UNITED STATES COAST GUARD AUXILIARY
NAVIGATION SPECIALTY COURSE

AUXNAV

Student Text and Study Guide

FOREWORD: The USCG Auxiliary Navigation Specialty Course is divided into two distinct and separate, yet interdependent, parts. The first part, AUXNAV A, is the general knowledge, or theoretical, part. The second, AUXNAV B, is the practical, or application, part. The first involves almost no chart work; the second is totally chart work. The first part does involve plotting with maneuvering boards and serves the dual purpose of providing practice in the use of the boards as well as training in the use of polar coordinates to determine location. AUXNAV A is a prerequisite for AUXNAV B, and both must be successfully completed for a member to be designated a Navigation Specialist.

This course provides you extensive training in one of the most important skills of a mariner, the ability to determine where you are, where you want to go, and how to move from the one to the other. Upon successful completion of both parts you should be able to navigate a small vessel in coastal waters with accuracy and confidence. If you are a qualified instructor you will be able to pass this important knowledge on to the general public through Basic and Advanced Coastal Navigation courses.

This text and study guide has relied heavily on the following references, texts which are considered classics in navigation: Dutton's Navigation and Piloting, Fourteenth Edition, by Elbert S. Maloney, Naval Institute Press, Annapolis, MD, 1985 [1]; American Practical Navigator, subtitled "An Epitome of Navigation", Volume 1, originally by Nathaniel Bowditch, Defense Mapping Agency Hydrographic/ Topographic Center, 1995 [2] ; and Piloting and Dead Reckoning, Third Edition, by H. H. Shufeldt, Capt., USNR (Ret), and G. D. Dunlap, Naval Institute Press, 1991. [3] Other books and publications referenced in the development of this text are cited in footnotes, as appropriate.

The AUXNAV Student Text and Study Guide is divided into chapters roughly equating to two-hour lessons. This is a function of basic knowledge that the Auxiliarist is expected to have when he or she comes to the course and of the attempt to relate the text to classroom presentation. Chapter 1 provides an introduction to

[1] Identified in following text as "Dutton's"
[2] Identified in following text as "Bowditch"
[3] Identified in following text as "Shufeldt"

the earth and coordinate systems, chart basics, and position, distance, and direction. It touches on Aids to Navigation, a subject with which you should be familiar as a Basically Qualified Auxiliarist. (Chapter 12 provides a basic review for those whose training in this important area was long ago and who need or could use an update or refresher). Chapter 2 treats the compass and navigators' tools. Chapter 3 covers dead reckoning, the basic skill of navigation. Chapters 4 and 5 will deal with elementary and more complex piloting. Chapter 6 acquaints you with the various aspects of current sailing. Chapter 7 treats tides while Chapter 8 covers currents. Even though closely related, experience has shown that the entire subject of tides and currents cannot be covered properly in one two-hour class. Chapter 9 covers electronic navigation. Although included in this chapter, the Radio Direction Finder (RDF) is de-emphasized while LORAN and Global Positioning System (GPS) are highlighted. Chapter 10 covers radar navigation and relative motion (collision avoidance). Chapter 11 picks up general information of value not covered in the first ten chapters. Chapter 12 contains Aids to Navigation information. It is added to provide a refresher for those who have forgotten much of what they've learned concerning ATONs and as a handy reference. The Chapter need not be taught in classroom presentations of AUXNAV A; there are no student questions or problems in the chapter. It is added information and a refresher, only.

Annex I is the continuous cruise problem that constitutes AUXNAV B. This problem is worked on the standard training chart, 1210 Tr, and uses the table extracts in Appendix A. The cruise problem contains at least one of every type of problem in the AUXNAV B examination. Unlike the exam, which does not contain any problems that depend on correct answers to previous problems, the cruise problem in this text contains interdependent situations and questions. That is because real world piloting consists of sequential situations that depend on what went before. The cruise problem does contain periodic given fixes that begin a new, independent series of problems. It is also divided into legs, roughly equating to two-hour instructional blocks.

Appendix A to this text and study guide provides extracts of tables from Tide Tables. 1994, and Tidal Current Tables, 1994, both published by the National Oceanic and Atmospheric Administration. It also contains a speed curve, deviation table, and Napier diagram for the USCG Auxiliary Facility Helena, call sign 46143. The tables are all identified as they are in the Tide Tables and Tidal Current Tables; consequently, there are two Tables 1, etc. They could have been numbered sequentially; that is, Tidal Current Table 1 could have been called Table 6. That might have been easier for the students, but it doesn't help when using the actual tables, which after all, is the purpose of the drill. Appendix B provides answers to the questions and problems posed at the end of each chapter, including paragraph references to where the answers are found in the textual material. It also provides solutions to all of the problems. Students are cautioned to do their best to solve the

problems without reference to the solutions, saving them to check your work. Appendix C has extra problems and Appendix D contains enough extra copies of the worksheets developed for this course to work all of the exercises in both NAV A and NAV B that require worksheets.

The Navigation Specialty Course is the most extensive and most demanding of the seven specialty courses leading to designation as an Auxiliary Operational Member, an AUXOP. It is not difficult; it does require time and it requires care. Comfort comes with practice and experience. AUXNAV A will provide you with the theoretical knowledge necessary to take advantage of the practice that AUXNAV B will provide you. It is a start. Take advantage of every opportunity to gain experience while on the water.

DEPARTMENT OF TRAINING
Advanced StudiesDivision
Navigation Branch

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CHAPTER 1
INTRODUCTION AND BASICS

1. Chapter 1

1.1. BACKGROUND. The art of navigation embraces two basic concepts and four basic disciplines. The concepts are location and direction. The disciplines are dead reckoning, piloting, celestial navigation, and electronic navigation.

1.1.1. A Fanciful History... Navigation was born when some man, at the dawn of history, went from where he was to somewhere else, and back again. Marine navigation was born when another man decided he could travel easier and faster astride a log floating down a river. He soon found that he could hollow out the log and ride inside and by adding a means of propulsion, a form of sail or a paddle, and a means of steering, he introduced a modicum of control. As he went further afield, he found that he could find his way back to his starting point by noting objects on shore or fixed in the water and referring to them on the return journey. Thus came into being what we now call piloting.

Time passed, boats improved. The ancients, whether in pursuit of food, or through a desire to interact with their own kind, or to enrich themselves by giving to others some things of their own in order to obtain some of what the others had, wanted to travel further from home. This sometimes required passages out of sight of land and landmarks which, in turn, required development of a means of finding both the destination and the way home. On land it was easy. “Go to the tree that was split by lightning and look to the left. You’ll see a big rock that looks like a face; go to it and look for ....” and so on and on. But at sea, out of sight of land and its landmarks, there were no split trees and big rocks and.... Somewhere in this evolutionary process the lodestone was discovered, with its magnetic properties that led to the first primitive compasses. Without some means of establishing a reference when out-of-sight of visual references, the determination of direction would have been impossible and so would such voyages. With compasses the means was provided. The concept of direction became reality and dead reckoning was born.

More time passed. The relationships of heavenly bodies to each other and to the earth became apparent and a means of measuring the relationships and their changes, the astrolabe (which allowed measurement of altitude), brought about celestial navigation which allowed longer voyages out of sight of land and led to the age of exploration. In its infancy, celestial navigation could determine latitude with fair

accuracy, but longitude required the application of dead reckoning. It took the development of an accurate means of measuring time, the chronometer, to achieve a method of measuring longitude. With this advance, the precise position of ships at sea, far out of sight of land, could be determined.

1.1.2. To the Present. Now we have electronic navigation. The most obvious forms are GPS, the Global Positioning System, and LORAN, LOng RAnge Navigation, both of which will be discussed in greater detail in Chapter 9.

1.2. CONCEPTS:

1.2.1. Location. Location is where you are or where you want to be. It is determined through addresses called coordinates. Every place on earth can be defined by one form of coordinates or another. The most commonly used in navigation are rectangular in form and are called geographic coordinates, further defined as latitude and longitude. Another increasingly common form is hyperbolic coordinates generated as radio signals and measured as time differences between electronic pulses from pairs of master and secondary stations. A third form is known as polar coordinates and is generally defined by angular measure (degrees from an origin - direction) and distance. Location can be determined in many ways, but it is expressed in one of these three ways.

1.2.2. Direction. Direction is the concept which allows navigators to go from where they are to where they want to be.

1.3. DISCIPLINES:

1.3.1. Dead Reckoning. Dead reckoning is the determination of position by course and distance from a last known position without regard for current or other external influences. It is arguably the most basic discipline, yet without it, none of the other disciplines would be possible.

1.3.2. Piloting. Piloting is navigation by reference to known, charted, visible objects. It is used in coastal waters where charted objects are almost universally located. The objects used can be on shore or in the water. They can be stationary or floating, such as aids to navigation; however, the use of floating aids is discouraged because they can move, thereby going off station.

1.3.3. Celestial Navigation. Celestial navigation relies on references to celestial bodies. It is an advanced navigation, used primarily in open waters, and is beyond the scope of this course.

1.3.4. Electronic (Radio) Navigation. Electronic navigation uses radio signals to determine position. It requires special receivers aboard the vessel to pick up the signals transmitted by land or space based transmitters. This course will touch on some forms of electronic (or radio) navigation.

1.3.5. Non Disciplines. Contrary to expectation, RADAR is not electronic navigation. It is actually a sophisticated form of piloting. The RADAR detects, and displays on its screen, known, charted, visible objects. It is the electronic representation of the object, and bearings and distances to it as shown by the screen, that is used for navigation.

Inertial navigation, the devices used by trans-oceanic airplanes and by submerged submarines, is super-sophisticated dead reckoning. Inertial navigation projects present positions by direction and distance from a last known position, using a very complex arrangement of gyroscopes. These devices can measure minute changes in direction and speed and can track the progress of the vessel.

1.4. THE EARTH: The earth is not a perfect sphere (even allowing for mountains and oceanic deeps); it is an oblate spheroid, a form of ellipsoid. That is, its circumference at the equator is greater and it is somewhat flattened at the poles. The equatorial diameter is slightly more than 23 miles greater than the polar diameter. The earth rotates about its axis from west to east and the ends of the axis where it comes into contact with the surface, were it a metal rod, are what we call the north and south poles.

1.5. CIRCLES: The whole system of navigation is based on two types of circles on the earth's surface, named simply great circles and small circles.

1.5.1. Great Circles. A great circle is one whose plane passes through the center of the earth. Great circles can be vertical (the plane passes through the axis with all such circles converging at the poles, horizontal (passing through the earth's center perpendicular to the axis) defining the equator , and diagonal. All three types figure prominently in navigation. The vertical and horizontal circles are obvious, they define the *meridians of longitude* (see Figure 1-1)[4] and the *equator* (Figure 1-2)[5] , respectively. A diagonal great circle can be passed through any two points on the earth's surface and the short arc represents the shortest distance between those points.

1.5.2. Small Circles. Small circles are ones whose plane does not pass through the center of the earth. The only type of small circle applicable to navigation is one whose plane is parallel to the plane of the equator. These circles form the *parallels of latitude*.

