* No. 70, p. 38.

Anon, (1995b). Delaware Pilot Charged with Negligence After Study of Grounding, *Professional Mariner,* No. 13, June/July, p. 63.

Anon, (1995c). Freighter Runs Aground in Chesapeake as Pilot Nods off in Pilot Seat, *Professional Mariner,* No. 10, pp. 40-41.

Anon, (1987). Nantucket LNB Goes Adrift, *Ocean Navigator,* No. 11, January/February, p. 12.

Bachand, R. G., (1989). *Northeast Lights: Lighthouses and Lightships Rhode Island to Cape May, New Jersey,* Sea Sports Publications, Norwalk, CT.

Bartlett, T., (1992). *Navigation at Speed,* Fernhurst Books, Brighton, UK.

Bloomfield, H. V., (1966). *The Compact History of the United States Coast Guard,* Hawthorn Books, New York, NY.

Bright, C., (1987). A Confusing Night Off Cape Hatteras, *Ocean Navigator,* No. 14, July/August 1987, pp. 6, 44.

Cahill, R. A., (1985). *Strandings and Their Causes,* Fairplay Publications, London, UK.

Chichester, Sir F. (1967). *Gypsy Moth Circles the World,* Coward-McCann, Inc., New York, NY.

Coote, J. O., (1988). *Yacht Navigation—My Way,* W. W. Norton and Company, New York, NY.

Creamer, M., (1986). Dead Reckoning during the Onslaught, *Ocean Navigator,* January/February, p. 39.

Dement, W.C. and Vaughan, C., (1999). *The Promise of Sleep,* Delacorte Press, New York, NY.

Hadaway, R. B., (1957). Course Zero Nine Five, *United States Naval Institute Proceedings,* Vol. 83, pp. 40-48.

Haines, T. B. (1990). Retrospective, *AOPA Pilot,* Vol. 33, No. 2, February, p. 102.

Hall, G. E., (1989). The Correct Use of Corrections, *Ocean Navigator,* No. 23, January/February, pp. 15-16.

Hoffer, W., and Hoffer, M. M., (1989). *Freefall, 41,000 Feet and Out of Fuel,* St. Martin's Press, New York, N.Y.

Howell, S., (1985). Aground in the Bahamas, *Ocean Navigator* (then called The Navigator), July/August, No. 2, pp. 8 - 10.

SELECTED REFERENCES

Jervis, R., (1968). Hypotheses on Misperception, *World Politics,* Vol. 20, No. 3, pp. 454 - 479.

Jones, R. V. (1967). The Theory of Practical Joking; Its Relevance to Physics, *Bulletin of the Institute of Physics,* June, p. 7.

Kane, G. R., (1984). *Instant Navigation,* Second Edition, Associated Marine, San Mateo, CA.

Kettlewell, J. J. and Kettlewell, L., (1993). *Reed's Nautical Companion, The Handbook to Complement Reed's Almanacs,* North American Edition, Boston, MA.

Leonard, B.A., (1998). Navigating Safely with GPS, *Sail,* Vol. 29, No. 1, January, pp. 96 et seq.

Lockwood, C. A., and Adamson, H.C., (1960). *Tragedy at Honda,* Chilton Company, Philadelphia, PA.

Lord, W., (1988). *A Night To Remember,* Bantam Books, New York, NY, p. 135.

MacLeish, W. H., (1989). *The Gulf Stream,* Houghton Mifflin Co., Boston, MA.

McClench, D., and Millar, D.B., Eds., (1979). *Mixter's Primer of Navigation,* Fifth Edition, Van Nostrand Reinhold Co., New York, NY.

McCullough, D., (1977). *The Path Between the Seas,* Simon and Schuster, New York, NY.

Milligan, J. E., (1974). *The Amateur Pilot,* Cornell Maritime Press, Centerville, MD.

Mueller, W., (1980). Seven Out at Pt. Honda, *Sea Classics,* Special Edition, Spring, p. 40 et seq.

Pike, D., (1990). *Fast Boat Navigation,* Adlard Coles, London, UK.

Quinn, W. P., (1988). *Shipwrecks Along the Atlantic Coast,* Parnassus Imprints, Orleans, MA.

Rousmaniere, J., (1989). *The Annapolis Book of Seamanship,* New Revised Edition, Simon and Schuster, NY, p. 264.

United States Department of Transportation, United States Coast Guard. *Boating Statistics,* COMDT-PUB P 16754.1, Washington, DC, Various years.

United States Department of Transportation, United States Coast Guard. (1988). *Shiphandling D 42601-0,* U.S. Coast Guard Institute, Oklahoma City, OK.

United States Power Squadrons®, (1986). *The Advanced Piloting Course,* USPS, PAP-85/86, Appendix SM B-2.

Walsh, G., (1987). Poor Navigation Leads to Disaster, *Ocean Navigator,* No. 13, May/June, p. 5, 6.

Waters, J. M., Jr., (1989). *Rescue at Sea,* Second Edition, Naval Institute Press, Annapolis, MD.

Wright, F. W., (1982). *Celestial Navigation,* Cornell Maritime Press, Centreville, MD.

GLOSSARY

This section contains a glossary of nautical terms for convenient reference. Many, but not all, of these terms are used in this *Advanced Coastal Navigation* (ACN) text or on the 1210-Tr chart. These definitions are brief, of necessity. Definitions are also included for some specialized terms of art that space and scope constraints prevented from being discussed at any length in the text.

The reader is sometimes referred to the appropriate chapter in the text and the associated references for a more complete discussion. Certain of these definitions have been taken from the *Light List,* the *Tide Tables*, the *United States Coast Pilot,* and *Bowditch*.

Many specialized terms that are used on nautical charts are included. The 1210-Tr chart is an important part of this course, and it is appropriate to provide the technical definitions of many of the terms used on this chart. To many, the distinctions among such terms as rock awash, rock, and submerged rock may seem pedantic. But, these distinctions could be important to the navigator. As it is, aside from *Bowditch* (which, though excellent, is sometimes found to be intimidating by many beginning students of navigation), there is no single, generally accessible, and easily readable source for these specialized terms. It is hoped that the ACN student finds this a worthwhile source.

A

Abeam—At right angles to the keel of the boat, but not on the boat.

Aboard—On or within the boat.

Abreast—Side by side; by the side of.

Absolute Accuracy—Term often used in connection with a navigation system to mean the difference between the system's estimate of position and the actual position. Also called geodetic accuracy. For example, within the designated coverage area, the absolute accuracy of Loran-C is 0.25 NM or better.

Acquisition—Loran-C: The reception and identification of transmitted navigation signals from master and selected secondaries to permit reliable measurement of position. GPS: The reception and identification of transmitted signals from various satellites to permit reliable measurement of position.

Additional Secondary Factors—Land path factors due to variation in the conductivity of the earth's surface that alter the speed of propagation of loran signals over land compared to over water. ASFs degrade the absolute accuracy of a loran system (unless compensated for) but do not affect the repeatable accuracy.

Adrift—Loose, not on moorings or towline.

Advanced LOP—A line of position which has been moved forward, parallel to itself, along a course line to obtain a line of position at a later time. If the same procedure is followed to move the line to an earlier time, the LOP is said to be retired.

Aft—The stern or back of the vessel.

Agger—See Double Tide.

Agonic Line—The imaginary line connecting points of zero variation.

Aground—A vessel touching or fast to the bottom.

Aid to Navigation (ATON or NAVAID)—Any device external to a vessel or aircraft specifically intended to assist navigators in determining their position or safe course, or to warn them of dangers or obstructions to navigation.

Alee—Away from the direction of the wind. Opposite of windward.

Align—To place objects in line.

Allision—n. [L. allisio, Fr. Allidere, to strike against or dash against; ad + laedere to dash against.] The act of dashing against, or striking upon. Term used in admiralty law to denote the act of striking or collision of a moving vessel against a stationary object. Thus, for example, a vessel could have an allision with a bridge, dock, or vessel tied to a dock. This differs from a collision, which occurs if a moving vessel strikes another moving object—particularly a vessel.

Alternating Light—A rhythmic light showing light of alternating colors.

Amidships—The center of the boat with reference to its length or breath.

Anchor Alarm—Feature of many navigation receivers that can be set to warn the user that the vessel has moved outside the swing circle of the anchor. This is also termed an anchor watch.

Anchor Rode—See Rode.

Anchor Scope—See Scope.

Anchorage—A place suitable for anchoring in relation to the wind, seas and bottom; and permitted by regulations.

Anchorage Mark—A navigation mark, which indicates an anchorage area or defines its limits.

Angle of Cut—The smaller angular difference of two bearings or lines of position. See also crossing angle.

Annotation—Any marking on illustrative material for the purpose of clarification, such as numbers, letters, symbols, or signs.

Annual Inequality—Seasonal variation in the water level or current, more or less periodic, due chiefly to meteorological causes.

Apogean Tides or Tidal Currents—Tides of range or currents of decreased speed monthly as the result of the moon being in apogee (farthest from the earth).

Apogee—Point in the lunar cycle when the moon and the earth are furthest apart. Tides have decreased range when the moon is in apogee.

Arc Measure—The angle included between radii connecting the ends of an arc with the center of the circle of which it is a part.

Arc of Visibility—The portion of the horizon over which a lighted aid to navigation is visible from seaward.

Armed Lead—A weight that has a hollowed bottom and is filled with tallow, grease, wax, chewing gum, or bedding compound to bring up a sample of the bottom.

Articulated Beacon—A beacon-like buoyant structure, tethered directly to the seabed and having no watch circle. Called articulated light or articulated daybeacon, as appropriate.

Assigned Position—The latitude and longitude position for an aid to navigation.

Astern—Direction of movement, opposite of ahead; toward a vessel's stern.

Athwartships—Across or at right angle to the centerline of a boat; rowboat seats are generally placed athwartships (thwarts).

Automated Notices to Mariners System—Computer system that can be accessed by authorized users to obtain chart corrections and notices to mariners. Users need a Teletype, computer terminal, or other device, and an access code available from NIMA.

Autopilot—Device for automatic steering of a vessel. Depending upon the sophistication of the autopilot, these can be used to maintain a heading, or to interface with a loran or other electronic navigation system. Sometimes informally called "George" or "Iron Mike."

Axis of Rotation—The imaginary line connecting the poles of the earth and on which the earth supposedly spins or rotates.

B

Back Range—A range observed astern, particularly one used as guidance for a craft moving away from the objects forming the range.

Bar—A ridge or mound of sand, gravel, or other unconsolidated material below the high water level, especially at the mouth of a river or estuary, which may obstruct navigation.

Bare Poles—Term used to describe a sailboat that is underway with no sails set.

Bare Rock—A rock that extends above the mean high water datum in tidal areas or above the low water datum in the Great Lakes. See also rock awash, submerged rock.

Baseline—The segment of a great circle that joins the master and a secondary station in a loran chain.

Baseline Extension—The extension of the baseline beyond the two joined stations. Loran positions in baseline extension areas are problematic and ambiguous.

Bay—A recess in the shore, on an inlet of a sea or lake between two capes or headlands, that may vary greatly in size but is usually smaller than a gulf and larger than a cove.

Beacon—A lighted or unlighted fixed aid to navigation attached directly to the earth's surface. (Lights and daybeacons both constitute "beacons.")

Beam—The greatest width of the boat.

Beam Sea—Waves act directly on the vessel's sides (coming from abeam) and, in rough water, could roll some boats over on their side. Commonly known as "in the trough."