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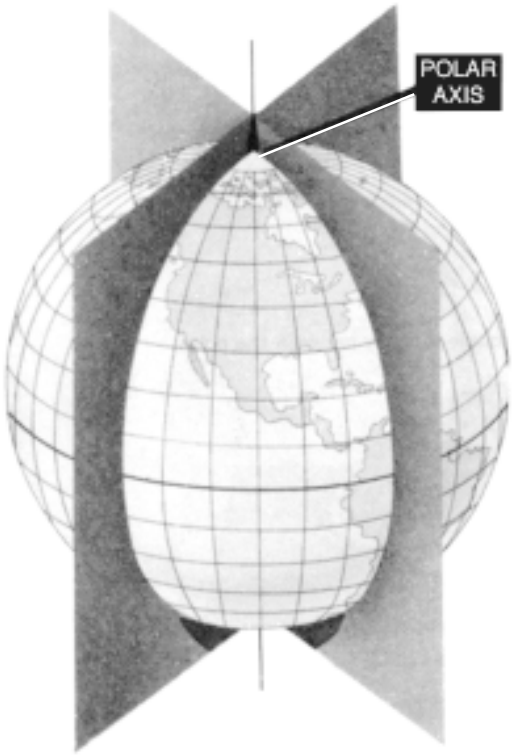
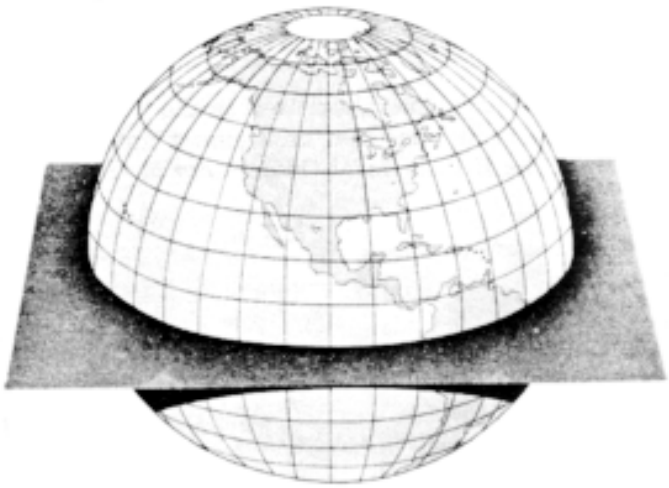
[4] Bowditch, Fig. 104a, p. 4

[5] Bowditch, Fig. 104b, p. 4



Planes of Meridians Meet at Poles
Figure 1-1

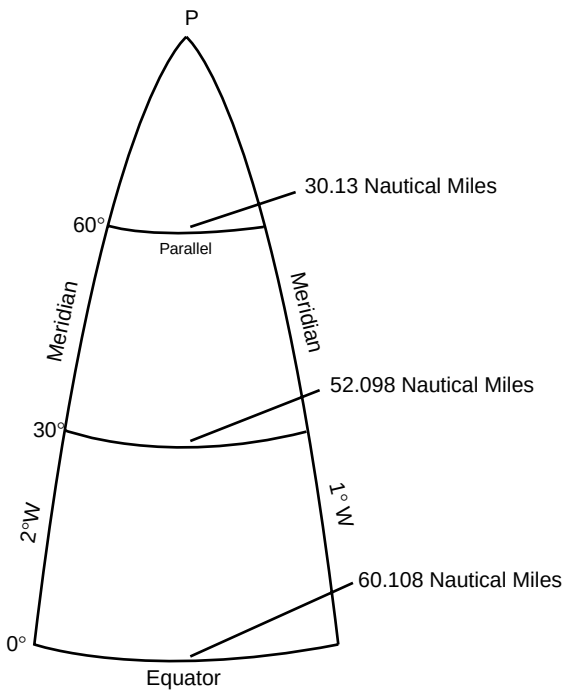


Equator is Horizontal Great Circle
Figure 1-2

1.6. SYSTEM OF GEOGRAPHIC COORDINATES: Every spot on earth lies on a meridian of longitude and a parallel of latitude. The combination of latitude and longitude makes up the geographic coordinate system of location and the precise location of any spot on earth is marked by identifying upon which meridian and which parallel it lies. It should be noted that geographic coordinates are a grid system of location. This is apparent when using a Mercator Projection chart wherein the parallels and the meridians form a rectangular grid. In this type of system, the grid is defined by the corner from which both sets of coordinates increase. That is, a location of 37°N, 76°W, actually defines the area from 37° to 38°N and from 76° to 77°W, an approximately 3000 square mile area (a degree of longitude at 37°N or S of the Equator is about 50 miles long). The area defined runs north from the entrance of the Chesapeake Bay to the mouth of the Potomac River and west from Cape Charles on Virginia's Eastern Shore to just east of Richmond. Similarly, a location of 37° 11' N, 76° 28' W, actually defines an approximately 0.8 square mile area of York County, Virginia, from 37° 11' to 37° 12'N and from 76° 28' to 76° 29'W.

1.6.1. Latitude (L). Latitude is the angular measurement north or south of the equator with the vertex of the angle at the point where the equatorial plane intersects the polar axis; i.e., the center of the earth. The angular measurement is identified as

degrees and minutes (including decimal fractions of minutes). Seconds are sometimes used instead of tenths or hundredths of minutes, but are much less common because of the necessity to convert the seconds to decimal fractions of minutes in calculations. Latitude has an interesting and very important characteristic: one minute of latitude equals one nautical mile, 6076 feet. Latitude can be used as a distance measure. For estimating purposes one nautical mile is considered to be 2000 yards. This is not precise; hence, "for estimating purposes."

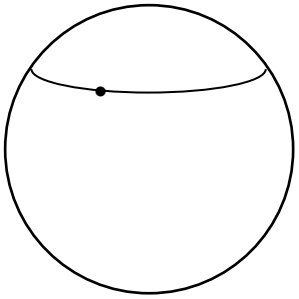


Length of a Degree of Longitude
Figure 1-3

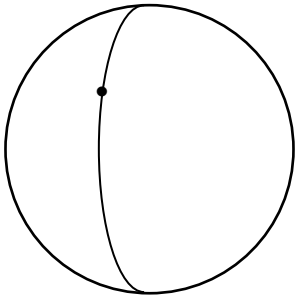
1.6.2. Longitude (λ or Lo). Longitude is the angular measurement east or west of the Prime Meridian with the vertex of the angle where the planes of the meridians intersect at the polar axis. The longitudinal measurement is expressed in the same terms as the latitudinal measurement. The Prime Meridian is the upper branch of the meridian passing through Greenwich, England. It is labeled 0°. Since a meridian is the circle superimposed on the earth's surface by the plane passing through the polar axis and longitude is measured east or west from the Prime Meridian it is easy to see that vast confusion would exist unless we consider that the meridian has a front side and a back side which are 180° apart and are so labeled. The front side from the navigator's perspective is the side on the same side of the earth as he or she. It is called the upper branch of the meridian and that part of the circle on the back side of the earth from the navigator is called the lower branch. Thus, the meridian whose upper branch is 15° west (15°W) of the prime meridian is the same meridian as the one labeled 165°E . Unlike latitude, longitude cannot be used as a distance measure, even at the equator where there is a bulge, because the meridians converge towards the poles. Figure 1-3[6] shows that one degree of longitude at the Equator (0° of latitude) is 60.108 miles, decreasing to 52.098 miles at 30° of latitude, to 30.130 miles at 60° latitude, to 0 miles at the pole (90° latitude). NOTE: In this text, the word "miles" will always mean nautical miles (M). Whenever statute miles are used or discussed they will be identified as statute miles.

[6] Shufeldt, Fig. 1-5, p. 4

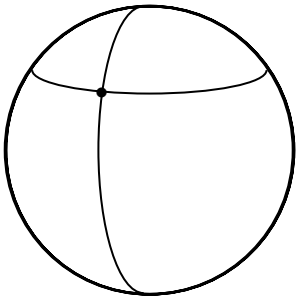
1.6.3. Addresses. The coordinates of a location are its latitude and longitude, that is, the parallel of latitude and the meridian of longitude upon which it lies. Put this in perspective. 41° 23.7’ N is a small circle, a parallel of latitude that circles the earth 2483.7 miles north of the equator. As an address it’s not very helpful because an object with that address could be anywhere on an approximately 15000 mile circle. Similarly, 71° 02.0’ W doesn’t work as an address because it locates an object as being anywhere in 10800 miles (the upper branch of the meridian identified as 71° 02.0’ W). When the two are put together, the location is pinpointed where the two parts of the address meet , where the meridian and the parallel intersect at Buzzards Light in Rhode Island Sound near the entrances to Buzzards Bay and Vineyard Sound (Figures 1-4, 1-5, and 1-6).



Parallel 43° 27.1’N
Figure 1-4



Meridian 71° 02.0’W
Figure 1-5



Address 43°27.1’N, 71° 02.2’W
Figure 1-6

1.6.4. Precision. Considering that one minute of latitude equals one nautical mile, 0.1 minute equals 607.6 feet. That means that the address for Buzzards Light as published in the Coast Guard’s Light List locates the light within a more than 280,000 square foot area (a football field is 54,000 sq. ft., so we are talking about an area the size of five plus football fields). To put this in perspective, consider a vessel in distress on a stormy day when seas are running high and visibility is limited. The skipper reports his or her position to the nearest tenth of a minute. You navigate to the area until your navigation equipment shows you to be at the same place. You may never find the target vessel even though you are at the correct location. Obviously, the more refinement in determining position, the better. Locating Buzzards Light to the nearest hundredth of a minute (41° 23.79’N, 71° 02.03’W) defines a grid square only 60.7 x 46.2 ft. at this latitude (60.7 ft. x 60.9 ft. at the equator), or the floor area of a moderate sized house. Imagine trying to locate a target from a small boat in seas like those in Figure 1-7.

Moderate Seas (Beaufort Force 5 or 6) From Bow of 30' Vessel
Figure 1-7[7]

1.7. DIRECTION. Direction is the position of one point relative to another measured as the inclination of the line passing through both points from the meridian of the first point. Meridians run north and south. The inclination is measured clockwise from true north, represented by 000°, to the line. Directions are always expressed as three digits; i.e., zero zero zero degrees for north, through zero nine zero degrees (090° — east), one eight zero degrees (180° — south), two seven zero degrees (270° — west), to three six zero degrees (360° — north, again). Lines run in both directions, consequently the direction from B to A is the *reciprocal* of the direction from A to B. If B lies 035° from A, then A lies 215° from B. The reciprocal is the reverse of the direction meant when a line is labeled with its bearing or course (see paragraph 1.7.4 for definitions of bearing and course).

1.7.1. True Direction (T). The inclination of the line through two points from the true meridian of the first point.

[7]Photo: USCG

1.7.2. Magnetic Direction (M). The inclination of the line through two points from the magnetic meridian of the first point and can be determined by applying variation to the true direction or by reading a compass not influenced by a local magnetic field (deviation). The magnetic meridian is the upper branch of the great circle through the magnetic pole. Variation and deviation are defined in paragraph 2.1.2, Chapter 2.

1.7.3. Compass Direction (C). Bearing or course determined by a compass affected by deviation.

1.7.4. Definitions

1.7.4.1. Bearing. Usually refers to the direction in which an object of interest lies from the observer as a tower on shore from a vessel, or one vessel from another.

1.7.4.2. Course (C). The intended horizontal direction of travel to get from point A to point B. It refers to what must be steered through the water to carry out the intention.

1.7.4.3. Course Line. The graphic representation of the course laid out on a chart.

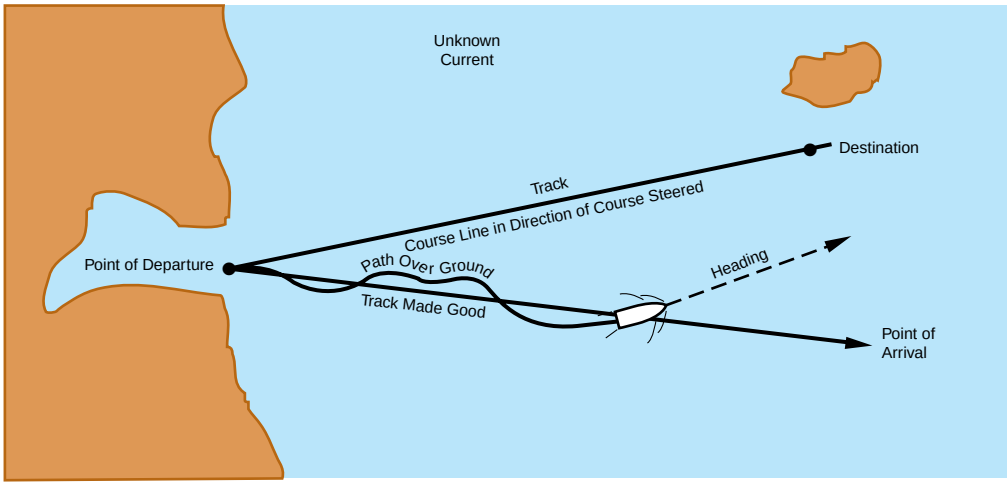
1.7.4.4. Course Made Good (CMG). The straight line direction from the start to present location, regardless of course changes or other distractions from the course that occurred in between. It can be more precisely stated as the single resultant direction from a given point of departure to a subsequent position.

1.7.4.5. Heading (Hdg). The horizontal direction the vessel is pointed at any given instant. Heading changes constantly as the vessel yaws back and forth across the course because of sea action and other external forces.

1.7.4.6. Reciprocal. The back course, the bearing from B to A when the observer is at A. The bearing ±180°.

1.7.4.7. Relative Bearing (R). The direction of an object from the vessel measured clockwise from straight ahead (over the bow). An object dead ahead of the vessel is at 000°R; one 30° to the left is at 330°R.

1.7.4.8. Track (Tr). The path over the ground a vessel intends to follow or has followed.



Directional Terms
Figure 1-8[8]

1.8. DISTANCE. Simply stated, distance is how far it is from one point to another. Because the shortest distance between two points on the surface of a sphere is the short arc of the great circle passing through both points, it is convenient that one minute of arc equals one nautical mile is the accepted international standard. Nautical miles are used exclusively in navigation except on the Great Lakes and Intracoastal Waterways, where statute miles are used.

1.9. SPEED. Knots are used exclusively in navigation except where statute miles are used. In those cases miles per hour are used. Knot means nautical miles per hour.

1.10. CHARTS. A map is a graphic representation of a portion of the earth's surface. A chart is defined as a map that shows coastlines and water features such as depth. Marine and air navigators use charts, land navigators use maps. A chart is the single most important tool used in navigating close to land, where most of the hazards lie.

1.10.1. Chart Projections. Since the earth is a sphere it is impossible to accurately represent the total earth on a single flat surface. As a result, there are various projections that accurately represent some areas while distorting others.

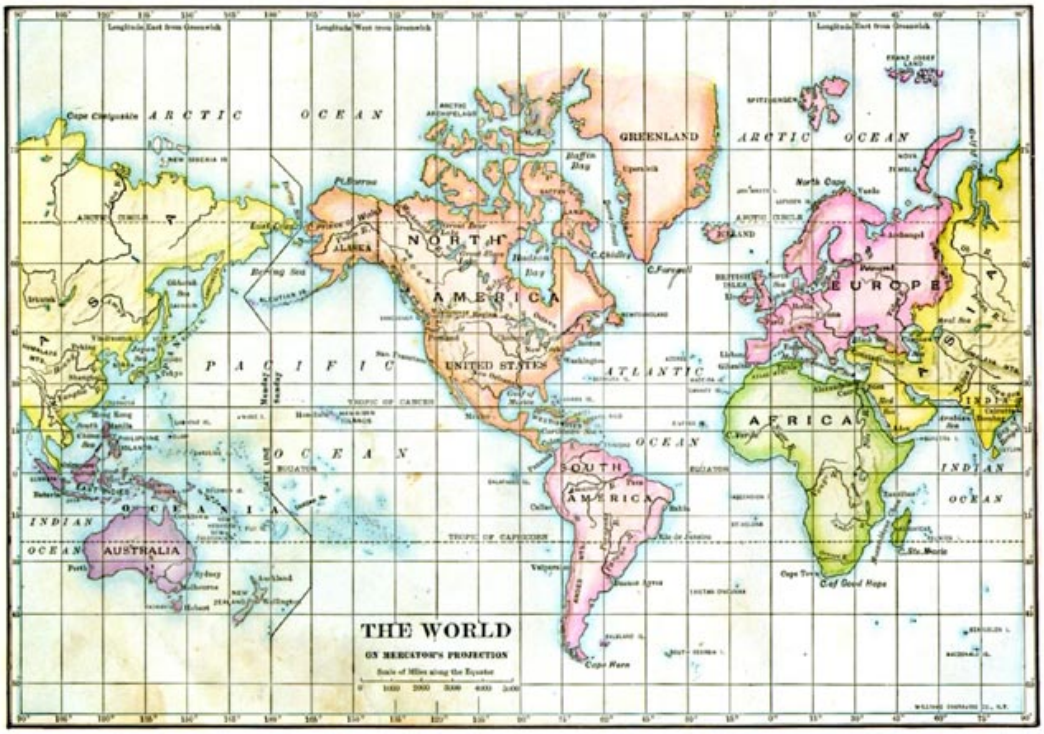
1.10.1.1. *Conformal* shows true shapes and correct angular relationships.

[8] Shufeldt, Fig. 1-7, p. 5

1.10.1.2. *Azimuthal Orthomorphic* shows area sizes in correct proportion to other area sizes.

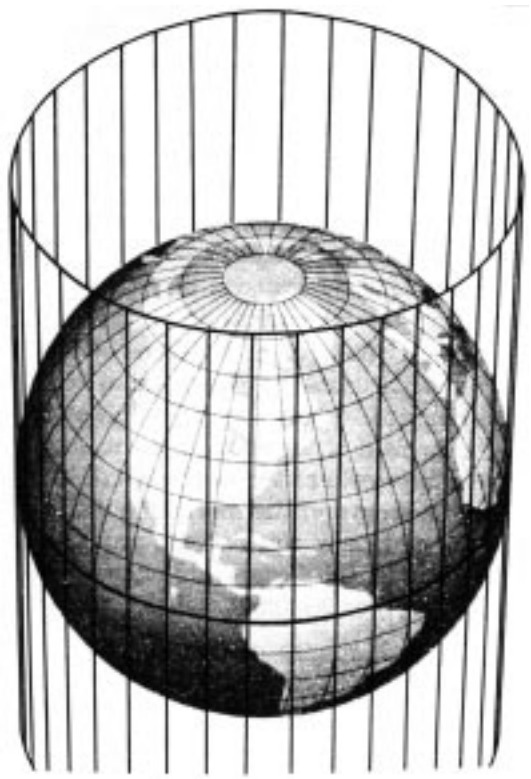
1.10.1.3. *Azimuthal Equidistant* has a constant scale throughout the chart.

1.10.1.4. *Mercator Projection* transforms the globe's image to a cylinder. Meridians project as straight lines. Since the meridians actually converge toward the poles and the chart shows them as parallel, the scale changes. Additionally, to keep balance, the distance on the chart between equidistant parallels of latitude is increased as the longitudinal distances increase. This allows the chart to show relatively accurate shape at high latitudes while grossly distorting size so that Greenland, which is one third its size, looks much larger than Australia. Figure 1-9 [9] shows a Mercator projection. Note that the meridians, which are 20° apart are shown parallel and equidistant from each other throughout their length while the parallels of latitude, which are also 20° apart, are shown at increasing distances from each other. Note also the difference in apparent size of Australia and Greenland. Figure 1-10 [10] shows the cylindrical projection that translates to the Mercator projection.

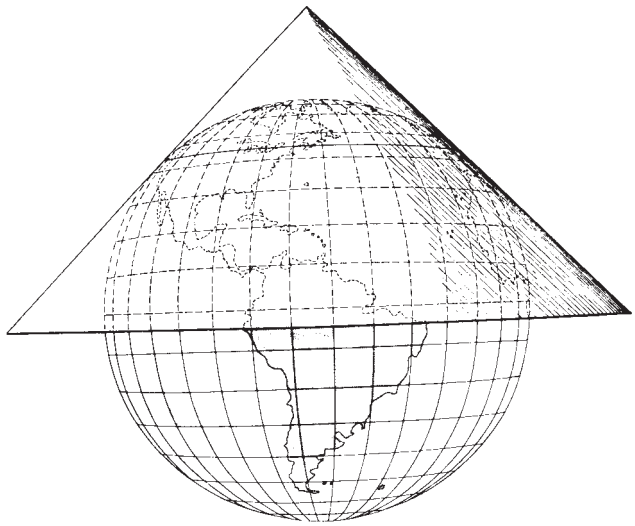


A Mercator Map of the World
Figure 1-9

[9] Bowditch, Fig. 306, p. 25
[10] Bowditch, Fig. 304, p. 24



A Cylindrical Projection
Figure 1-10



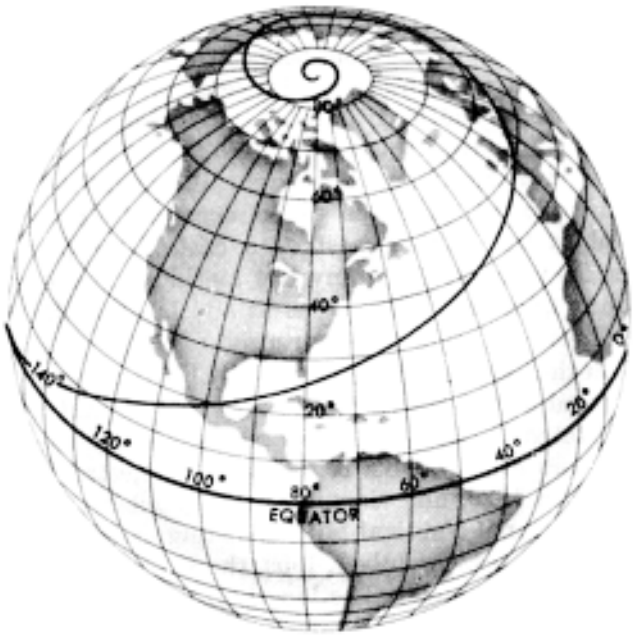
A Simple Conical Projection
Figure 1-11

1.10.1.5. *Polyconic Projection* transforms the globe's image to a series of tangent or intersecting cones. Meridians are shown as straight lines converging toward the apex of the cone. Parallels are shown as sections of circles that cross the meridians at 90°. Figure 1-11 [11] shows a simple conic projection. Polyconic charts are created from several simple projections, hence the term "polyconic."

1.10.2. Characteristics of Marine Charts.

1.10.2.1. Mercator Projection. A conformal projection because it shows true shapes and correct angular relationships; it is the preferred projection for coastal piloting in moderate latitudes. A straight line on the chart crosses each meridian at the same angle. Since the meridians converge, a line on a sphere which crossed each meridian at the same angle would actually spiral to the point where all the meridians come together, the pole. Such a line is called a *rhumb line* or *loxodrome* and is ideal for small boat navigation. A straight line laid out on the chart provides the course to steer and the track to follow.

[11] Bowditch, Fig. 312a, p. 28



Loxodrome (Rhumb Line Extended for a Long Distance on a Sphere)
Figure 1-12 [12]

1.10.2.2. Polyconic Projection. Used on the Great Lakes. A straight line on the chart crosses each meridian at a different angle and represents a great circle. This projection is preferred on small scale charts for long voyages where the great circle course is desirable (There is no great circle course, per se. The course is constantly changing).

1.10.3. Scales of Charts. Marine charts generally use a natural scale rather than the numerical scale seen on road maps. The numerical scale expresses relationships as one inch equals so many miles; the natural scale is a ratio, such as 1:80000, which means that 1 inch on the chart or map equals 80000 inches on the ground. Charts are large or small scale with no dividing line between them, which means the terms are relative. That is, if one chart is a larger scale than another, it is large scale and the other is small scale. There's an apparent dichotomy in that the scale with the larger number is the smaller scale. This is easy to understand when one considers that 1/4 (1:4) is less than 1/2 (1:2). Nautical chart scales generally range from 1:2,500 to 1:14,000,000. Charts are classified as follows:

[12] Bowditch, Fig. 106, p. 5

* Sailing Charts	1:600,000 or smaller
* General Charts	1:150,000 to 1:600,000
* Coast Charts	1:50,000 to 1:150,000
* Harbor Charts	1:50,000 or larger
* Intracoastal Waterway Charts	1:40,000

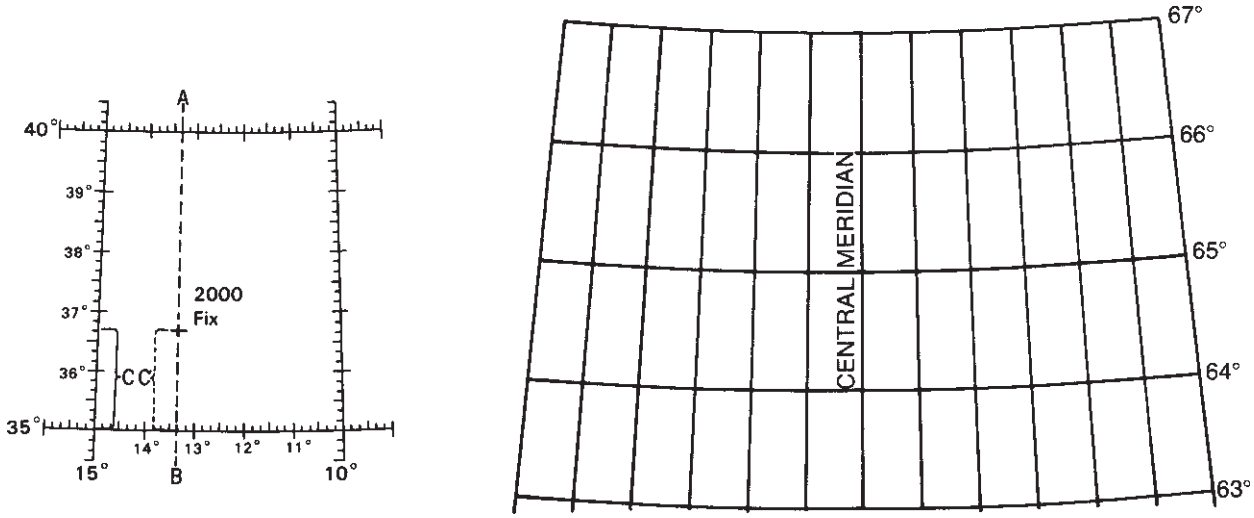
1.10.4. Position.