Bearing—The horizontal direction of a line of sight between two objects on the surface of the earth.

Beat—To sail to windward, generally in a series of tacks. Beating is one of the three points of sailing, also referred to as sailing "close-hauled" or "by the wind."

Bell—A sound signal producing bell tones by means of a hammer actuated by electricity or, on buoys, by sea motion.

Bifurcation—The point where a channel divides when proceeding from seaward. The place where two tributaries meet.

Bight—1. A long and gradual bend or recess in the coastline that forms a large open receding bay. 2. A bend in a river or mountain range.

Binnacle—A stand holding the steering compass.

Binocular—An optical instrument for use with both eyes simultaneously.

Blink—An indication that the master or secondary signals in a loran chain is out of tolerance and not to be used. Loran-C receivers have a blink alarm that warns the user that the indicated positions may not be reliable. Blink conditions warn that the signal power or TD is out-of-tolerance (OOT) and/or that an improper phase code or GRI is being transmitted. GPS receivers have analogous integrity checks.

Bluff—A headland or stretch of cliff having a broad, nearly perpendicular, face. See also cliff.

Boat—A fairly indefinite term. A waterborne vehicle smaller than a ship. One definition is a small craft carried aboard a ship. Submarines, however, are universally referred to as boats

Bobbing a Light—Quickly lowering the height of eye several feet and then raising it again when a navigational light is first sighted to determine whether or not the observer is at the geographic range of the light. If he/she is, the light disappears when the eye is lowered and reappears when it is restored to its original position.

Bolt Holes—Safe places to anchor or moor in the event that the weather worsens or mechanical difficulties occur.

Boulder—A detached water-rounded stone more than 256 millimeters in diameter, i.e., roughly larger than a basketball.

Bow—The forward part of a boat.

Breakwater—Anything that breaks the force of the sea at a particular place, thus forming protection for vessels. Often an artificial embankment built to protect the entrance to a harbor, or to form an artificial harbor. See also jetty.

Bridge–1. An elevated structure extending across or over the deck of a vessel or part of such a structure. 2. A structure erected over a depression or an obstacle, such as a body of water, railroad, etc., to provide a roadway for vehicles or pedestrians.

Broach—The turning of a boat parallel to the waves, subjecting it to possible capsizing.

Broad on the Beam—At right angles to the keel or centerline.

Broad On the Bow—A direction midway between abeam and dead ahead.

Broad On the Quarter—A direction midway between abeam and dead astern.

Broadcast Notice to Mariners—A radio broadcast designed to provide important marine information.

Building or House—One of these terms, as appropriate, is used on nautical charts when the entire structure is a landmark, rather than an individual feature of it.

Bulkhead—A transverse, vertical partition separating compartments.

Buoy—A floating object of defined shape and color, which is anchored at a given position and serves as an aid to navigation.

Buoy System—IALA (See IALA) Maritime Buoyage System B applies to buoys and beacons in U.S. waters that indicate the lateral limits of navigable channels, obstructions, dangers (such as wrecks), and other areas or features of importance to the mariner.

Burdened Vessel—That vessel which, according to the applicable Navigation Rules, must give way to another (privileged) vessel. The terms have been superseded by the terms "give-way" and "stand-on."

C

Cable Area—Area shown on charts transited by submarine cables. Formal anchorage restrictions may apply in cable areas.

Cairn—A mound of rough stones or concrete, particularly one serving, or intended to serve, as a landmark. The stones are customarily piled in a pyramidal or beehive shape.

Cape—A relatively extensive land area jutting seaward from a continent, or large island, which prominently marks a change in, or interrupts notably, the coastal trend.

Channel—1. That part of a body of water deep enough for navigation through an area otherwise not suitable. It is usually marked by a single or double line of buoys and sometimes by ranges. 2. The deepest part of a stream, bay, or strait, through which the main current flows. 3. A name given to large straits, for example, the English Channel.

Characteristic—The audible, visual or electronic signal displayed by an aid to navigation to assist in the identification of an aid to navigation. Characteristic refers to lights, sound signals, racons, radiobeacons, and daybeacons.

Chart—A nautical map for use by mariners or aviators, which depicts features and displays information of interest to these groups.

Chart No. 1—A booklet prepared by the National Ocean Survey that contains symbols and abbreviations that have been approved for use on nautical charts published by the U. S. Government.

Chart Scale—The number of distance units on the earth's surface represented by the same distance unit on the chart. Charts are typically partitioned on the basis of scale. Sailing charts have scales of 1:600,000 and greater. General charts have scales between 1:150,000 and 1:600,000. Coast charts have scales between 1:40,000 and 1:150,000. Harbor charts have scales larger than 1:40,000.

Chart Symbol—A character, letter, or similar graphic representation used on a chart to indicate some object, characteristic, etc. May be called map symbol when applied to any map.

Chimney—A relatively small, upright structure projecting above a building for the conveyance of smoke.

Clay—See Mud.

Clear—To leave or pass safely, as to clear port or clear a shoal.

Clearing Bearing—British term for danger bearing.

Cliff—Land arising abruptly for a considerable distance above water or surrounding land. See also bluff.

Close Aboard—Not on, but near to, a vessel.

Close-hauled—Sailing with the boom hauled as close to the centerline of the vessel as is possible, thus sailing as much into the wind as is possible. Also known as beating, or "by the wind", one of the three points of sailing.

Closest Point of Approach—The closest distance that a target will pass clear of the reference vessel. This distance is estimated from the relative motion plot. The estimated time that this occurs is called the time to closest point of approach (TCPA).

Clutter (Radar)—Unwanted radar echoes reflected from heavy rain, snow, waves, etc., which may obscure relatively large areas on the PPI—and, thus, targets of interest. Related terms: sea clutter, sea return, rain clutter.

Cobble—See Stones.

Coastal Confluence Zone—A zone extending seaward 50 nautical miles from shore or to the 100-fathom curve, whichever is greater.

Coastal Navigation—Navigation in coastal (sometimes called 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.

Cocked Hat—Error triangle formed by lines of position that do not cross at a common point. So named because of the characteristic appearance of these lines in the vicinity of the fix. The size of the cocked hat is an indication of the precision of the fix—and is valuable information to the navigator. For this reason, conservative navigators term a position a fix only if at least three objects are used to determine the fix. Fixes determined from only two LOPs would be relegated to the status of estimated positions in this view.

Cockpit—An opening in the deck from which the boat is handled.

COLREGS, 72—The international rules for preventing collisions at sea, called the International Rules.

Coming About—The changing of course when close-hauled by swinging the bow through the eye of the wind and changing from one tack to another; reverse course or nearly so.

Commissioned—Specialized term of art to denote the action of placing a previously discontinued aid to navigation back in operation.

Compass Card—Part of a compass, the card is graduated in degrees, to conform with the magnetic meridian-referenced direction system inscribed with direction which remains constant; the vessel turns, not the card.

Compass Errors—Generic term used to describe all compass errors including variation, deviation, northerly turning error, acceleration error, heeling error. These are discussed at length in Chapter 2.

Compass Heading—The direction a vessel is heading at any one instant as shown by its compass.

Compass Point—One of 32 points of the compass equal to 11-1/4 degrees.

Compass Rose—The resulting figure when the complete 360-degree directional system is developed as a circle with each degree graduated upon it, and with the 000 indicated as true north. Also called true rose. This is printed on nautical charts for determining direction.

Composite Group-Flashing Light—A group-flashing light in which the flashes are combined in successive groups of different numbers of flashes.

Composite Group-Occulting Light—A light similar to a group-occulting light, except that the successive groups in a period have different numbers of eclipses.

Conformal Projection—A map or chart projection that preserves correct angular relationships.

Contact—Any echo detected on the radarscope not evaluated as clutter or as a false echo. The term "contact" is used in a general sense, whereas "target" (q.v.) is used in a more particular sense to denote a contact about which more information (such as CPA, TCPA, course, or speed) is desired. Thus, radar targets would typically be plotted. Of course, the difference is not clear-cut—one navigator's contact might be another's target.

Contour Lines—Lines that connect points of equal depth on a nautical chart.

Conventional Direction of Buoyage—The general direction taken by the mariner when approaching a harbor, river, estuary, or other waterway from seaward, or proceeding upstream or in the direction of the main stream of flood tide, or in the direction indicated in appropriate nautical documents (normally, following a clockwise direction around land masses).

Coriolis Force—The deflective effect of the earth's rotation on an object in motion, which causes it to divert to the right in the Northern Hemisphere. See Rotary Current.

Correcting—Converting a compass heading or a magnetic heading to its equivalent true heading.

Course (C)—Course is the average heading and the horizontal direction in which a vessel is intended to be steered, expressed as the angular distance relative to north, usually from 000 degrees at north, clockwise through 359 degrees from the point of departure or start of the course to the point of arrival or other point of intended location.

Course Deviation Indicator—An indicator, shown on some navigation receivers, that graphically displays whether or nor the vessel is on course and, if not, the direction to return to course.

Course LOP—An LOP situated approximately directly ahead or behind the vessel, so named because the LOP provides a good indication of the vessel's CMG.

Course Made Good (CMG)—This indicates the single resultant direction from a point of departure to a point of arrival at a given time. (Synonym: Track Made Good)

Course Of Advance (COA)—This indicates the direction of the intended path to be made good over the ground.

Course over the Ground (COG)—This indicates the direction of the path actually followed by the vessel over the ground, usually an irregular line.

Cove—A small sheltered recess or indentation in a shore or coast, generally inside a large embayment.

Cross Rate (Cross Chain) Interference—Interference in the reception of radio signals from one loran chain caused by signals from another loran chain.

Cross-Track Error (XTE)—Distance between the vessel's actual position and the direct course between two waypoints.

Cross-Track Error Alarm—Alarm that can be set on many navigation receivers that warns the navigator if the vessel's cross-track error exceeds some prespecified value.

Crossing Angle—Generally, the angle between two LOPs which determine a fix. The closer this angle is to 90 degrees, the better the fix. Also used with loran LOPs.

Cupola—A small dome-shaped tower or turret rising from a building.

Current—Term used in two senses: It is used to refer either to the horizontal motion over the ground, including ocean current, tidal, and river currents, or more generally to these factors together with the effect of wind and seas, steering error of the helmsman, compass error, speed curve error, and other factors. (See Chapter 7.)

Current (alternate definition)—Generally, a horizontal movement of water. Currents may be classified as tidal and nontidal. Tidal currents are caused by gravitational interactions between the sun, moon, and earth and are a part of the same general movement of the sea that is manifested in the vertical rise and fall, called tide. Nontidal currents include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from more pronounced meteorological variability.

Current Correction Angle—The difference between the intended track and the calculated course to steer to compensate for the estimated current.

Current Difference—Difference between the time of slack water (or minimum current) or strength of current in any locality and the time of the corresponding phase of the tidal current at a reference station, for which predictions are given in the *Tidal Current Tables*.

Current Drift Angle—The difference in angle between the course steered and the resulting CMG in the presence of current.

Current Ellipse—A graphic representation of a rotary current in which the velocity of the current at different hours of the tidal cycle is represented by radius vectors and vectorial angles. The cycle is completed in one-half tidal day or in a whole tidal day according to whether the tidal current is of the semidiurnal or the diurnal type. A current of the mixed type will give a curve of two unequal loops each tidal day.

Current Sailing—The process of allowing for current in determining the predicted course made good, or in determining the effect of a current on the direction and speed of motion of a vessel.