1.10.4.1. Determining Location on Mercator Projection. Determining the location of a fix or an object on a Mercator Chart is easy, requiring only dividers and a parallel ruler or its equivalent. For latitude, the parallel rulers are placed on the nearest parallel on the chart and walked to the fix. The latitude of the fix is ticked off on the nearest meridian. Dividers are used to transfer the tick mark to the latitude scale on either side of the chart, where the latitude of the fix is read. The dividers are then set to the distance from the meridian, using the tick mark on the meridian, to the fix which is then transferred to the longitude scale at the top or bottom of the chart, where the longitude is read.

1.10.4.2. Determining Location on Polyconic Projection. Determining location on a polyconic projection is a little different as shown in Figure 1-13. A line is drawn through the fix to equal longitude readings on the parallels immediately above and below it. Dividers are used to tick the central meridian (latitude scale) at a distance from the nearest parallel equal to the distance of the fix from the same parallel (using the line drawn through the fix).

1.11. AIDS TO NAVIGATION. The lateral system of buoyage is a subject with which every Navigation Specialist candidate should be thoroughly familiar. Regardless, Chapter 12 contains a discussion of the lateral system of bouyage, the western rivers system, the uniform state waterway marking system, and the intracoastal waterway system. Systems designed for high seas and for vessels approaching the coasts from the sea, such as light ships (none now in service), lighthouses, light towers, and large navigation buoys are covered in the following paragraphs.

1.11.1. Lightships and Lighthouses. Lightships and lighthouses are placed in locations of importance or interest to mariners such as prominent land features, entrances to harbors, and to identify and mark hazards. The lightships are mostly gone, totally so in the United States. They have been replaced by light towers and



Location on a Polyconic Chart
Figure 1-13[13]

large navigational buoys. Many of the approximately 10000 lighthouses that were once along the coasts and waterways of the United States are still in service, but almost all have been remoted; only a handful are still manned. Lighthouses were built to raise high intensity lights as high as possible to make them visible as far as possible. Lightships were located where lighthouses could not possibly or practically be built.

1.11.2. Light Towers. Light towers are large structures built at the former locations of the more important lightships. The towers consist of four legs sunk into the sea bottom upon which is mounted a structure containing the living quarters of the crew, maintenance facilities, power generation equipment, etc. The roof of the structure is a helipad and the light tower, raising a very high intensity light (around six million candlepower) to one hundred feet or more above the ocean's surface, is mounted on one corner.

[13] Shufeldt, Fig. 3-7, p. 23; Fig. 2-4, p. 12

Nantucket Light Ship
Figure 1-14[14]

Cape Henry Light House
Figure 1-15[15]

[14] Photo: USCG
[15] Photo: USCG

Ambrose Light Tower, Helicopter on the Pad
Figure 1-16[16]

1.11.3. Large Navigational Buoys (LNB). The lightships not replaced by light towers have been replaced by LNBs. These are unmanned floating buoys with a hull about 40 feet in diameter which supports a high intensity light 42 feet above the ocean's surface. They usually contain radio controlled fog signals and radio-beacon transmitters. Some can report weather conditions. They have the inherent disadvantage of all floating aids to navigation. Because they are anchored, there must be a certain amount of scope to the anchor rode; they are not precisely located as is a fixed structure. They can also be displaced by severe weather and sea conditions. Regardless, they are much less costly to build and operate than lightships or light towers. Figure 1-17 shows a LNB, indicated by the letters SF on the light tower, and the San Francisco lightship which it replaced. If the LNB needs repair or replacement, a temporary LNB, indicated by the word RELIEF on the tower, is used until the permanent one is returned.

1.11.4. Light Sectors. The lights of lighthouses and other light structures are sometimes divided into sectors of different colors. The light is usually white, but

[16] Photo: USCG

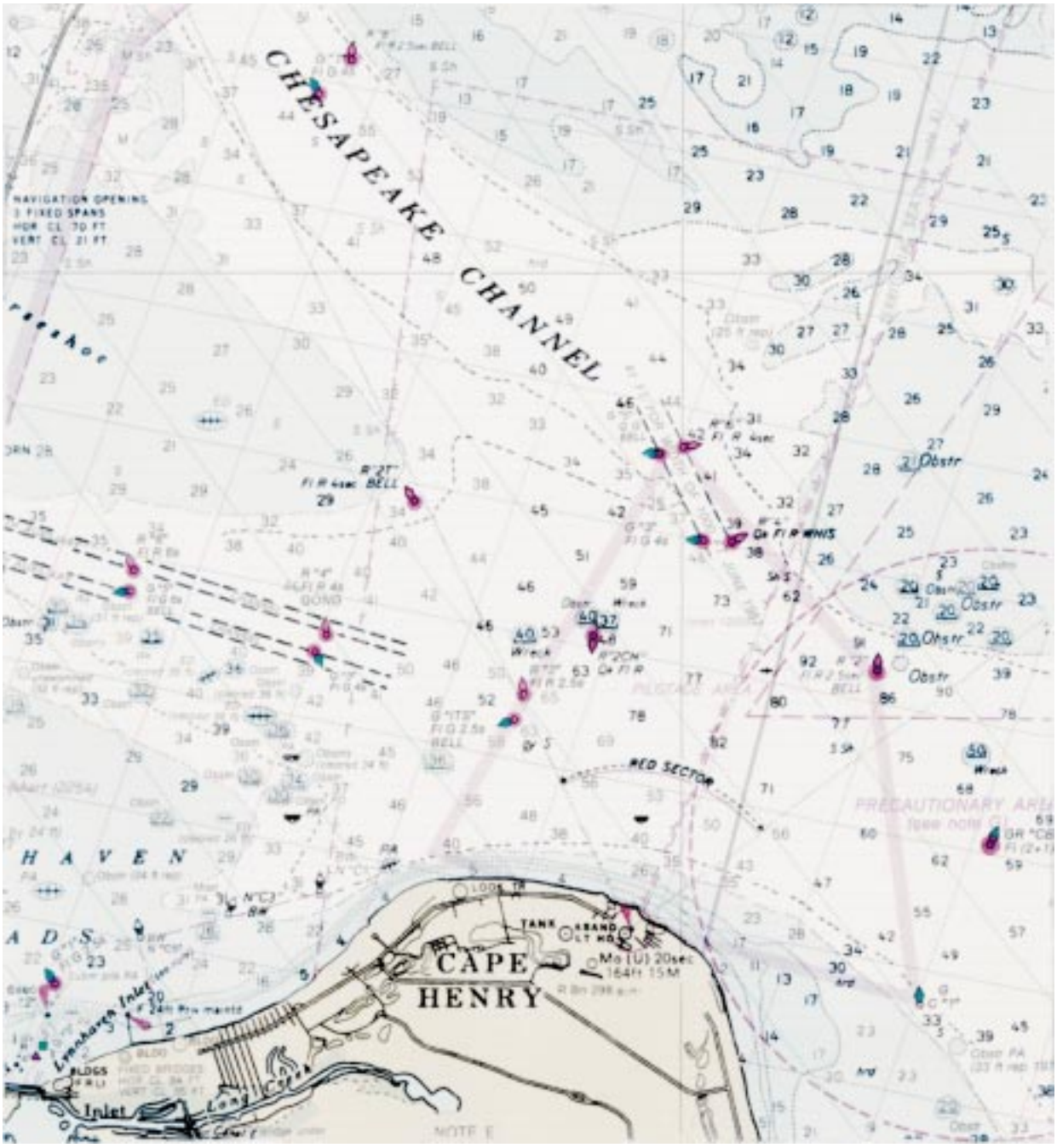
Large Navigation Beacon Replacing the San Francisco Lightship
Figure 1-17[17]

between specified bearings can appear green or red. Naturally enough the sectors mark safe (preferred) approaches or dangerous waters and can usually be interpreted when viewed in conjunction with the Light List. The Light List describes the hazard which the sector is marking and must be used in conjunction with a chart of the area. Flashing or occulting sequence does not change between sectors. Because the range at which the sector color can be seen is a function of light intensity and has nothing to do with how far the dangerous or safe area is from, or extends from the light, the message of the sector color pertains to any vessels that can observe the colored light. The skipper or the navigator of a vessel passing the light who sees a colored sector would be well-advised to immediately check his or her chart and light list to determine what the hazard is and to ensure safe passage. Following is an extract of the data for Light Number 365, Cape Henry Light:

[17] Photo: USCG

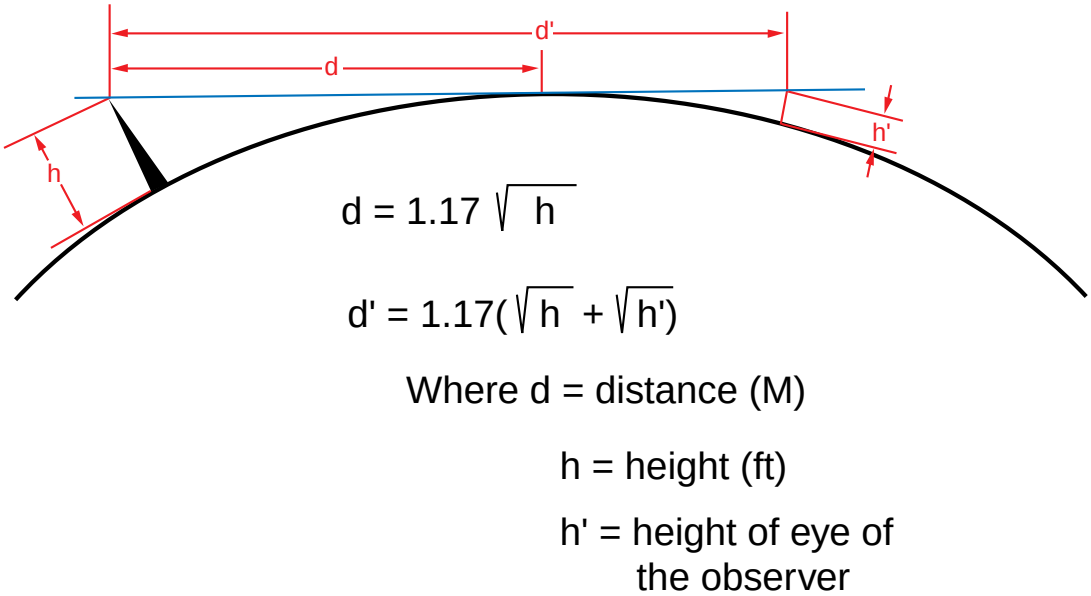
Mo (U) W 20s 164 W 17 **(R sector)** R 15 1s fl 2sec. 1s fl 2sec. 7s fl 7sec.	Octagonal pyramidal tower, upper and lower half of each face alternately black	Red from 154° to 223°, covers shoals outside Cape Charles and Middle Ground inside bay.

Below is a chart segment from Chart 12221, Chesapeake Bay Entrance, showing Cape Henry with the Red Sector highlighted. Note that the sector bearings in the light list are true bearings from a vessel to the Light.