D

Danger Bearing—The maximum or minimum bearing of a point for safe passage of an off-lying danger. As a vessel proceeds along a coast, the bearing of a fixed point on shore, such as a lighthouse, is measured frequently. As long as the bearing does not exceed the limit of the predetermined danger bearing, the vessel is on a safe course with respect to the hazard in question.

Danger Buoy—A buoy marking an isolated danger to navigation, such as a rock, shoal or sunken wreck.

Datum—The technical term for the baseline from which a chart's vertical measurements are made—heights of land or landmarks, or depths of water.

Daybeacon—A fixed NAVAID structure used in shallow waters upon which is placed one or more daymarks.

Daylight Saving Time—A time used during the summer in some localities in which clocks are advanced one hour from the usual standard time.

Daymark—A signboard attached to a daybeacon to convey navigational information presenting one of several standard shapes (square, triangle, or rectangle) and colors (red, green, orange, yellow, or black). Daymarks usually have reflective material indicating the shape, but may also be lighted.

Dead Ahead—A relative bearing of 000 degrees.

Dead Astern—Directly aft.

Dead in the Water—Adrift, floating with the current.

Dead Reckoning—The practice of estimating position by advancing a known position for courses and distances run. The effects of wind and current are not considered in determining a position by dead reckoning.

Dead Reckoning Plot—A DR plot is the charted movement of a vessel as determined by dead reckoning.

Dead Reckoning (DR) Position—A position determined by dead reckoning.

Deck—A permanent covering over a compartment, hull, or any part thereof.

Demarcation Line—Boundary shown on nautical charts between areas where inland navigation rules and international navigation rules apply.

Departure—A known location (fix) from which a dead reckoning plot is initiated.

Depth Sounder—An electronic means of measuring water depth by sound waves.

Deviation—The effect of the vessel's magnetic fields upon a compass. Deviation is the difference between the direction that the compass actually points and the direction that the compass would point if there were no magnetic fields aboard the vessel.

Diaphone—A sound signal which produces sound by means of a slotted piston moved back and forth by compressed air. A "two-tone" diaphone produces two sequential tones with the second tone of lower pitch.

Dinghy—A small open boat. A dinghy is often used as a tender for a larger craft.

Direction (true)—The angle between the local true meridian and a line from the observer's position to an object or another location.

Direction of Relative Motion—Determined from the relative motion plot, this is the apparent course of the target as inferred from observations on the radar screen.

Directional Light—A light illuminating a sector or very narrow angle and intended to mark a direction to be followed.

Discontinued—To remove from operation (permanently or temporarily) a previously authorized aid to navigation.

Discrepancy—Failure of an aid to navigation to maintain a position or function as prescribed in the *Light List*.

Discrepancy Buoy—An easily transportable buoy used to temporarily replace an aid to navigation that is not watching properly. See Watching Properly.

Displacement—The weight of water displaced by a floating vessel, thus, a boat's weight.

Displacement Hull—A type of hull that plows through the water, displacing a weight of water equal to its own weight, even when more power is added. (See Chapter 11.)

Diurnal—Having a period or cycle of approximately one tidal day. Thus, the tide is said to be diurnal when only one high water and one low water occur during a tidal day, and the tidal current is said to be diurnal when there is a single flood and single ebb period in the tidal day. A rotary current is diurnal if it changes its direction through all points of the compass once each tidal day.

Diurnal Inequality—The difference in height of the two high waters or of the two low waters of each day; also, the difference in speed between the two flood tidal currents or the two ebb tidal currents of each day. The difference changes with the declination of the moon and, to a lesser extent, with the declination of the sun.

Dividers—An instrument consisting of two pointed legs joined by a pivot, and used principally for measuring distances or coordinates. An instrument having one pointed leg and the other carrying a pen or pencil is called a drafting compass.

Dock—A protected water area in which vessels are moored. The term is often used to denote a pier or a wharf.

Dolphin—A minor aid to navigation structure consisting of a number of piles driven into the seabed or riverbed in a circular pattern and drawn together with wire rope.

Dome—A large, rounded, hemispherical structure rising above a building or a roof of the same shape.

Double Ebb—An ebb tidal current where, after ebb begins, the speed increases to a maximum called first ebb and then decreases, reaching a minimum ebb near the middle of the ebb period (and, at some places, it may actually run in a flood direction for a short period); it then again ebbs to a maximum speed called second ebb, after which it decreases to slack water.

Double Flood—A flood tidal current where, after flood begins, the speed increases to a maximum called first flood; it then decreases, reaching a minimum flood near the middle of the flood period (and, at some places, it may actually run in an ebb direction for a short period); it then again floods to a maximum speed called second flood, after which it decreases to slack water.

Double Tide—A double-headed tide; that is, a high water consisting of two maxima of nearly the same height separated by a relatively small depression, or a low water consisting of two minima separated by a relatively small elevation. Sometimes, it is called an agger.

Doubling the Angle on the Bow—A method of calculating a running fix by measuring the distance a vessel travels on a steady course while the relative bearing (right or left) of a fixed object doubles. The distance from the object at the time of the second bearing is equal to the distance run between bearings, neglecting drift.

Draft—The vertical depth from the bottom of the keel to the top of the water.

Drift—The speed in knots at which the current is moving. Drift may also be indicated in statute miles per hour in some areas, the Great Lakes, for example. This term is also commonly used to mean the speed at which a vessel deviates from the course steered due to the combined effects of external forces such as wind and current.

Drms—A term used to describe the statistical accuracy of an electronic or other fix. Twice the Drms is the radius of a circle that should include the fix point with at least 95 percent certainty.

Drogue—Any device streamed astern to slow a vessel's speed, or to keep its stern to the waves in a following sea.

Drying Heights—Heights above chart sounding datum of those features which are periodically covered and exposed by the rise and fall of the tide.

Dumping Ground—Area shown on charts where dumping took place (the practice is no longer permitted) and which may present a hazard to navigation.

Duration of Flood and Duration of Ebb—-Duration of flood is the interval of time in which a tidal current is flooding, and the duration of ebb is the interval in which it is ebbing.

Duration of Rise and Duration of Fall—Duration of rise is the interval from low water to high water, and duration of fall is the interval from high water to low water.

Dutchman's Log—A buoyant object thrown overboard to determine the speed of a vessel. The time required for a known length of the vessel to pass the object (assumed to be dead in the water) is measured. Speed can be computed from the two known values of time and distance. The Dutchman's log can also be used to measure the drift of a current if a vessel can be held stationary (keep station) with respect to a fixed object.

E

Ebb Current—The movement of a tidal current away from shore or down a tidal river or estuary. In the mixed type of reversing tidal current, the terms greater ebb and lesser ebb are applied, respectively, to the ebb tidal currents of greater and lesser speed of each day. The terms maximum ebb and minimum ebb are applied to the maximum and minimum speeds of a current running continuously ebb, the speed alternately increasing and decreasing without coming to a slack or reversing.

Echo—Term used in radar to denote an object that reflects the radar beam, often used interchangeably with the terms return, target, blip, contact, and pip. Properly speaking, however, there are subtle distinctions among these. See, for example, contact.

Eclipse—An interval of darkness between appearances of a light.

Electronic Bearing Line—An adjustable bearing line, which appears as a spoke radiating from the center of the PPI. EBLs are used to measure the bearing of a target. Also called electronic bearing marker.

Electronic Bearing Marker—See electronic bearing line.

Electronic Chart—A device that can display a chart-like representation on a screen. Some electronic charts are very elaborate and allow the user to "zoom in" to examine an area at a larger scale. Depth contours, NAVAIDS, and other chart features can be displayed—even down to individual docks at certain locations. Electronic charts can interface with other shipboard electronics, such as a GPS or loran, and display the vessel's current position, waypoints, and related information.

Emergency Light—A light of reduced intensity displayed by certain aids to navigation when the main light is extinguished.

Emergency Position Indicating Radio Beacon (EPIRB)—A device which emits a continuous radio signal, alerting authorities to the existence of a distress situation and leading rescuers to the scene.

Endurance—The time in hours that the vessel can be operated at a given throttle setting until the en route fuel is exhausted.

En Route Fuel—Fuel intended for use in a voyage. Numerically, the en route fuel is the fuel on board minus an allowance for a fuel reserve. Also termed voyage fuel.

Ensign—A national or organizational flag flown aboard a vessel.

Equator—Great circle formed by passing a plane perpendicular to the axis of rotation of the earth.

Equatorial Tidal Currents—Tidal currents occurring semimonthly as the result of the moon being over the equator. At these times, the tendency of the moon to produce a diurnal inequality in the tide is at a minimum.

Equatorial Tides—Tides occurring semimonthly as the result of the moon being over the equator. At these times, the tendency of the moon to produce a diurnal inequality in the tide is at a minimum.

Establish—To place an authorized aid to navigation in operation for the first time.

Estimated Position (EP)—An improved position based upon the DR position and which may include, among other things, factoring in the effects of wind and current, a single line of position, or all of the above.

Extinguished—A lighted aid to navigation that fails to show a light characteristic.

Existence Doubtful—Term used principally on charts to indicate the possible existence of a rock, shoal, or other obstruction, for which the actual existence has not been established.

F

Fair Current—Current moving in the same direction as the vessel.

Fall Off—To turn the bow of the boat away from the direction of the oncoming wind.

Fast—Said of an object that is secured to another.

Fathom—A nautical measure of length, six feet, used for measuring water depth and length of anchor rode.

Fix—A known position determined by passing close aboard an object of known position or determined by the intersection of two or more lines of position (LOPs) adjusted to a common time, determined from terrestrial, electronic, and/or celestial data (see Chapter 6). The accuracy, or quality of a fix, is of great importance, especially in coastal waters, and is dependent on a number of factors.

Fixed ATON—An aid to navigation placed on a fixed structure such as a lighthouse, tower, etc.

Fixed Bridge—A bridge that does not lift, swing, or otherwise open for vessel traffic.

Fixed Light—A light showing continuously and steadily, as opposed to a rhythmic light. (Do not confuse with "fixed" as used to differentiate from "floating.")

Fixed Range Markers—A series of concentric range rings displayed on a PPI. A range switch can adjust the spacing of these rings, but all FRMs are fixed in relation to each other.

Flag Tower—A scaffold-like tower from which flags are displayed.

Flagpole—A single staff from which flags are displayed. The term is used when the pole is not attached to a building.

Flagstaff—A flagpole rising from a building.

Flash—A relatively brief appearance of a light, in comparison with the longer interval of darkness in the same character.

Flash Tube—An electronically controlled high-intensity discharge lamp with a very brief flash duration.

Flashing Light—A light in which the total duration of light in each period is clearly shorter than the total duration of darkness and in which the flashes of light are all of equal duration. (Commonly used for a single-flashing light that exhibits only single flashes, which are repeated at regular intervals.)

Float Plan—A document that describes the route(s) and estimated time of arrival of a particular voyage. The float plan generally includes a description of the vessel, radio and safety equipment carried, planned stops, names of passengers, and other pertinent information.

Floating Aid to Navigation—A buoy secured in assigned position by a mooring.

Flood Current—The movement of a tidal current toward the shore or up a tidal river or estuary. In the mixed type of reversing current, the terms greater flood and lesser flood are applied, respectively, to the flood currents of greater and lesser speed of each day. The terms maximum flood and minimum flood are applied to the maximum and minimum speeds of a flood current, the speed of which alternately increases and decreases without coming to a slack or reversing.

Fluxgate Compass—A compass that senses the earth's magnetic field electronically, rather than with magnets. Fluxgate compasses can interface with other shipboard electronics such as radar, GPS, and loran.

Flying Bridge—An added set of controls above the level of the normal control station for better visibility. Usually open but may have a collapsible top for shade.

Fog Detector—An electronic device used to automatically determine conditions of visibility which warrant the turning on and off of a sound signal or additional light signals.

Fog Signal—See Sound Signal.

Following Sea—Sea in which the waves move in a direction approximately the same as the vessel's heading. Opposite of head sea.

Fore-and-Aft—In a line parallel to the keel.

Forward—Toward the bow of the boat.

Fouled—Any piece of equipment that is jammed entangled, or dirty.

Foul Current—Current moving in the opposite direction to the vessel.

Foul Ground—An area unsuitable for anchoring due to being strewn with rocks, boulders, coral, or obstructions. Foul grounds are often shown on nautical charts.

Founder—When a vessel fills with water and sinks.

Freeboard—The minimum vertical distance from the surface of the water to the gunwale cap.

Frequency—The rate at which a cycle is repeated.

Fuel Consumption Chart—Chart or graph that relates the engine throttle setting, speed through the water, and the fuel burn rate in gallons per hour.

Fuel Efficiency—The distance that a vessel can travel on each gallon of fuel. Fuel efficiency is a function of the throttle setting and several other factors discussed in Chapter 11.

Fuel Reserve—A quantity of fuel set aside for possible contingencies.

G

Gear—A general term for rope, block(s), tackle, and other equipment.

Geometric Dilution of Precision (GDOP)—Term used to include all geometric factors (gradient, crossing angle) that degrade the accuracy of position fixes from externally referenced navigation systems, such as GPS or Loran-C. GDOP can be calculated from an equation, which summarizes these effects in one single number.

Gimbals—A pair of rings pivoted on axes at right angles to each other, so that one is free to swing within the other; a ship's compass, for instance, will keep a horizontal position when suspended on gimbals.

Give-way Vessel—A term, from the Navigational Rules, used to describe the vessel which must yield in meeting, crossing, or overtaking situations.

Gong—A wave-actuated sound signal on buoys, which uses a group of saucer-shaped bells to produce different tones.

GPS—Global Positioning System, an electronic navigation system using satellites for worldwide coverage. See Chapter 9 of this text.

Gradient—The ratio of the spacing between adjacent loran TDs, as measured in nautical miles, yards, or feet, and the number of microseconds difference between these lines. Generally speaking, the smaller the gradient, the better the fix.

Graticule—The network of lines representing parallels and meridians on a map, chart, or plotting sheet.

Gravel—See Stones.

Great Circle—The circle formed on the earth's surface when a plane is passed through the earth's center.

Great Diurnal Range—The difference in height between mean higher high water and mean lower low water. The expression may also be used in its contracted form, diurnal range.

Ground Swell—See Swells.

Ground Tackle—A collective term for the anchor and its associated gear.

Ground Wave—A radio wave that travels near or along the earth's surface. Ground wave signals are used for the present loran system

Group Flashing Light—A navigational aid light that emits flashes in groups, specified repeated at regular intervals.

Group Occulting Light—An occulting light in which a group of eclipses, specified in number, is regularly repeated.

Group Repetition Interval—Length of time (in microseconds) between the start of one transmission from the master station in a Loran-C chain and the start of the next. For convenience, the GRI is usually divided by 10. Thus, for example, the 9960, or Northeast U. S. Chain, has a group repetition interval of 99,600 microseconds.

Gudgeon—The eye supports for the rudder, mounted on the transom and designed to receive the pintles.

Gulf—That part of an ocean or sea extending into the land, usually larger than a bay.

Gulf Coast Low Water Datum—A chart datum. Specifically, the tidal datum formerly designated for the coastal waters of the Gulf Coast of the United States. It was defined as mean lower low water when the type of tide was mixed and mean low water when the type of tide was diurnal.

Gunwale—The upper edge of a boat's sides.

H

Hachures——Short marks on topographic maps or nautical charts to indicate the slope of the ground or the submarine bottom. These marks usually follow the direction of the slope.

Half-Tide Level—See mean tide level.

Hand-Bearing Compass—Portable compass (magnetic or electronic) that is used aboard ship for taking bearings.

Head Sea—Sea in which the waves move in a direction approximately opposite the vessel's heading. Opposite of following sea.

Heading (HDG)—The instantaneous direction of a vessel's bow. It is expressed as the angular distance relative to north, usually 000 degrees at north, clockwise through 359 degrees. Heading should not be confused with course. Heading is a constantly changing value as a vessel yaws back and forth across the course due to the effects of sea, wind, and steering error. Heading is expressed in degrees with respect to true, magnetic, or compass north.

Heading Flash—An illuminated radial line on the PPI of a radarscope for indicating the reference ship's heading on the bearing dial. Also called heading marker.

Headway—The forward motion of a boat through the water. Opposite of sternway.

Heave To—To bring a vessel up in a position where it will maintain little or no headway, usually with the bow into the wind or nearly so. To stop.

Heavy Iron—-Slang expression used to denote large ships.

Heel—To tip or lean to one side.

Helm—The wheel or tiller controlling the rudder.

High Frequency (HF)—A special frequency band used in long-distance communications.

High Water (HW)—The maximum height reached by a rising tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions.

Higher High Water (HHW)—The higher of the two high waters of any tidal day.

Higher Low Water (HLW)—The higher of the two low waters of any tidal day.

Hole—A small bay (or channel), particularly in New England.

Homing—Process of moving towards a location by continually pointing the bow of the vessel in the direction of the station. In the absence of current, homing will lead to a ground track that is a straight line. With any current, however, the ground track will become curved, bowed in the direction of the prevailing current.

Hook—Something resembling a hook in shape, particularly, a spit or narrow cape of sand or gravel which turns landward at the outer end; or a sharp bend or curve, as in a stream.

Horn—A sound signal, which uses electricity or compressed air to vibrate a disc diaphragm.

Howgozit Chart—Chart that depicts the vessel's actual fuel quantity at various points in a voyage in comparison to the amount of fuel required to reach the destination with various levels of fuel reserves.

Hug—To remain close to, as to hug the shore.

Hull—The main body of a vessel.

Hull Speed—The maximum speed of a displacement vessel. It is limited by the length of the vessel and the shape of its underwater construction.

Hydraulic Current—A current in a channel caused by a difference in the surface level at the two ends. Such a current may be expected in a strait connecting two bodies of water in which the tides differ in time or range.

Hyperbolic Grid—Lattice of curved (hyperbolic) lines of position produced by a hyperbolic system.

Hyperbolic System—Navigation system, such as Loran-C, that operates by measuring the time difference between signals transmitted by two or more transmitters.

I

IALA—Acronym for the International Association of Lighthouse Authorities, an organization founded in 1957 to gather together marine navigation authorities, manufacturers, and consultants throughout the world. For details, see International Association of Lighthouse Authorities.

IALA Region A—IALA region in which red is to port on entering. Region A includes Europe, Australia, New Zealand, Africa, the Gulf, and some Asian countries.

IALA Region B—IALA region in which red is to starboard when entering from seaward (i.e., the "red-right-returning" system). Region B includes the countries of North, Central, and South America, Japan, Korea, and the Philippines.

Inclinometer—Device to measure the angle of roll of a vessel.

Index Diagram—An inset in a nautical chart where contiguous or related charts at different scales are noted.

Inoperative—Sound signal or electronic aid to navigation out of service due to a malfunction.

International Association of Lighthouse Authorities (IALA)—(In French, *Association Internationale de Signalisation Maritime* (AISM)), also known as the International Association of Marine Aids to Navigation and Lighthouse Authorities. IALA is a non-profit international technical association established in 1957 and headquartered in St. Germain en Laye, France. IALA comprises 200 members, 80 of which are national navigation authorities and 60 are commercial firms. Delegates to IALA have established a uniform system of maritime buoyage now being implemented by most maritime nations. Within the single system, there are two *regions*: denoted Region A and Region B, where lateral marks differ only in the colors of port and starboard hand marks. In Region A, red is to port on entering; in Region B, red is to starboard on entering. (Although this system—in which buoys have the opposite lateral significance in the two regions—may appear confusing, it is an improvement. As late as 1976 there were more than thirty different buoyage systems in use throughout the world.) Details of the buoyage system and other relevant information are available from the IALA web site (http://www.iala-aism.org/iala.htm) or another that provides several interesting documents (http://www.beta.ialahq.org/).

Interrupted Quick Light—A quick flashing light in which the rapid alternations are interrupted at regular intervals by eclipses of long duration.

Intrusion Alarm—Alarm that can be set on a radar unit to alert the radar operator that a target has penetrated a range ring.

Iron Genny—Slang expression to denote the engine of a sailboat.

Iron Mike—Slang expression for autopilot.

Isogonic Lines—Lines on a chart connecting points of equal magnetic variation.

Isolated Danger Mark—A mark erected on, or moored above or very near, an isolated danger which has navigable water all around it.

Isophase Light—A rhythmic light in which all durations of light and darkness are equal. (Formerly called equal interval light.)

Isthmus—A narrow strip of land connecting two larger portions

J

Jetty—A structure built out into the water to restrain or direct currents, usually to protect a river mouth or harbor entrance from silting, etc.

Junction—The point where a channel divides when proceeding seaward. Also used to describe the place where a tributary departs from the main stream.

K

Keel—The main structural member of a vessel running fore-and-aft; the backbone of a vessel.

Knot (kn. sometimes kt.)—A measure of speed equal to one nautical mile (6,076 feet) per hour.

L

Landmark—A conspicuous artificial feature on land, other than an established aid to navigation, which can be used as an aid to navigation. Sometimes also used in a less technical sense to include natural features as well as artificial features.

Large Navigational Buoy (LNB)—Buoys developed to replace lightships and are placed at points where it is impractical to build a lighthouse. The unmanned LNBs are 40 feet in diameter with light towers approximately 40 feet above the water. LNBs are equipped with lights, sound signals, radiobeacons, and racons. LNBs are painted red, not for lateral significance, but to improve visibility.

Lateral System—A system of aids to navigation in which characteristics of buoys and beacons indicate the sides of the channel or route relative to a conventional direction of buoyage (usually upstream).

Latitude—Distance north or south of the equator expressed in degrees from zero to ninety, north or south; i.e., 073° N.

Lead Line—A line used to measure the depth of the water.

Leading Lights—British terminology for range lights.

Ledge—A rocky projection or outcrop on the sea floor.

Lee—The side sheltered from the wind; the direction toward which the wind is blowing.

Leeward—The direction away from the wind. Opposite of windward.

Leeway—The sideways movement of the boat caused by either wind or current.

Leg—That portion of a voyage track that can be represented by a single course line. A track could be composed of several legs.

Legend—A title or explanation on a chart, diagram, or illustration.

Light—Lighthouses or beacons, fixed aids to navigation, or a vessel's navigation lights. On a vessel, lights are designed to help identify the size, direction of movement, status of the vessel, and sometimes the tasks being performed.

Light List—-USCG Publication discussed in Chapter 10.

Light Sector—The arc, over which a light is visible, described in degrees true, as observed from seaward towards the light. May be used to define distinctive color difference of two adjoining sectors, or an obscured sector.

Lighted Ice Buoy (LIB)—A lighted buoy without a sound signal, and designed to withstand the forces of shifting and flowing ice. Used to replace a conventional buoy when that aid to navigation is endangered by ice.

Lighthouse—A lighted beacon of major importance.