1.11.5. Visibility of Lights. The distance at which a light can be seen is determined by the lesser of its luminous and geographic ranges. The range given on the chart and in the light list is the nominal range. It is a function of the intensity of the light (its candle power) and is the distance the light can be seen under normal atmospheric conditions (visibility of ten miles) without regard for height of eye, height of the light, or curvature of the earth. The luminous range is the distance the light can be seen under varying atmospheric conditions considering its nominal range but disregarding geographic range. Geographic range is the distance the light can be seen considering height of eye, height of the light, and curvature of the earth but disregarding intensity of the light and visibility.

1.11.6. Geographic Range



Geographic Visibility (Distance at Which an Object Can be Seen)
Figure 1-18

1.11.7. Luminous Range. The frontispiece to the Coast Guard's Light List contains a luminous range diagram which shows how far a light can be seen under various conditions of visibility shown in the International Visibility Code. Quoting from the diagram, "The nominal range given in this light list is the maximum distance a given light can be seen when the meteorological visibility is 10 nautical miles. If the existing visibility is less than 10 miles, the range at which the light can be seen will be reduced below its nominal range. And, if the visibility is greater than 10 miles, the light can be seen at greater distances. The distance at which a light may be expected to be seen in the prevailing visibility is called its luminous range."

Again quoting from the Luminous Range Diagram in the Light List, "This diagram enables the mariner to determine the approximate luminous range of a light when the nominal range and the prevailing meteorological visibility are known." The diagram is entered from the bottom border using the nominal range listed in column 6 of the Light List. The intersection of the nominal range with the appropriate visibility curve (or more often, a point between the two curves) yields, by moving horizontally to the left border, the luminous range.

Meteorological visibility, from the International Visibility Code is:

CODE	METRIC	NAUTICAL (approximate)
0	Less than 50 meters	Less than 50 yards
1	50 - 200 meters	50 - 200 yards
2	200 - 500 meters	200 - 500 yards
3	500 - 1000 meters	500 - 1000 yards
4	1 - 2 kilometers	1000 - 2000 yards
5	2 - 4 kilometers	1 - 2 nautical miles
6	4 - 10 kilometers	2 - 5.5 nautical miles
7	10 - 20 kilometers	5.5 - 11 nautical miles
8	20 - 50 kilometers	11 - 27 nautical miles
9	Greater than 50 kilometers	Greater than 27 nm

CAUTION: When using this diagram it must be remembered that:

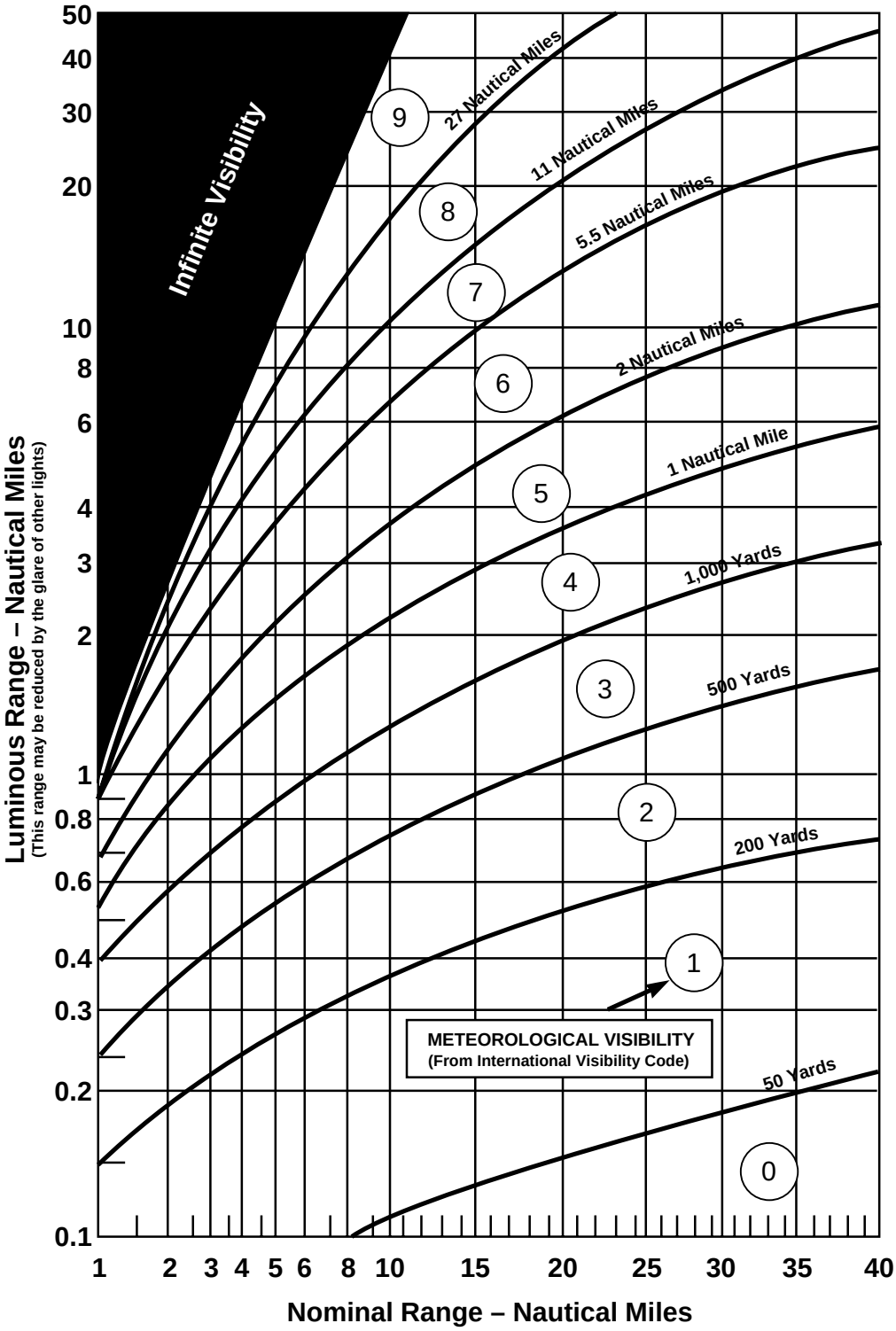
1. The ranges obtained are approximate.

2. The transparency of the atmosphere may vary between the observer and the light.

3. Glare from background lighting will considerably reduce the range at which lights are sighted.

4. The rolling motion of the mariner and/or the lighted aid to navigation may reduce the distance at which lights can be detected and identified."

Note that the nominal range can intersect a point between two visibility curves. That means that the navigator must visually interpolate. For example, if the nominal range is 17 miles and the visibility is 15 miles, the luminous range is about 20 miles. (Solution: Enter the diagram at 17 miles on the bottom scale. Go up past the 11 mile curve to a point approximating the location of a 15 mile curve between the printed 11 and 27 mile curves. From this point, go horizontally to the luminous range scale on the left margin of the diagram, intersecting it at approximately 20 miles.



Luminous Range Diagram
Figure 1-19

1-1. The two concepts that define navigation are:

a. piloting and dead reckoning
b. location and direction
c. position and distance
d. location and distance

1-2. The four disciplines comprising navigation are:

a. dead reckoning, celestial navigation, electronic navigation, piloting
b. dead reckoning, inertial navigation, piloting, celestial navigation
c. Radar, Loran, Global Positioning System, Omega
d. dead reckoning, piloting, celestial navigation, Radar

1-3. The earth is a(n) _____, flatter at the _____, with a bulge at the _____. It rotates about its axis from ____ to ____.

a. sphere, poles, equator, west, east
b. orb, equator, poles, west, east
c. oblate spheroid, poles, equator, east, west
d. oblate spheroid, poles, equator, west, east

1-4. There are two types of circles that can be drawn on the face of the earth, the _____ and the _____.

a. loxodrome, equator
b. meridian of longitude, parallel of latitude
c. great circle, small circle
d. great circle, parallel of latitude

1-5. (True/False) The great circle is produced by a plane which passes through the center of the earth.

1-6. (True/False) The only other type is the small circle, whose plane passes through the prime meridian.

1-7. These circles enable us to establish _____, which we use to label the circles used in locating objects on the earth's surface. The coordinates are called _____ and _____.

a. hyperbolic coordinates, radio signals, X and Y lines of position
b. time differences, latitude, longitude
c. geographic (rectangular) coordinates, latitude, longitude
d. polar coordinates, distance, direction

1-8. _____ (L) is defined by _____ formed by planes passed through the earth parallel to the _____ great circle which forms the _____.

a. Latitude, great circles, horizontal, equator
b. Longitude, small circles, horizontal, equator
c. Latitude, small circles, horizontal, equator
d. Latitude, small circles, vertical, Prime Meridian

1-9. _____(Lo or λ) is defined by _____ great circles which pass through the center of the earth and the _____.

a. Longitude, horizontal, equator
b. Longitude, vertical, axis
c. Longitude, vertical, Prime Meridian
d. Latitude, vertical, Prime Meridian

1-10. We speak in terms of _____ of latitude and _____ of longitude.

a. rhumb lines, loxodromes
b. parallels, meridians
c. meridians, parallels
d. nautical miles, arcs

1-11. (True/False) The Prime Meridian is the upper branch of the meridian that passes through the US Naval Observatory.

1-12. (True/False) All other meridians are labeled with their angular distance north or south of the equator, which is zero degrees.

1-13. (True/False) Latitudinal distance is expressed as the angular measurement north or south of the Equator.

1-14. One of the most useful characteristics of latitude is the fact that _____ _____ equals exactly one _____.

a. one degree, nautical mile
b. one minute, statute mile
c. one degree, statute mile
d. one minute, nautical mile

1-15. Unlike latitude, longitude may not be used as a measure of distance, even at the equator. _____ of longitude at the equator is equal to 60.108 nautical miles because of the _____ shape of the earth. The further north or south of the equator, the fewer the miles in a degree of longitude due to the _____ toward the poles.

a. one degree, spheroidal, convergence
b. one degree, spherical, convergence
c. one minute, spheroidal, convergence
d. one degree, spheroidal, divergence

1-16. _____ refers to the position (location) of one place relative to another.

a. Variation
b. Distance
c. Direction
d. Convergence

1-17. (True/False) Meridians run true north and south; therefore, angles measured clockwise from them represent true directions.

1-18. (True/False) Direction can be expressed as true, magnetic, or relative degrees.

1-19. (True/False) Course is the intended direction of travel. It is what you plan to steer.

1-20. (True/False) Course made good is the resultant (straight line) direction between the point of departure and a subsequent dead reckoning position, regardless of the course over the ground.

1-21. (True/False) Track is the path over the ground representing the path the vessel intends to follow or did follow. Course line and track are often used interchangeably.

1-22. _____ is the horizontal direction in which a vessel points at any given moment.

a. Course
b. Track
c. Bearing
d. Heading

1-23. _____ is the angular direction between North (represented by the meridian passing through the observer) and an object. If true North is used as the reference, the _____ is the true direction; if magnetic North is used, the _____ is the magnetic direction.

a. Bearing, bearing, bearing
b. Course, course, course
c. Heading, heading, heading
d. Course, heading, bearing

1-24. _____ is the angular direction between the observing vessel's heading and the object.

a. True bearing
b. Magnetic bearing
c. Compass bearing
d. Relative bearing

1-25. For estimating purposes, one nautical mile equals ____ yards.

a. 6076
b. 2000
c. 2080
d. 60.108

1-26. _____ miles are used for navigation except on the Great Lakes and inland waters where _____ miles are used.

a. Metric, English
b. Statute, nautical
c. Nautical, statute
d. English, metric

1-27. In navigation, speed is usually expressed in _____ which mean _____ _____.

a. fpf, furlongs per fortnight
b. mph, miles per hour
c. k, kilometers per hour
d. knots, nautical miles per hour

1-28. A chart which shows the _____ of features and _____ relationships is a Conformal Projection.

a. true shape, personal
b. true shape, correct angular
c. true size, correct angular
d. true size, correct directional

1-29. A chart which shows a line crossing successive meridians at a _____ angle as a _____ is a Mercator Projection.

a. constant, straight line
b. varying, straight line
c. constant, loxodrome
d. varying, loxodrome

1-30. A chart which shows a _____ as a _____ line is a Polyconic Projection.

a. loxodrome, straight
b. great circle route, straight
c. rhumb line, spiral
d. course made good, arced

1-31. A _____ is a spiral, or _____, which crosses every meridian _____.

a. rhumb line, loxodrome, at a constant angle
b. rhumb line, loxodrome, from west to east or east to west
c. great circle, helix, at a constant angle
d. small circle, helix, from west to east or east to west

1-32. A Mercator Projection is _____ because it shows true shapes and correct angular relationships. It distorts ____, particularly when treating _____ latitudes.

a. azimuthal, shape, equatorial
b. conformal, size, northern
c. conformal, size, southern
d. conformal, size, higher

1-33. A Polyconic Projection shows _____ drawn as straight lines converging toward the poles; _____ are drawn as _____ crossing each meridian at _____.

a. meridians, parallels of latitude, arcs, 90°
b. meridians, parallels of latitude, arcs, a constant angle
c. meridians, parallels of latitude, circle segments, varying angles
d. longitude, parallels of latitude, circle segments, 90°

1-34. (True/False) Light ships, marking approaches to major harbors, dangerous shoals in frequently traveled waters, and departure points for transoceanic and coastwise traffic[18] have been replaced by large navigation buoys and, for the more important approaches, by lighthouses.