Line of Position (LOP)—A line of bearing to a known origin or reference, upon which a vessel is assumed to be located (see Chapter 6, Line of Position). An LOP is determined by observation (visual bearing) or measurement (radar). An LOP is assumed to be a straight line for visual bearings, an arc of a circle (radar range), a sphere (GPS), or part of some other curve such as hyperbola (loran). LOPs resulting from visual observations (magnetic bearings) are generally converted to true bearings prior to plotting on a chart.

Line of Sight—The straight line between two points. This line is in the direction of a great circle, but does not follow the curvature of the earth.

Local Notice to Mariners (LNM)—A written document issued by each U. S. Coast Guard District to disseminate important information affecting aids to navigation, dredging, marine construction, special marine activities, and bridge construction on the waterways within that district.

Log—A daily record of a ship's progress or operations and messages sent or received on its radio. A device to measure a vessel's speed. To record a ship's progress in a journal.

Longitude—Distance east or west of the prime meridian expressed in degrees from zero to 180 degrees east or west.

Lookout Station (watchtower)—A tower atop a small house used for observation.

Loran—A contraction of long-range navigation, used to describe an electronic navigation system using a chain of transmitting stations that allows mariners (or aviators) to determine their position

Loran-C LOP—Line of position as determined from reception of the loran master signal and that of one secondary. Loran-C LOPs at convenient intervals are plotted on NOAA charts.

Loran Chain—Series of three to five transmitting stations consisting of a master station and two to four secondary stations used in the loran system.

Loran Linear Interpolator—A small inset diagram shown on loran overprinted charts that enables interpolation of time differences.

Loran Pulse—Basic "building block" of the transmitted loran signal. The loran pulse exhibits a characteristic (and well-controlled) waveform which can be identified and timed by a receiver. The loran signal from a master station actually consists of nine pulses. The first eight pulses are spaced 1,000 microseconds (ms) apart, followed at an interval of 2,000 microseconds by the ninth pulse. Secondary stations transmit only eight pulses, each separated by 1,000 microseconds. Pulsed transmission saves on the power required for signal transmission and facilitates signal identification. Multiple pulse transmission is used rather than single pulse transmission to increase the average power of the loran signal.

Low Water (LW)—The minimum height reached by a falling tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of meteorological conditions. Use of the synonymous term, low tide, is discouraged.

Lower High Water (LHW)— The lower of the two high waters of any tidal day.

Lower Low Water (LLW)— The lower of the two low waters of any tidal day.

Loxodrome—Any line on the earth's surface (other than due east or due west) which cuts successive meridians of longitude at the same oblique angle. When extended, it spirals toward, but never reaches, one of the earth's poles.

Lubber's Line—A mark or permanent line on a compass, which is used to read the compass heading of a vessel. When properly mounted it is parallel to the vessel's keel.

Luminous Range Diagram—A diagram used to convert the nominal range of a light to its luminous range under existing conditions. The ranges obtained are approximate. (See Chapter 10.)

Lunar Day—The duration of one rotation of the earth on its axis, with respect to the moon. Its average length is about 24 hours and 50 minutes.

M

Magnetic Compass—A magnet, balanced so that it can pivot freely in a horizontal plane; a sailor's most common and most reliable direction-indicating aid.

Magnetic Direction (M)—A direction relative to the earth's magnetic field and magnetic north. Magnetic courses are labeled with an "M" to signify "magnetic."

Magnetic Meridian—A system of "meridians" passing through the earth's magnetic poles. A compass aligns with these "meridians" if there is no local magnetic field on the vessel to cause deviation.

Make Fast—To secure by belaying or hitching; to fasten in place, as a sail; to secure a ship at a pier, etc., by dock lines.

Maneuvering Board—A printed compass rose that is used together with parallel rulers and dividers to solve problems of the movement of vessels relative to each other, such as those that arise when the vessels change position relative to each other. Used, for example, when another vessel is observed on a radarscope.

Marine Radiotelephone—VHF-FM radio; an important safety device in emergencies.

Mark—A visual aid to navigation. Often called navigation marks; includes floating marks (buoys) and fixed marks (beacons).

Masking—Obscuration of an object. Radar masking (also radar shadow) refers to a phenomenon in which a target is obscured (masked) by virtue of its location behind another larger target—such as a mountain, structure, or other vessel. Visual masking can also occur.

Master Station—Essential component of a Loran-C chain. This station broadcasts the signal that is used to identify the chain (the GRI) and is the common base against which all time differences are calculated.

Mean High Water (MHW)—The arithmetic mean of the high water heights observed over a specific 19-year cycle. For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value.

Mean Higher High Water (MHHW)—The arithmetic mean of the higher high water heights of a mixed tide observed over a specific 19-year cycle. Only the higher high water of each pair of high waters, or the only high water of a tidal day, is included in the mean.

Mean Low Water (MLW)—A tidal datum. The arithmetic mean of the low water heights observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value.

Mean Low Water Springs (MLWS)—Frequently abbreviated spring low water. The arithmetic mean of the low water heights occurring at the time of the spring tides observed over a specific 19-year cycle.

Mean Lower Low Water (MLLW)—The arithmetic mean of the lower low water heights of a mixed tide observed over a specific 19-year cycle. Only the lower low water of each pair of low waters, or the only low water of a tidal day is included in the mean. This is the vertical datum used on U.S. charts for portraying water depths.

Mean Range of Tide—The difference in height between mean high water and mean low water.

Mean Sea Level (MSL)—The arithmetic mean of hourly water elevations observed over a specific 19-year cycle. Shorter series are specified in the name, e.g., monthly mean sea level and yearly mean sea level.

Mean Tide Level (MTL)—Also called half-tide level. A tidal datum midway between mean high water and mean low water.

Mercator Projection—The projection technique most commonly used in navigational charts; shapes and distances are increasingly distorted as you move into extreme northern and southern areas. This is a cylindrical projection ingeniously modified by expanding the scale at increasing latitudes to preserve ship's direction and angular relationships.

Meridian (Geographic Meridian)—A great circle of the earth passing through both the geographic poles and any given point on the earth's surface.

Meteorological Visibility—The greatest distance at which a black object of suitable dimension could be seen and recognized against the horizon sky by day, or, in the case of night observations, could be seen and recognized if the general illumination were raised to the normal daylight level.

Microsecond (μsec)—One millionth of a second.

Midship—Approximately in the location equally distant from the bow and stern.

Mileage Number—A number assigned to aids to navigation which gives the distance in sailing miles along the river from a reference point to the aid to navigation. The number is used principally in the Mississippi River System

Mixed Tide—Type of tide with a large inequality in the high and/or low water heights, with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed but the name is usually applied to the tides intermediate to those predominantly semidiurnal and those predominantly diurnal.

Most Probable Position—Vessel's probable position considering all available navigational information. The term is generally used when there is position uncertainty as a result of conflicting or ambiguous information.

Mud—A general term applied to mixtures of sediments in water. Where the grains are less than 0.002 millimeter in diameter, the mixture is called clay. Where the grains are between 0.002 and 0.0625 millimeter in diameter, the mixture is called silt. See also sand, stones, and rock.

Multiple Ranges—A group of two or more ranges having one of the range marks in common.

Mushroom Anchor—A stockless anchor with a cast iron bowl at the end of the shank; used principally in large sizes for permanent moorings.

N

NAVCEN—The United States Coast Guard's Navigation Center. The center maintains a web site, which provides information on the organization and its services (http://www.navcen.uscg.gov/).

NIMA—National Imagery and Mapping Agency (successor to the Defense Mapping Agency). For information on NIMA, see its web site at (http://www.nima.mil/).

Nautical Chart—See Chart.

Nautical Mile (M)—One minute of latitude; approximately 6,076 feet—about 1/8 longer than the statute mile of 5,280 feet.

Nautical Slide Rule—Analog device for solving time-speed-distance calculations. In present manufacture, these are typically circular slide rules with three separate scales graduated in units of time, speed, and distance.

Navigation—The art and science of conducting a boat safely from one point to another.

Navigation Rules (NAVRULES)—Regulations governing the movement of vessels in relation to each other, formerly "Rules of the Road."

Neap Tides or Tidal Currents—Tides of decreased range or tidal currents of decreased speed occurring semimonthly as the result of the moon being in quadrature. The neap range of the tide is the average semidiurnal range occurring at the time of neap tides

Neck—1. A narrow isthmus, cape, or promontory. 2. The land between streams flowing into a sound or bay. 3. A narrow strip of land, which connects a peninsula with the mainland. 4. A narrow body of water between two larger bodies.

NOAA—National Oceanic and Atmospheric Administration. For details on this organization and its services, visit its web site at (http://noaa.gov/).

North Geographic Pole—A reference for specifying a position on the earth's surface, at the north end of the earth's axis. Also called true north.

North Magnetic Pole—The central point of the north end of the earth's magnetic core to which a compass points when it is free of other influences.

North Up—Type of relative motion radar display with own ship at center. This is linked to a gyrocompass or fluxgate compass to display a continuous north up picture on the PPI.

Notch Filters—Filters in a loran receiver that are either fixed or capable of being tuned to reduce ("notch out") the effects of interfering signals. Some filters (termed "PacMan" filters) can automatically seek and notch out interfering signals. Typical signals that can cause loran interference are listed in the Loran-C Handbook. The notch filters on a loran should be adjusted for the area of intended cruising to maximize the efficiency of the filtering.

Notice to Mariner (NTM or NM)—Publication, similar to *Local Notice to Mariners* that contains information applicable to routes traversed by larger ships. (See Chapter 10.)

O

Oblate Spheroid—Sphere flattened at the poles, resembling a pumpkin.

Occulting Light—A light in which the total duration of light in each period is clearly longer than the total duration of darkness and in which the intervals of darkness (occultations) are all of equal duration. (Commonly used for single occulting light, which exhibits only single occultations that are repeated at regular intervals.)

Ocean Data Acquisition System (ODAS)—Certain very large buoys in deep water for the collection of oceanographic and meteorological information. All ODAS buoys are yellow in color and display a yellow light.

Offshore Tower—Monitored light stations built on exposed marine sites to replace lightships.

Off Station—A floating aid to navigation not on its assigned position

Omega—Electronic navigation system (now no longer used). This is not discussed in the ACN text. See references listed at the end of Chapter 9 for details.

On Plane—As more and more speed is gained, a boat feels as though it has “climbed out of its hole,” and it rides up “on plane.”

Ooze—A soft, slimy, organic sediment covering part of the ocean bottom.

Out of Tolerance—A condition in which a Loran-C signal or time difference exceeds established tolerances. An out-of-tolerance (OOT) condition causes the secondary transmitter to blink.

Outfall—The discharge end of a narrow stream, sewer drain, etc.

Overboard—Over the side.

P

Palisades—A line of cliffs.

Paraline Plotter—Plotter that has a set of rollers attached to enable the device to be moved parallel to itself and used for the same purpose as parallel rules.

Parallel of Latitude—Any of the imaginary lines parallel to the equator and representing latitude.

Parallel Rules—An instrument for transferring a line parallel to itself, used in chartwork for drawing and measuring courses or bearings.

Passing Light—A low intensity light, which may be mounted on the structure of another light to enable the mariner to keep the latter light in sight when passing out of its beam during transit.

Pebble—See Stones.

Pelorus—A sighting device, marked off in degrees, used to determine relative bearings.

Peninsula—A section of land nearly surrounded by water. Frequently, but not necessarily, a peninsula is connected to a larger body of land by a neck or isthmus.

Perigean Tides or Tidal Currents—Tides of increased range or tidal currents of increased speed occurring monthly as the result of the moon being in perigee or nearest the earth. The perigean range of tide is the average semidiurnal range occurring at the time of Perigean tides.

Perigee—Point in the lunar cycle when the moon and the earth are closest together. Tides have increased range when the moon is in perigee.

Period—The interval of time between the commencement of two identical successive cycles of the characteristic of the light or sound signal.

Personal Flotation Device (PFD)—A life preserver which, when properly used, will support a person in the water. PFDs are available in several sizes and types.

Phase Code Interval—That interval over which the phase code repeats itself. For the Loran-C system, phase codes repeat every two GRIs.

Phase Coding—Not discussed in the text, this is a scheme of changing the phase of the pulses in a transmitted loran signal to minimize pulse-to-pulse skywave interference and to reject synchronous interfering signals. Master and secondary transmitters use different phase codes for signal identification.

Pier—A loading or mooring platform extending at an angle (usually a right angle) from the shore.

Pile—A wood, metal or concrete pole driven into the bottom. Craft may be made fast to a pile; it may be used to support a pier (see piling) or a float.

Piling—Support, protection for wharves, piers, etc., constructed of piles (see pile).

Pilot Waters—Areas in which the services of a pilot are recommended or required. Also used in a more general sense to denote waters in which navigation is done using pilotage/piloting.

Piloting—Piloting is navigation involving frequent or continuous reference to charted landmarks, ATONs, or charted objects, and depth soundings.

Pivot Point—A point somewhat aft of the bow, somewhere forward of the midpoint. To an observer on board, a vessel appears to turn about its pivot point.

Plan Position Indicator (PPI)—The screen display of a modern radar unit, so named because it presents a plan view of the area scanned.

Planing—A boat is said to be planing when it is essentially moving over the top of the water.

Planing Hull—A type of hull with flat surfaces (not necessarily horizontal) which enable a vessel to climb up its bow wave and to glide across the water when it has attained a sufficient speed.

Plotter—Device for drawing straight lines on a nautical chart, and measuring courses, bearings, and (with some plotters) distances.

Plotting Sheet—A blank chart, usually on the Mercator projection, showing only the graticule and a compass rose. The meridians are usually unlabeled by the publisher so that these can be appropriately labeled when the chart is used in any longitude. Plotting sheets are often used in lieu of charts when the vessel is "off soundings" (in deep water).

Point—A tapering piece of land projecting into a body of water. It is generally less prominent than a cape.

Point of No Return—The point of no return is the point beyond which there is not sufficient fuel on board to return on an out-and-back journey using the entire fuel on board, including the reserve.

Point System—A nearly obsolete system of dividing a circle into 32 parts of 11 1/4 degrees each, for reference to direction.

Polyconic Projection—A map or chart projection in which the earth is projected on a series of cones concentric with the earth's axis and tangent to the sphere of the earth. Charts of the Great Lakes are typically based on the polyconic projection.

Port—The left side of a boat looking forward. A harbor.

Port Hand Mark—A buoy or beacon which is left to the port hand when proceeding in the "conventional direction of buoyage."

Position—On the earth, this refers to the actual geographic location of a vessel defined by two parameters called coordinates. Those customarily used are latitude and longitude. Position may also be expressed as a bearing and distance from an object, the position of which is known.

Position Approximate (PA)—Term used on nautical charts to denote an inexact position. This term is used principally on charts to indicate that the position of a wreck, shoal, or other obstruction has not been accurately determined or does not remain fixed.

Position Doubtful—Of uncertain position. This term is used principally on charts to indicate that a wreck, shoal, or other obstruction has been reported in various positions and not definitely determined.

Position Line—See Line of Position.

Predictable Accuracy—Term meaning the same as absolute accuracy.

Preferred Channel Mark—A lateral mark indicating a channel junction or bifurcation, or a wreck or other obstruction which, after consulting a chart, may be passed on either side.

Primary Aid to Navigation—An aid to navigation established for the purpose of making landfalls and coast-wise passages from headland to headland.

Prime Meridian—The meridian from which longitude is measured both east and west: 0° longitude. It passes through Greenwich, England, and divides the earth into Eastern and Western Hemispheres.

Privileged Vessel—Obsolete term for a vessel, which according to the applicable Navigation Rule has right-of-way (this term has been superseded by the term "stand-on").

Prohibited Area—An area shown on nautical charts within which navigation, anchoring, or other activities are prohibited except as authorized by appropriate authority.

Prolate Spheroid—Sphere flattened at the equator, resembling a football.

Promontory—High land extending into a large body of water beyond the line of the coast. Called headland when the promontory is comparatively high and has a steep face.

Protractor—An instrument for measuring angles on a surface, such as a chart. Typically a protractor is constructed of transparent plastic and has a semicircular scale measured in degrees.

Pseudorange—Range as determined from a satellite to a GPS receiver that has not been corrected for the receiver's clock error.

Pulse Repetition Frequency—Term used in radar to denote the average number of pulses per unit of time.

Q

Quarter—The sides of a boat aft of amidships.

Quartering Sea—Sea coming on a boat's quarter.

Quay—A structure of solid construction along a shore or bank which provides berthing and cargo handling facilities for ships. A similar facility of open construction is called a wharf.

Quick Light—A light with more than 50, but less than 80, flashes per minute. (Previously called quick flashing light.)

R

Race—A rapid current or a constricted channel in which such current flows.

Racon—Racons are devices placed on certain buoys or other ATONs to increase the likelihood of detection and aid identification. Racons, when triggered by pulses from a vessel's radar, will transmit a coded reply that is displayed on the vessel's PPI. This reply identifies the racon station by exhibiting a series of dots and dashes which appear on the PPI emanating radially from the racon. All racons operate in the marine radar XBand from 9,300 to 9,500 MHz. Some "frequency agile" racons also operate in the 2,900 to 3,000 MHz marine radar SBand.

Radar—Self-contained navigation and collision avoidance system consisting of a shipboard transmitter and receiver. The transmitter transmits briefly, then shuts off to permit the receiver to "listen" for the reflected transmission or echo.

Radar Bearing—A bearing obtained with radar.

Radar Fix—A position fix determined by radar alone, or by radar in conjunction with some other method for determining a LOP. Conventionally, radar fixes can be determined by a radar range and bearing from an identified radar conspicuous object, by two ranges from two such objects, or by two bearings from two such objects.

Radar Range—1. A range (distance) obtained with radar. 2. The maximum distance at which a radar unit is effective in detecting targets.

Radar Reflectors—Objects that reflect radar waves very well and which serve to increase the size or strength of the radar return. Some buoys, for example, are equipped with a radar reflector to increase the ease of detection and identification. Radar reflectors are also made to carry aboard fiberglass or wood vessels to increase the likelihood of detection by other radar-equipped vessels.

Radar Transfer Plotting Sheet—Plotting sheet similar to a maneuvering board used for plotting radar targets. This sheet is discussed in Chapter 9.

Radio Beacons—Transmitting stations used for radio direction finding.

Radio Direction Finding—Older short-range radio navigation system consisting of a series of land based stations broadcasting in the LF/MF band and onboard receivers with directional antennas. Use of the directional antenna enables relative bearings to be determined and, by simple conversion, lines of position. For practical purposes, the RDF system no longer exists in the United States.

Radio Mast—A relatively short pole or slender structure for elevating radio antennas, usually found in groups.

Radionavigation—Determining positions using radio waves of known characteristics emitted from known locations. Forms include Loran-C, GPS, and DGPS.

Radio Tower—A tall pole or structure for elevating radio antennas.

Radiobeacon—An electronic aid to navigation.

Radius of Action—The greatest distance (in an out-and-back voyage) that the vessel can travel and still leave sufficient fuel to return without drawing down the fuel reserve.

Rake—The slant of a ship's funnels, bow, or stern. The fore-and-aft slant of a vessel's mast.

Range—The distance in nautical miles that the vessel can travel with the available fuel on board. The range may or may not include an allowance for a fuel reserve. Range is a function of throttle setting and other factors discussed in Chapter 11.

Range Lights—Two lights associated to form a range, which often, but not necessarily, indicates a channel centerline. The front range light is the lower of the two, and nearer to the mariner using the range. The rear range light is higher and further from the mariner.

Range of Tide—The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water and mean low water. Where the type of tide is diurnal, the mean range is the same as the diurnal range.

Range Ring—Circular line on PPI (either fixed or variable) denoting a particular distance from the observer.

Ranges—A pair of ATONs placed a suitable distance apart, with the far daymark mounted higher than the near one. When the range marks are in line, the vessel is in the channel. Other charted objects can also establish ranges.

Rate—Generic term sometimes used to describe a Loran-C LOP. Nautical charts, for example, will identify the “rates” shown, e.g., 9960 W, 9960 X, 9960 Y, 9960 Z, 7980 W, etc.

Reach—The comparatively straight segment of a river or channel between two bends.

Real Time Method—An alternative radar plotting method, not discussed in this text, that provides a rapid means of plotting radar targets. Readers interested in radar plotting are well-advised to study this method.

Rebuilt—A fixed aid to navigation, previously destroyed, which has been restored as an aid to navigation.

Reciprocal Bearing or Course—A bearing or course that differs from the original by 180 degrees.

Reciprocal Direction—Corresponding but reversed direction.

Red Sector—A sector of the circle of visibility of a navigational light in which a red light is exhibited. Such sectors are designated by their limiting bearings, as observed at some point other than the light. Red sectors are often located such that they warn of danger to vessels.

Reef—An offshore consolidated rock hazard to navigation at a depth of 16 fathoms (30 meters) or less. Also used as a term for a low rocky or coral area—some of which is above water.

Reference Station—A tide or current station for which independent daily predictions are given in the *Tide Tables* and *Tidal Current Tables,* and from which corresponding predictions are obtained for subordinate stations by means of differences and ratios.

Regulatory Marks—A white and orange aid to navigation with no lateral significance. Used to indicate a special meaning to the mariner, such as danger, restricted operations, or exclusion area.

Relative—See Relative Direction.

Relative Direction (Bearing)— A direction relative to the fore-and-aft line of a vessel, expressed in degrees and labeled “R.”

Relative Motion Plot—Typical plot prepared on a maneuvering board to determine the point of closest approach and time of closest approach of a radar target. See Chapter 9 for details.

Relighted—An extinguished aid to navigation returned to its advertised light characteristics.

Repeatable Accuracy—Term used with the loran or GPS systems to measure the repeatability of the Lat/Lo at a fixed point. Repeatable accuracy is typically much greater than absolute accuracy for the Loran-C system, but not so for GPS.

Replaced—An aid to navigation previously off station, adrift, or missing, restored by another aid to navigation of the same type and characteristics.

Replaced (Temporarily)—An aid to navigation previously off station, adrift, or fussing, restored by another aid to navigation of different type and/or characteristic.

Reset—A floating aid to navigation previously off station, adrift, or missing, that has been returned to its assigned position (station).

Restricted Visibility—Any condition in which visibility is restricted by fog, mist, falling snow, heavy rainstorms, sandstorms, or other similar causes.

Reversing Current—A tidal current which flows alternately in approximately opposite directions with a slack water at each reversal of direction. Currents of this type usually occur in rivers and straits where the direction of flow is more or less restricted to certain channels.

Rhumb Line—A line that is formed that spirals around the globe toward the nearer pole when a direction (other than due east or due west) is specified on the surface of the earth and followed for any distance, so that each subsequent meridian is crossed at the same angle relative to the direction of the pole. Also called a loxodrome. This appears as a straight line on a Mercator chart.