1-35. (True/False) Lighthouses show a red sector, an area in which the light appears to be red, to mark waters through which a vessel should not head toward or close to the light.

1-36. The Light Lists (and charts) show the nominal range of the light, a distance the light can be seen, as a function of _____, and without regard for the curvature of the earth.

a. atmospheric conditions
b. its height above the water
c. an observer who's eye is 15 feet above the water
d. its candle power

1-37. Geographical range of the light is the distance it can be seen as a function of its _____, the _____, and the _____ without regard for its _____.

a. luminance, atmospheric conditions, curvature of the earth, height
b. height, over the horizon refraction, curvature of the earth, intensity
c. height, height of the observer, curvature of the earth, intensity
d. refraction, curvature of the earth, height of the observer, intensity

1-38. The distance at which a light can be seen, under normal conditions, is the lesser of its _____ range and its _____ range.

a. nominal, geographic
b. nominal, luminous
c. slant, horizontal
d. luminous, geographical

[18] Dutton's, p. 59

PROBLEMS (Refer to page I-3, Annex I for precision required for this course).

1-1. How far north of 27°16’N is 39°08’N? _____

1-2. How far south of 12°27.8’N is 8°12.6’S? _____

1-3. How far north of Thimble Shoal Light (37°00’54"N) is Janes Island Light (37°57’48"N)? _____

1-4. A light’s nominal range is 22M; its geographical range is 16.7M. Visibility is 10M. How far can it be seen? _____

1-5. A lights nominal range is 18M; its geographical range is 21M. Visibility is 5.5M. How far can it be seen? ____

1-6. A light is 65 feet off the ground in a light house atop a 105 foot high cliff (placing the light 170 feet above the water). The eye of an observer is at 13 feet above the water. Visibility is 19M. The nominal range of the light is 18M. How far can it be seen? _____

1-7. A vessel is heading 063° True. The relative bearing from the vessel to a tower on shore is 027°. What is the true bearing of the tower? _____

1-8. A vessel is heading 335°M. The relative bearing from the vessel to a second vessel is 000°. What is the magnetic bearing of the second vessel? _____

1-9. AT 0900 a vessel at anchor is heading 127° True. The relative bearing to a shore transmitter antenna is 197°. At 0930 the relative bearing to the transmitter antenna is 185°. What is the true heading of the vessel at 0930 (disregard change of location as the result of swinging on the anchor)? _____

1-10. A vessel lies exactly 1.0M dead ahead of an anchored vessel bearing 000° True. A second vessel lies exactly 1.0M off the starboard beam bearing 090° True. What is the true bearing of the vessel lying abeam from the one dead ahead? _____

CHAPTER 2
THE COMPASS AND OTHER NAVIGATOR'S TOOLS

2. Chapter 2

2.1. COMPASS. The compass is easily the single most important piece of equipment aboard any vessel. It's history is long; no one knows when it was first used but the Vikings were known to have used compasses in the eleventh century. No one knows where the compass was first developed. Legend has it that Marco Polo introduced the compass to the west upon his return from one of his trips to China but historians generally believe that the compass was discovered, developed, first used (choose your term) in the west. The first known compass was a magnetized needle, floated in or on a piece of straw, which aligned itself with the Earth's magnetic field. Today, a thousand years or so later, the compass, though more sophisticated and precise, consists of a floating magnetized needle which aligns itself with the Earth's magnetic field.

2.1.1. Types of Compass. There are three types of compass: magnetic, gyro, and fluxgate.

2.1.1.1. Magnetic. The magnetic compass is the most common, found on almost all vessels. It is simple, self-contained, and not easily damaged. Marine compasses differ from land compasses in that they use a circular card, with magnets attached, instead of a needle. The cards are easier to damp so the motion is steadier than the needle and easier to read on a pitching, rolling vessel.

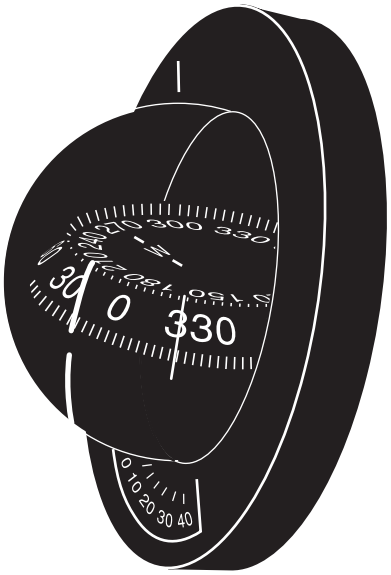
Modern marine compasses usually consist of magnets attached to a card which is pivoted within a nonmagnetic bowl covered with a transparent material and filled with a liquid such as ethyl alcohol mixed with water, which won't freeze.[19] The liquid dampens vibration, slows down oscillation, and reduces friction. The pivot is a vertical pin topped with a jewel (synthetic sapphire, for example) or a hardened alloy to reduce friction. The transparent cover may be flat or domed and contains a reference mark, called the *lubber's line,* which is used to read the compass. The lubber's line must be aligned with (parallel to) the keel.

Most compasses, whether with flat heads or spherical, are read across the card. That is, the lubber's line by which the compass is read, is at the rear of the compass (away from the operator). The compass card numbers increase to the right which is the direction the vessel turns to increase the heading. Some compasses are read from the front. These are found in aircraft, as bulkhead mounted compasses on many

[19] Chapman's Piloting, Seamanship and Small Boat Handling contains a good description of small boat compasses.

sailboats, and on some small power boats. “Read from the front” means the lubber’s line is etched on the front of the hemispherical housing (nearest the operator). On these compasses the card numbers increase to the left, opposite to the direction the vessel turns to increase headings. This can cause confusion when deciding which way to turn when changing course. Remember, right turns always increase the heading. Figure 2-2 shows such a compass. [20]

Marine Magnetic Compass
Figure 2-1



Front Read Compass
Figure 2-2[21]

[20] Courtesy of USCG
[21] Courtesy of USCG

2.1.1.2. Gyrocompass. The gyrocompass, found mostly on larger vessels (and almost never, if ever, on Auxiliary vessels) is extremely accurate but highly complex, dependent on electrical power, and subject to mechanical damage. [22]

2.1.1.3. Fluxgate Compass. The latest advance is the fluxgate compass, which is becoming more popular and is found on many small vessels, including those of the Auxiliary. It is also dependent upon electrical power, but usually batteries rather than ship's power. This compass is significantly different from the standard magnetic compass. It uses a magnetometer, a donut shaped core wrapped with wire, similar to one bank of a transformer, which converts the Earth's magnetism to electricity. Magnetometers float in liquid and are encased to cancel out deviation. They must be calibrated, a relatively simple process (at least for hand-held fluxgate compasses), wherein internal microprocessors compensate for deviation. They can also be set, again using the microprocessors, to factor in local variation so they always read true.

2.1.2. Magnetism and Magnetic Fields. Understanding of the compass is helped by an understanding of magnetism and magnetic fields. The earth is, in effect, a huge bar magnet with its North Pole at approximately 79° N, 104° W and its South Pole at approximately 65° S, 140° E. Fig. 2-3 shows the lines of force, or magnetic field, around the typical magnet. Fig. 2-4 shows these same lines of force about the earth. Due to a process called gyroscopic precession (the earth, as a rotating sphere,

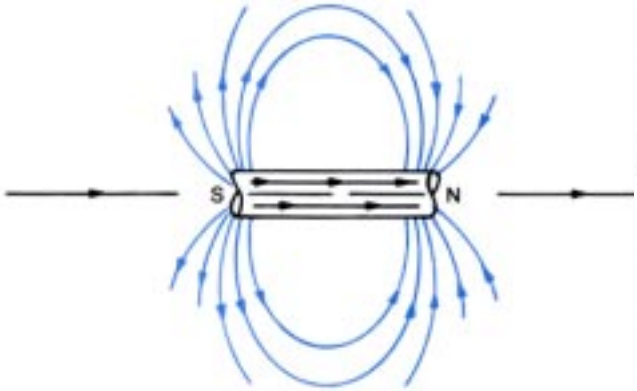


Figure 2-3
Lines of Force (Field) About a Magnet [23]