Rhythmic Light—A light showing intermittently with a regular periodicity.

Right-of-way—An obsolete term. Under the 1972 COLREGS, no vessel has the "right-of-way" in a meeting situation, and each is responsible for avoiding collision.

Riprap—Stones or broken rock thrown together without order to provide a revetment.

Road—An open anchorage affording less protection than a harbor. Reefs, shoals, etc., may afford some protection. Often used in the plural, e.g., Hampton Roads.

Rock Awash—A rock that becomes exposed, or nearly so, between chart sounding datum and mean high water. In the Great Lakes, the rock awash symbol is used on charts for rocks that are awash, or nearly so, at low water datum.

Rock—1. An isolated rocky formation or single large stone, usually one constituting a danger to navigation. It may be always submerged, always uncovered, or alternately covered and uncovered by the tide. A pinnacle is a sharp pointed rock rising from the bottom. 2. The naturally occurring material that forms the firm, hard, and solid masses of the ocean floor. Also, rock is a collective term for masses of hard material generally not smaller than 256 millimeters.

Rode—An anchor line and/or chain.

Root Mean Square (RMS)—The square root of the arithmetical mean of the squares of a group of numbers.

Rotary Current—A tidal current that flows continually, with the direction of flow changing through all points of the compass during the tidal period. Rotary currents are usually found offshore where the direction of flow is not restricted by any barriers. The tendency for the rotation in direction has its origin in the Coriolis force and, unless modified by location conditions, the change is clockwise in the Northern Hemisphere and counterclockwise in the Southern.

Round of Bearings—A group of bearings observed simultaneously, or over a short period of time, such as would he used to determine a visual fix.

Rudder—A vertical plate or board, which can be pivoted to steer a boat.

Running Fix (RFIX)—A fix obtained by means of two or more LOPs taken at different times and adjusted to a common time. This practice involves advancing or retiring LOPs as discussed in Chapter 6.

Running Lights—Lights required to be shown on boats underway between sundown and sunup; indicates location and orientation of vessel.

S

Sand—Sediment consisting of small but distinguishable separate grains between 0.0625 and 2.0 millimeters (mm) in diameter. It is called very fine sand if the grains are between 0.0625 and 0.125 mm in diameter, fine sand if between 0.125 and 0.25 mm, medium sand if between 0.25 and 0.50 mm, coarse sand if between 0.50 and 1.0 mm, and very coarse sand if between 1.0 and 2.0 mm. See also Mud, Stones, or Rock.

Scalar—A scalar is a quantity that has magnitude only—in contrast to a vector, which has both quantity and direction. Velocity, for example, is a vector because, properly speaking, it has both quantity (e.g., 10 knots) and direction (e.g., 045 degrees). Throttle setting, measured in revolutions per minute, for example, is a scalar quantity because it has magnitude only.

Scope—The ratio of the length of anchor line deployed to the depth of the water, including the distance from the vessel's bow to the water—see Chapter 8.

Screw—A boat's propeller.

Sea Anchor—Any device used to reduce a boat's drift before the wind.

Sea Room—A safe distance from the shore or other hazards.

Seaman's Eye—Navigation by informal means made possible by thorough familiarity with the area of operations.

Seaworthy—A boat or a boat's gear able to meet the usual sea conditions.

Secondary Coding Delay—Interval in microseconds between the reception of a loran signal at the secondary station and the time when the secondary station transmits a signal in the loran navigation system. Secondary coding delays are published for each secondary station.

Secondary Station—One of the two to four other transmitters in the Loran-C chain (designated W, X, Y, and Z) that transmits a signal, keyed in time to that of the master, used to compute a time difference. At one time, the secondary transmitter would transmit (after an interval known as the secondary coding delay) only on receipt of the master signal. Now, the secondary transmitters maintain their own time standard, but the time of transmission relative to the master signal is designed to be the same as before.

Sector—See Light Sector.

Secure—To Make Fast.

Semidiurnal—Having a period or cycle of approximately one-half of a tidal day. The predominating type of tide throughout the world is semidiurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semidiurnal when there are two flood and two ebb periods each day.

Set—The direction towards which the current is flowing, expressed in degrees. This term is also commonly used to mean the direction towards which a vessel is being deviated from an intended course by the combined effects of external force such as wind and current.

Sextant—Device for precise measurement of horizontal or vertical angles.

Ship—A larger vessel usually thought of as being used for ocean travel. A vessel able to carry a "boat" on board.

Ship's Head Up—Type of relative motion radar display with own ship in center and instantaneous relative bearings of targets displayed.

Shoal—An offshore hazard to navigation at a depth of 16 fathoms (30 meters) or less, composed of unconsolidated material.

Shoal Water—Shallow water or water over a shoal.

Short Legs—Slang expression to denote a vessel with a limited fuel capacity in relation to its fuel consumption. Opposite: long legs.

Signal-to-Noise Ratio (SNR)—The ratio of the signal strength to that of the electronic noise of a signal. Loran coverage diagrams are calculated so that the SNR is at least 1:3, even though many receivers are capable of processing weaker signals. Signal-to-noise is sometimes expressed in decibels (dB). The SNR in decibels is mathematically equal to 20 log (SNR), so that art SNR of 1:3 works out to approximately 9.54. The higher the signal-to-noise ratio, the better the signal.

Silt—See Mud.

Siren—A sound signal, which uses electricity or compressed air to actuate either a disc or a cup-shaped rotor.

Skeleton Tower—A tower, usually of steel, constructed of heavy corner members and various horizontal and diagonal bracing members.

Skywave—Not discussed in this text, skywave is an indirect radio wave that reflects off the ionosphere, rather than traveling a direct path from transmitter to receiver. Because these waves travel a different distance (in particular a longer distance), skywaves will give an erroneous TD reading in a loran receiver. The shape of the loran pulse and phase coding are used to attempt to minimize or eliminate the effects of skywave contamination.

Skywave Delay—The time interval between the arrival of the groundwave and the various skywave reflections. Typically, skywaves can arrive as early as 35 microseconds, or as late as 1,500 microseconds after the groundwave.

Slack Water—The state of a tidal current when its speed is near zero, especially the moment when a reversing current changes direction and its speed is zero. The term is also applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation. The relation of the time of slack water to the tidal phases varies in different localities. For standing tidal waves, slack water occurs near the times of high and low water, while for progressive tidal waves, slack water occurs midway between high and low water.

Slime—Soft, fine, oozy mud or other substance of similar consistency.

Small Circle—Any plane passing through the earth, but not through its center, produces a small circle at its intersection with the earth's surface.

Solar Day—The duration of one rotation of the earth on its axis, with respect to the sun.

Sound—A relatively long arm of the sea or ocean forming a channel between an island and a mainland or connecting two larger bodies of water, as a sea and the ocean, or two parts of the same body but usually wider and more extensive than a strait. The term has been applied to many features that do not fit the accepted definition. Many are very large bodies of water, such as Mississippi Sound and Prince William Sound; others are mere saltwater ponds or small passages between islands.

Sound Signal—A device that transmits sound, intended to provide information to mariners during periods of restricted visibility and foul weather.

Sounding—A measurement of the depth of water.

South Geographic Pole—A reference for specifying a position on the earth's surface, at the south end of the earth's axis. Also called True South Pole.

South Magnetic Pole—The end of the earth's magnetic core opposite the North Magnetic Pole. (Located in Antarctica.)

Special Purpose Buoy—A buoy having no lateral significance used to indicate a special meaning to the mariner, such as one used to mark a quarantine or anchorage area.

Speed (S)—The rate at which a vessel advances relative to the water over a horizontal distance. When expressed in terms of nautical miles per hour, it is referred to as knots (kn. or kt.). One knot equals approximately 1.15 statute miles per hour.

Speed Curve—A curve relating the vessel's speed through the water to the engine's throttle setting expressed in revolutions per minute (RPM) See Chapter 5 for details.

Speed LOP—An LOP situated at approximately right angles to the intended track, so named because the EP derived from this LOP provides a good indication of the vessel's SMG.

Speed Made Good (SMG)—Indicates the overall speed actually accomplished relative to the ground along the course line.

Speed of Advance (SOA)—The speed intended to be made relative to the ground along the track line.

Speed of Relative Motion—Apparent speed of the target on a radar display, determined from the relative motion plot.

Speed Over the Ground (SOG)—The actual speed made good at any instant in time with respect to the ground along the course being steered.

Speed Through the Water (STW)—The apparent speed indicated by log-type instruments or determined by use of tachometer and speed curve or table, at a particular point in time, along the course line.

Speed-Time-Distance—A formula to calculate speed, time, or distance.

Spherical Coordinate System—The system used to define positions on the earth's surface.

Spire—A slender pointed structure extending above a building. It is seldom less than two-thirds of the entire height of the structure, and its lines are rarely broken by stages or other features. The term is not applied to a short pyramid-shaped structure rising from a tower or belfry.

Spit—A small tongue of land or a long narrow shoal (usually sand) extending from the shore into a body of water.

Spoil Area—Area used for depositing dredged materials, usually near and parallel to dredged channels. Spoil areas are shown on charts because these may present hazards to navigation for even the smallest craft.

Spring Tides or Tidal Currents—Tides of increased range or tidal currents of increased speed occurring semimonthly as the result of the moon being new or full. The spring range of tide is the average semidiurnal range occurring at the time of spring tides.

Stack—A tall smokestack or chimney. The term is used when the stack is more prominent as a landmark than accompanying buildings.

Stadimeter—An instrument for determining the distance to an object of known height by measuring the angle, at the observer, subtended by the object. The instrument is graduated directly in distance.

Stand of Tide—Sometimes called a platform tide. An interval at high or low water when there is no sensible change in the height of the tide. The water level is stationary at high and low water for only an instant, but the change in level near these times is SO slow that it is not usually perceptible.

Stand-on Vessel—That vessel which continues its course in the same direction, at the same speed, during a crossing or overtaking situation, unless a collision appears imminent. (Was formerly called "the privileged vessel.")

Standard Time—A kind of time based upon the transit of the sun over a certain specified meridian, called the time meridian, and adopted for use over a considerable area. With a few exceptions, standard time is based upon some meridian, which differs by a multiple of 15° from the meridian of Greenwich.

Standardized Color Coding (Charts)—Standardized colors used to show Loran-C lines of position on nautical charts. These color codes for the various secondaries in the loran chain are W = blue, X magenta, Y = black, and Z = green.

Standpipe—A tall cylindrical structure, in a waterworks system, the height of which is several times the diameter.

Starboard—The right side of a boat when looking forward.

Starboard Hand Mark—A buoy or beacon which is left to the starboard side when proceeding in the "conventional direction of buoyage."

Station Buoy—An unlighted buoy set near a Large Navigation Buoy or an important buoy as a reference point should the primary aid to navigation be moved from its assigned position.

Station Pointer—See Three-Arm Protractor.

Stern—The after part of the boat.

Stones—A general term for rock fragments ranging in size from 2 to 256 millimeters. An individual water-rounded stone is called a cobble if between 64 to 256 millimeters, a pebble if between 4 and 64 millimeters, and gravel if between 2 and 4 millimeters. These specialized terms of art are used on nautical charts to describe the quality of the bottom.

Stow— To put an item in its proper place.

Strait—A relatively narrow waterway, usually narrower and less extensive than a sound, connecting two larger bodies of water.