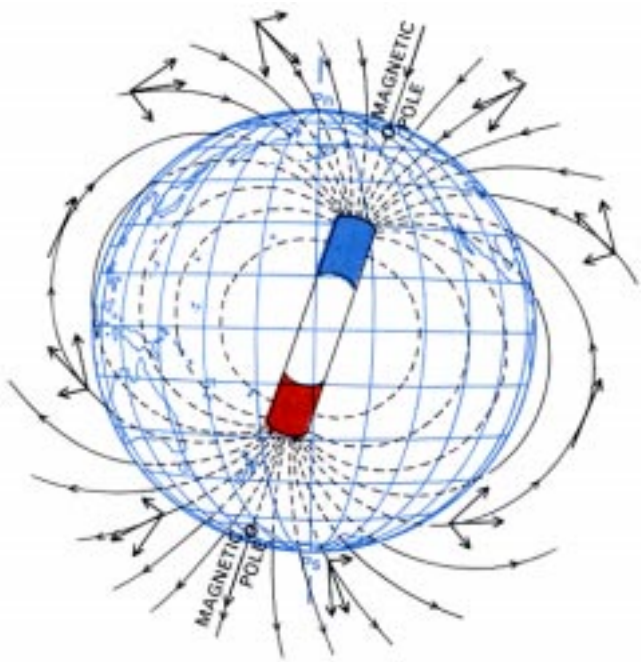


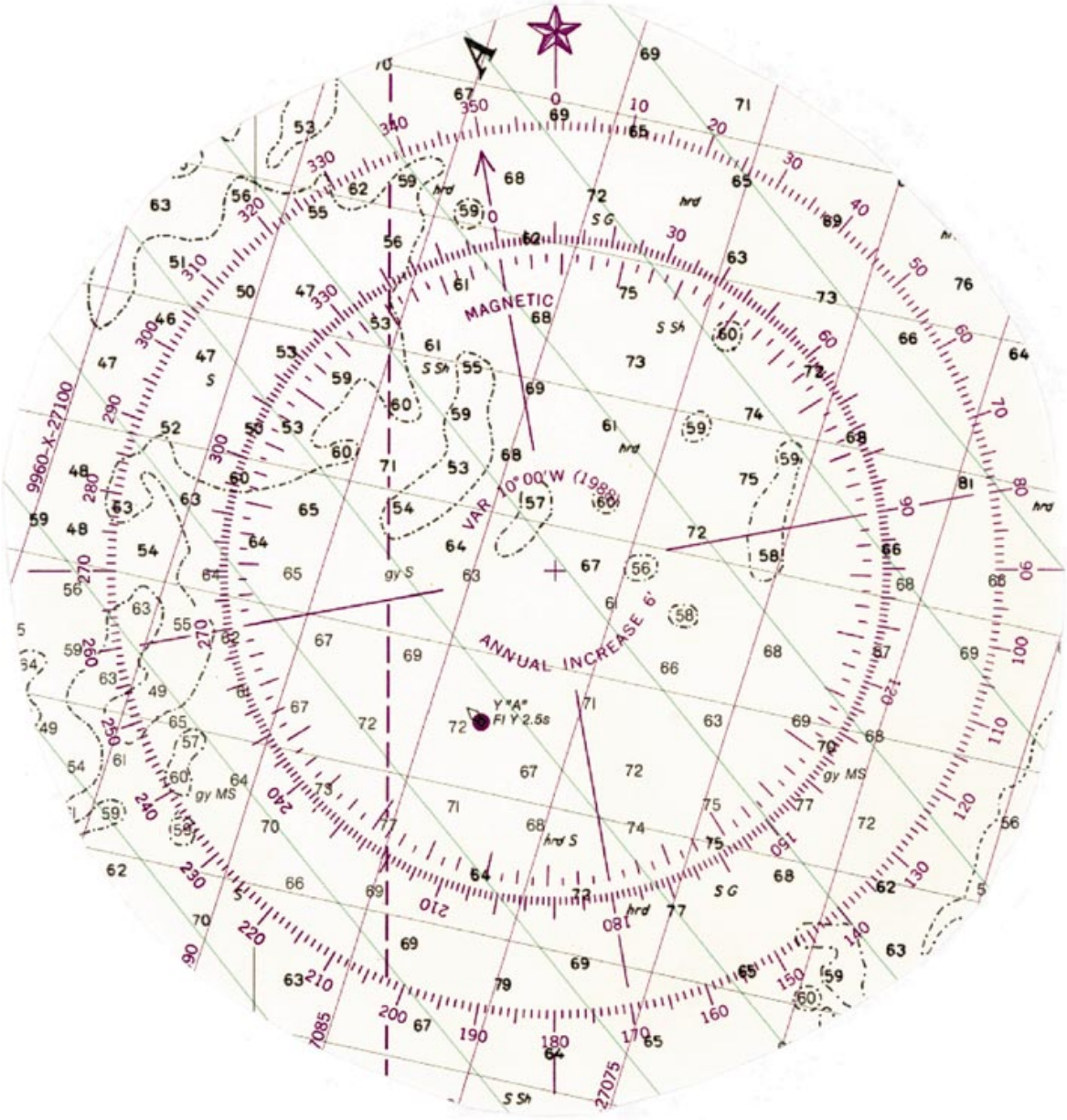
Figure 2-4
Lines of Force About the Earth [24]

[22] Dutton's, p. 14

[23] Dutton's, Fig. 302, p. 16

[24] Dutton's, Fig. 303, p. 16

is, in effect, a giant gyroscope), the magnetic poles move. The amount of movement is predictable and is shown on the inner magnetic rose of the compass roses shown on charts as “Annual Variation” (see Figure 2-5).



Compass Rose
Figure 2-5

2.1.2.1. Earth's Magnetic Field. A compass aligns itself with the earth's magnetic field. Note, in Figure 2-4, that the lines of force have only a horizontal component at the magnetic equator, but an increasingly large vertical component (dip) as the distance north or south increases. The affect of the alignment of the compass with the magnetic field is twofold. First, the compass points toward magnetic north, the desired effect. Second, the compass tends to dip as the field dips, an undesired effect which must be compensated for. There is a third component of the earth's magnetic field which must always be considered, direction. The direction of the magnetic pole varies from the geographic (true) pole as a function of the location of the observer. This directional change, or angular difference, is called *variation.*

2.1.2.2. Vessel's Magnetic Field. Every vessel has its own magnetic field which also works on the compasses aboard the vessel. This field is generated by the placement of structure and equipment. While the vessel's own field is constant, it's effect on the compass is not. The compass responds to both magnetic fields. The combined effect varies as the vessel swings. At some points the vessel's field is in alignment with the earth's field and the compass points directly to magnetic north. As the vessel turns, it's field deviates from the earth's field by varying degrees and it tends to pull the compass away from alignment with the earth's field by corresponding amounts to a position representing the resultant of the two forces (magnetic fields) working on the compass. (Figure 2-8, on page 2-10, illustrates this phenomena; an explanation of force vectors and their resultants will be found in Chapter 3). The vessel's "bar magnet" has a north and south pole, just as any other bar magnet. Consequently, as the vessel swings through 360°, the deviation of the compass from magnetic north changes from east to west or from west to east, depending on each vessel's own characteristics. This combined effect, not surprisingly, is called *deviation*; it must be compensated for.

2.1.3. Bearings. Bearings based on meridians through the poles are true bearings. Compasses measure bearings as angular differences from meridians through the magnetic poles; however, these bearings are distorted by the magnetic field of the vessel. This means that the vessel's compass shows a bearing which includes both effects, variation and deviation. We call this the compass bearing. Eliminating the effect of deviation leaves us with the magnetic bearing and eliminating the effect of variation yields the true bearing. This creates a sort of dichotomy. Our convention in navigation is to plot courses and fixes with true bearings and headings; yet we steer with compasses which provide compass headings and bearings. How do we get from one to the other?

2.1.3.1. Correcting and Uncorrecting. Determining a true direction of travel from the compass heading is called correcting. Converting from true on the plot to compass on the steering compass is called uncorrecting. We have a device called a

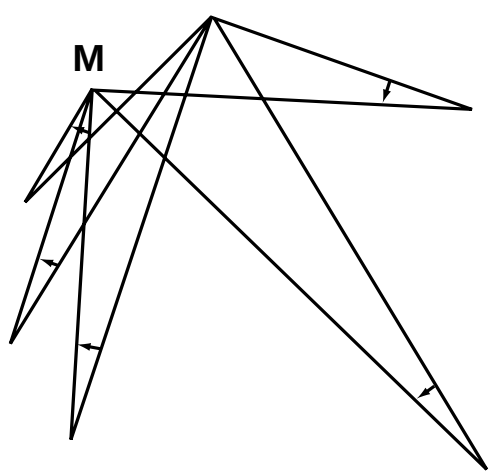
mnemonic (a saying based on the acronym) which helps us remember how to treat east and west variation and deviation: The mnemonic for uncorrecting is: **T**ele**V**ison **M**akes **D**ull **C**hildren, add **W**isdom (West). Correcting has its own mnemonic: **C**an **D**ead **M**en **V**ote **T**wice.

2.1.3.1.1. Uncorrecting. Uncorrecting, the mnemonic means that if we start with True and apply Variation, we get Magnetic, to which we apply Deviation to get Compass. When uncorrecting we add West, which, of course, means that we subtract east.

146° True	Tele	
+ 7°W Variation	Vision	
153° Magnetic	Makes	
- 4°E Deviation	Dull	
149° Compass	Children	add Wisdom (West) (subtract East)

2.1.3.1.2. Correcting. Correcting, the mnemonic says that if we start with the compass reading and take out the effect of deviation, we have a magnetic reading. If we eliminate variation the result is the true course, heading, or bearing. Since we add west when uncorrecting, we subtract it when correcting.

236° Compass	Can	
- 7°W Deviation	Dead	
229° Magnetic	Men	
+ 9°E Variation	Vote	
238° True	Twice	(subtract West) (add East)



15°W Variation
Figure 2-6

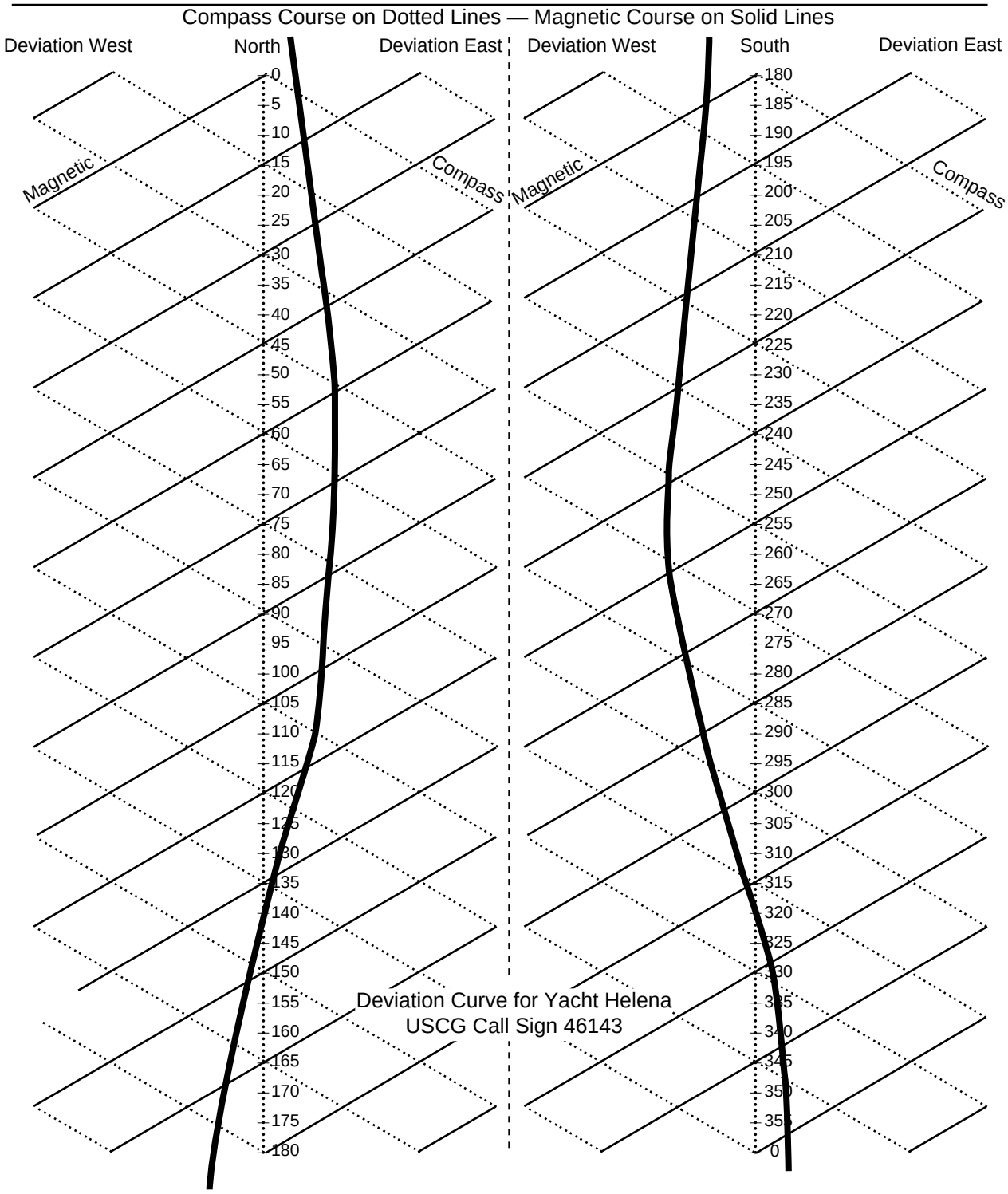
2.1.4. Compass Error. Variation is the angular difference between true north and magnetic north. It effects every compass in the same area in the same manner to the same degree of magnitude. Isogonic charts show lines of equal variation like contour lines; that is every point on a given line has the same variation. Fig 2-6 shows how the same variation, 15°W, can occur at different places. The combined effects of variation and deviation comprise compass error. Most standard navigation texts contain an isogonic chart. Compass roses printed on marine charts show the variation for the charted area and the amount of precession, the annual angular change in the variation.

On steel hulled vessels, quadrantal spheres must be used to compensate for severe athwart ship distractions of the compass. The spheres are hollow balls of steel placed on opposite sides of, and an adjustable but equal distance from the compass. Other adjustments are described in paragraph 2.1.7.