Strength of Current—Phase of tidal current in which the speed is a maximum; also the speed at this time. Beginning with slack before flood in the period of a reversing tidal current (or minimum before flood in a rotary current), the speed gradually increases to flood strength and then diminishes to slack before ebb (or minimum before ebb in a rotary current), after which the current turns in direction, the speed increases to ebb strength and then diminishes to slack before flood, completing the cycle.

Submerged Rock—A rock covered at the chart's sounding datum and considered to be potentially dangerous to navigation. See also bare rock, rock awash.

Subordinate Current Station—1. A current station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a control current station. 2. A station listed in the *Tidal Current Tables* for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station.

Subordinate Tide Station—1. A tide station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a tide station with a relatively long series of observations. 2. A station listed in the *Tide Tables* for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station.

Swells—After the deep-water waves are generated far out at sea, they move outward, away from their wind source, in ever-increasing curves, and become swells.

Swing Ship—A systematic procedure for adjusting a compass and/or developing a deviation curve for a compass aboard a vessel.

Syzygy—Alignment of earth, moons, and sun where the earth, moon, and sun are aligned, and the moon and sun are on the same side of the earth. Tides have larger ranges (termed spring tides) when this condition exists.

T

Tachometer—An instrument that indicates the speed of the engine measured in revolutions per minute (RPMs).

Tack—To come about; the lower forward corner of a sail; sailing with the wind on a given side of the boat, as starboard or port tack.

Tacking—Moving the boat's bow through the wind's eye from closehauled on one tack to closehauled on the other tack. Same as coming about.

Tank—A water tank elevated high above the ground by a tall skeletal framework. The expression "gas tank" or "oil tank" is used for the distinctive structures described by these words.

Target—Object seen on a radar screen. If the object is known, it is so identified. If not, targets are often given letter designations for plotting purposes, e.g., target alpha, bravo, charley, delta, etc.

Three-Arm Protractor—An instrument consisting essentially of a circle graduated in degrees, to which is attached one fixed arm and two arms pivoted at the center and provided with clamps so that these can be set at any angle to the fixed arm, within the limits of the instrument. It is used for finding a ship's position when the angles between three fixed and known points are measured. Also termed a station pointer.

Thwartships—At right angles to the centerline of the boat.

Tidal Current Tables—Tables that give daily predictions of the times and speeds of the tidal currents. These predictions are usually supplemented by current differences and constants through which additional predictions can be obtained for numerous other places.

Tidal Difference—Difference in time or height of a high or low water at a subordinate station and at a reference station for which predictions are given in the *Tide Tables*. The difference, when added or subtracted from the prediction at the reference station, gives the corresponding time tide height for the subordinate station.

Tide—The periodic rise and fall of the water resulting from gravitational interactions between the sun, moon, and earth. The vertical component of the particulate motion of a tidal wave.

Tide Tables—Tables which give daily predictions of the times and heights of high and low waters. These predictions are usually supplemented by tidal differences and constants through which additional predictions can be obtained for numerous other places.

Time Difference—In the loran system, the time difference (in microseconds) between the receipt of the master and secondary signals.

Time Meridian—A meridian used as a reference for time.

Time-To-Go (TTG)—Calculated time until the next waypoint is reached, obtained by dividing the distance to go by the ground speed.

Topmark—One or more relatively small objects of characteristic shape and color placed on an aid to identify its purpose.

Tower—A structure with its base on the ground and high in proportion to its base, or that part of a structure higher than the rest, but having essentially vertical sides for the greater part of its height.

Track (TR)—The intended or desired horizontal direction of travel with respect to the ground. (Synonym: Intended Track, Trackline.)

Tracking—Process of moving towards a location by adjusting the heading to compensate for prevailing current, so as to travel to the station in a straight line.

Tracking (Loran)—The process of measuring time differences from an acquired master-secondary Loran-C pair. The signal-to-noise ratio required for tracking of a pre-identified signal is generally less than that required for signal acquisition. For this reason, it is sometimes the case that a vessel that has already acquired a loran signal can continue to navigate with this signal, although an identical receiver turned on may be unable to acquire the signal.

Transducer—A device that converts one type of energy to another, as a loudspeaker that changes electrical energy into acoustical energy.

Transit—British term for range. See Range.

Trawler—A general term to describe a vessel with a displacement or semi-displacement hull designed for long distance cruising. Trawlers often resemble fishing vessels.

Trim—Fore-and-aft balance of a boat.

Tropic Currents—Tidal currents occurring semimonthly when the effect of the moon's maximum declination is greatest. At these times, the tendency of the moon to produce a diurnal inequality in the current is at a maximum.

Tropic Tides—Tides occurring semimonthly when the effect of the moon's maximum declination is greatest. At these times, there is a tendency for an increase in the diurnal range.

True North Pole—The north end of the earth's axis. Also called North Geographic Pole. The direction indicated by 000° (or 360°) on the true compass rose.

True Rose—The resulting figure when the complete 360-degree directional system is developed as a circle with each degree graduated upon it, and with the 000 indicated as true north. Also called compass rose.

True South Pole—A reference for specifying a position on the earth's surface, at the south end of the earth's axis. Also called South Geographic Pole.

True Wind—The direction from which the wind is blowing.

Turning Bearing—A bearing on a charted object, measured in advance by the navigator, at which the vessel should turn to reach the next leg of the course.

Turning Buoy—A buoy marking a turn, as in a channel.

Twin Propellers (Screws)—A boat equipped with two engines.

Type of Tide—A classification based on characteristic forms of a tide curve. Qualitatively, when the two high waters and two low waters of each tidal day are approximately equal in height, the tide is said to be semidiurnal; when there is a relatively large diurnal inequality in the high or low waters or both, it is said to be mixed; and when there is only one high water and one low water in each tidal day, it is said to be diurnal.

U

Uncorrecting (a Magnetic Direction)—Converting a true direction to an equivalent magnetic or compass direction.

Uncovered—Above water; the opposite of submerged.

Underway—A vessel not at anchor, made fast to a pier or wharf, or aground.

Unmanned Light—A light, which is operated automatically.

V

V-Bottom—A hull with the bottom section in the shape of a "V."

Vanishing Tide—In a mixed tide with very large diurnal inequality, the lower high water (or higher low water) frequently becomes indistinct (or vanishes) at time of extreme declinations. During these periods, the diurnal tide has such overriding dominance that the semidiurnal tide, although still present, cannot be readily seen on the tide curve.

Variable Range Marker—An adjustable range ring in a PPI that can be moved to measure the range of a target.

Variation—The angular difference between the magnetic meridian and the geographic meridian at a particular location.

Varsol—A liquid used in the bowl of a compass to damp the card's excessive motion and reduce response to a slower, more readable, gentle rotation and to lubricate the bearing on the pivot.

Vector—See Scalar.

Very High Frequency Radio (VHF)—Radio frequency of 30 MHz to 300 MHz. The VHF system is essentially a line-of-sight system limited in range to only a little beyond the horizon.

Vigia—A rock or shoal of uncertain position or existence. The same term is used to describe a printed warning to that effect.

Visual Aid to Navigation—An aid to navigation which transmits information through its visual observation. It may be lighted or unlighted.

Voyage Fuel—See En Route Fuel.

W

WAAS—An acronym for Wide Area Augmentation System, a system similar to DGPS that transmits correction signals from satellites, rather than a ground-based system.

Wake—Moving waves, track, or path that a boat leaves behind it when moving across the waters.

Watching Properly—An aid to navigation on its assigned position exhibiting the advertised characteristics in all respects.

Water Tower—A structure enclosing a tank or standpipe so that the presence of the tank or standpipe may not be apparent.

Waterline—A line painted on a hull which shows the point to which a boat sinks when it is properly trimmed.

Wave Height—The vertical distance between the crest and the trough of a wave.

Wave Length—The distance between consecutive crests of a wave.

Wave Shape—The height and length of the wave as it travels.

Way—Movement of a vessel through the water such as headway, sternway, or leeway.

Waypoint—Arbitrary geographic point entered into a navigation receiver (GPS or Loran-C) as a reference point for navigational calculations. Typically, voyages are organized into a series of waypoints marking the legs of the trip.

Waypoint Sequencing (Route Option)—A feature incorporated into many navigation receivers that allows an operator to store a sequence of waypoints in the navigation receiver's memory to describe a route. In this mode, whenever the vessel arrives at a waypoint, the next waypoint in a prestored route sequence automatically appears on the display screen.

Weighing Anchor—Raising the anchor when preparing to get underway.

Wharf—A man-made structure bounding the edge of a dock and built along or at an angle to the shoreline, used for loading, unloading, or tying up vessels.

Wheel—A circular frame with an axle attached to the rudder of a vessel used for steering. Also, a slang expression for a propeller.

Whistle—A wave-actuated sound signal on a buoy, which produces sound by emitting compressed air through a circumferential slot into a cylindrical bell chamber.

Windward—Toward the direction from which the wind is coming.

Winter Light—A light which is maintained during those winter months when the regular light is extinguished; it is of lower candlepower than the regular light but usually of the same characteristic.

Winter Marker—An unlighted buoy without sound signal, used to replace a conventional buoy when that aid to navigation is endangered by ice.

Withdrawn—The discontinuance of a floating aid to navigation during severe ice conditions or for the winter season.

Wreck—The ruined remains of a vessel which has been rendered useless, usually by violent action, as by the action of the sea and weather on a stranded or sunken vessel. In hydrography, the term is limited to a wrecked vessel, either submerged or visible, which is attached to or foul of the bottom or cast up on the shore.

Wreck Buoy—A buoy marking the position of a wreck. It is usually placed on the seaward or channel side of the wreck and as near to the wreck as conditions will permit. To avoid confusion in some situations, two buoys may be used to mark the wreck. The possibility of the wreck having shifted position due to sea action between the times the buoy was established and later checked or serviced should not be overlooked. Also called wreck-marking buoy.

Y

Yaw—To swing off course, as when due to the impact of a following or quartering sea.

Z

Zeroing In—Approaching a point or object by use of successive approximations such as in tacking.

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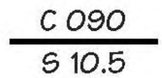
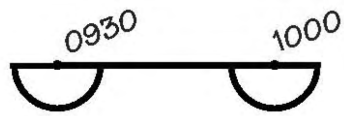
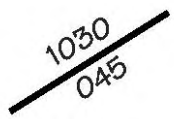
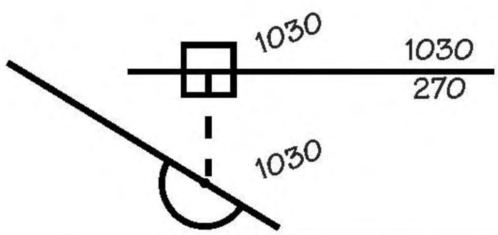
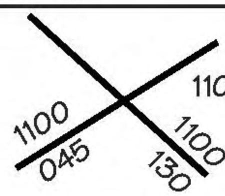
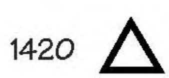
ITEM	DIAGRAM	DESCRIPTION
DR plot		Course (090 true) written above line, speed (10.5 knots) written below line.
DR position		Time (24 hour) written at angle to semicircle denoting DR positiion.
LOP		Lightly drawn line with time (24 hour) above LOP and true bearing beneath.
Estimated Position		Square located where dashed perpendicular line from DR position touches LOP.
Visual Fix		Circle where two or more LOPs cross. Time written parallel to chart axis.
Electronic Fix		Time and method (if relevant).
Running Fix		Circle with time written horizontally and abbreviation R FIX.
Known Position		Triangle with time written alongside.

A concise summary of Navigation Drafting symbols.