2.1.5. Compensating the Compass. A simple method of compensating the compass to take out as much deviation as possible consists of a piece of wood or sturdy cardboard and a dowel (a pencil will do). A hole for the dowel is put in the center of the board and a straight line is drawn across the board through the center. On a sunny day, around ten in the morning or two in the afternoon when a shadow can be obtained, and on a relatively calm day, take the boat out. Head due north by the compass. Place the dowel in the hole and rotate the board until the shadow of the dowel falls on the line. Turn the boat until the shadow falls on the other side of the line. You will have turned 180° (don't take too long to make the turn and steady on the reciprocal course; remember, the sun moves about one degree in four minutes). Read the compass. It almost certainly will not read 180°. Using a stainless steel or brass screwdriver on the athwartship adjusting screw, take out half of the difference between the compass reading and 180°. Turn back until the shadow falls on the other side and take out half of the difference between the compass reading and 000°. Repeat the process until you can't take out any more error. Then do the same thing for east and west. Head 090° by compass, align the shadow with the line, turn 180°, read the compass, and take out half the error with the front mounted adjusting screw.

2.1.6. Deviation Curves and Compass Cards. Napier diagrams are often used to plot a deviation curve, representing the deviation for any compass or magnetic heading. This is prepared on a complex looking form called a Curve of Deviations. It's really quite simple.

2.1.6.1. Napier Diagram. See Figure 2-7. The vertical dotted line represents the heading with a dot for each degree. The slanted cross lines represent compass and magnetic readings. The dots on the slanted compass line also represent a single degree. The first plotted point represents the deviation for a compass heading



Napier Diagram
Figure 2-7

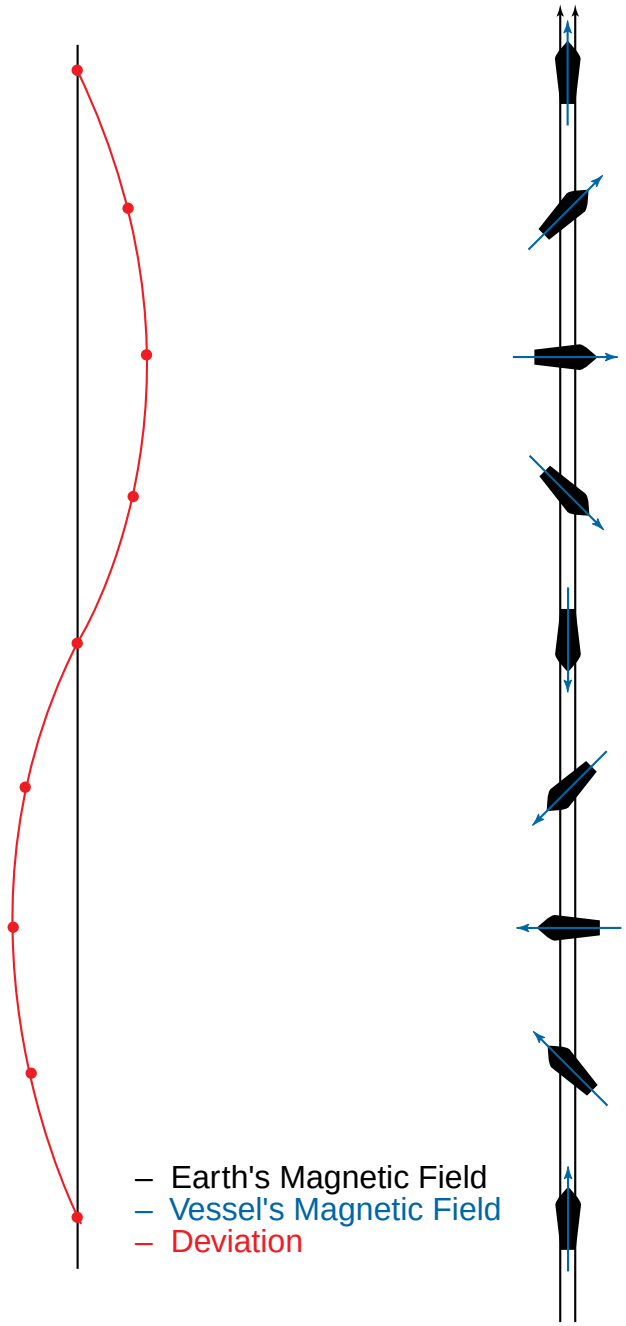
of 000° for a charted magnetic heading of 008°. If a line is constructed parallel to the solid magnetic lines and passing through the dot on the vertical line representing 008°, it will intersect the compass line passing through 000° at the 8°E deviation dot. Conversely, the magnetic heading for a compass heading of 060° with a 14°E deviation can be determined in a similar manner. On the compass line passing through course 060° on the vertical dotted line pick off 14 dots (14°) to the east. Draw a line through that dot parallel to the solid magnetic lines. It will intersect the vertical line at 074°, the magnetic course. The Napier Diagram makes it clear that deviation varies on a rather smooth curve. Figure 2-8 shows how deviation affects a compass. Note that the deviation trace in the figure replicates that of the curve of deviation of the Napier Diagram. A deviation table (compass card) is usually made up for every fifteen degrees. It should be clear that determination of deviation for compass (or magnetic) headings between the headings of the table requires interpolation. Interpolating is simply solving a ratio problem. For example, if the deviation for 045° is 5°E and the deviation for 060° is 1°E, the deviation for 050° is 4°E, determined as shown below.

$\frac{15}{5} = \frac{4}{x}$ where 15 is the difference between 045° and 060°

5 is the difference between 045° and 050°
4 is the difference between 5°E and 1°E
x is the difference between 5°E and the deviation for 050°
Solving, $15x = 20$ and $x = \frac{20}{15} = 1.3° = 1°$ (rounded).
5° (dev for 045°) - 1° (dif) = 4° (dev for 050°)

2.1.6.2. Determination of Deviation. Deviation is determined by comparing compass readings to charted magnetic references. The “deviation by ranges” method, described below, is one form of this comparison.

2.1.6.2.1. Deviation by Ranges (Running Ranges). Any two charted objects which can be lined up and run towards will work. A stationary light, surrounded by navigable water and within sight of other stationary charted objects is best. Run towards the light while aligned with one of the other objects (the familiar range). Record the compass heading. Set up another range with one of the other charted objects and run it. Record the compass heading. Continue this process with other objects and other range situations. Later, compare your recorded compass headings with the charted magnetic headings between the objects. The difference between the two is your deviation for that heading.



Deviation Trace, Alignment of Vessel and Earth Magnetic Fields
Figure 2-8

2.1.6.2.2. East or West? Is it east or west? Since you are determining a magnetic heading from a compass heading, you are correcting; therefore, you add East Deviation and subtract West. Simply put, if your compass heading is less than the magnetic heading, the deviation is East, if more, it is West. This can be easily remembered with a simple memory aid:

East is least and west is best

Remember, this refers to the compass. If its reading is less (least), deviation is East. If its reading is more (best), deviation is West.

2.1.6.2.3. Pelorus Method. Another method of determining deviation requires the use of a *pelorus,* a device often called a dumb compass, which is used to read relative bearings if the card of the pelorus is set so that 000° is dead ahead. Relative bearings, as their name implies, are relative to the heading of the vessel at the moment the bearing is taken. They are measured from dead ahead (over the bow) clockwise through 360°. To determine deviation for any compass heading, the skipper has only to determine a range from a combination of any two charted objects. He or she crosses the range and at that instant the pelorus provides the relative bearing of the range (the pelorus sights straight across both objects), the skipper determines the heading on the steering compass. Adding the relative bearing to the steering compass heading provides the compass bearing of the range. That is compared to the charted magnetic bearing as above, but remember, the deviation is applied to the compass heading, not the compass bearing. Repeat the process, crossing the range on different compass headings. As an aside, a mounted pelorus will be truly effective only if it is placed in a position where bearings can be taken through 360°. Without a pelorus, the second method of determining deviation is not possible.

A Pelorus
Figure 2-9 [25]

[25] Dutton's, Fig. 706, p. 103

2.1.6.3. Compass (Deviation) Card. Remember also, a deviation card should be made up for every fixed-in-place compass on the vessel. Insofar as possible, the card should show deviation for no less than every 15°. Every 10° would be better. If a vessel has more than one helm station, and each has its own steering compass, a deviation card should be made for each compass. This is because the compasses are in different locations; therefore, the vessels magnetic field affects each in a different manner.

2.1.6.4. Deviation and Bearings. Bearings to objects can be taken without a pelorus,. Most small boats have only a steering compass which can be sighted across only from astern looking forward. The steering compass can be used if it can be sighted across. This is imprecise because there are no sighting vanes on the steering compass. The vessel can be turned to point towards the object. This will give a fairly accurate bearing but if the navigator is trying to obtain a fix it will be inaccurate because of the time and vessel movement between observations. Deviation must always be considered when using the steering compass; however, **it is the deviation appropriate to the heading of the vessel at the moment of observation**, not the bearing of the object. The use of a hand-held compass will allow near simultaneous observations. The hand held compass, called a hand bearing compass, can be used from anywhere on the boat. For this reason, deviation is not considered (yet it is present) so precision is still less than desirable. The best solution, though somewhat expensive, is to use a hand held fluxgate compass. They can be obtained for around $100 up. Note that these must be held level to be precise.

2.1.7. Other Adjustments. In addition to compensation and determination of deviation, compasses require other adjustments to maintain accuracy. Some compasses, primarily those on larger vessels, have heeling magnets and some have a Flinder's Bar, an adjustable in length vertical soft-iron bar, in addition to the quadrantal spheres. The compass accuracy is affected by the heel of a vessel as it rolls and pitches. The heeling magnets provides a means of adjusting the compass to compensate for this effect. Flinder's Bars are intended to compensate for the vertical component, or dip, of the compass caused by the characteristics of the earth's magnetic field. Both adjustments are beyond the scope of this course. Often the compass is placed in a binnacle, a nonmagnetic stand or support that protects and holds the compass and, when so equipped, the heeling magnets and Flinder's Bar.

2.1.8. Compass Points and "Boxing the Compass". Compasses used to be divided into 32 points of 11° each. Each point has a name and can be further divided into quarter points for a total of 128. The almost lost art of boxing the compass was the ability to name all of the points. The following list "boxes" the compass through the first quadrant, from North to East:

North
North by East
North North East
North East by North
North East
North East by East
East North East
East by North
East

2.2. NAVIGATORS' TOOLS. The prudent navigator will have the best compass he or she can afford. The navigator will also have the latest charts of the areas in which he or she operates and intends to operate. The perfect navigator will combine that prudence with a meticulous, organized, even nit-picking, approach to record keeping and with deliberate and systematic observations plus an abiding interest in anything which will help him or her accurately and quickly determine where the vessel is at any given moment. Events, such as passage of buoys, encountering strong currents, sightings of charted objects, particularly when in reduced visibility, and anything else that might be of interest and help in locating the vessel should be recorded in great detail.

2.2.1. Record Keeping and Observation. If the essence of good navigation is systematic observation and detailed record keeping, it follows that the serious navigator will have aboard the devices, equipment, and tools necessary to perform those tasks. The basic means of fixing position is a good lookout and accurate timing. There must be a log, a means of recording observations and data. At the very minimum the navigator must have a notebook and pencil at the helm or navigation station. Information and data recorded in the notebook can be transferred to the formal log at a more leisurely time. Regardless of how, it must be done. A good watch and decent binoculars are a must. It's even better if the watch is a stop watch which can used to measure elapsed time between events, such as passing pairs of buoys to determine actual speed. The most desirable size of binoculars for marine work is 7 x 50. This means that they have magnification of 7 powers (they magnify objects seven times) and have an objective lens 50 mm in diameter. More magnification decreases the field of view while less increases it. Seven powers appears to be the best compromise between magnification (important to identify objects viewed) and field of view (the area seen through the binoculars). The 50 mm objective lens have excellent light gathering qualities which makes them particularly suitable for night use. [26]

[26] Dutton's, p. 116

2.2.2. Electronics. Sophisticated equipment, such as LORAN C, DGPS, and RADAR, is a real plus when it comes to accurate position location. Own it, become familiar with it, use it, but always remember that it can, and does, fail. If the failure is due to loss of power, it all goes. Never become so dependent upon the electronics that you can't navigate without it. We've all heard vessel operators say, "Why do I need to know piloting? I've got a LORAN." The prudent navigator will practice basic piloting whenever possible. If he or she determines a fix from observations, it can be checked with the LORAN or GPS.

2.2.3. Sextant. There are a multitude of navigators tools and aids on the market in a multitude of price ranges and with highly varying degrees of sophistication. The compass, stop watch, binoculars, and pelorus already mentioned are part of the list. One of the more sophisticated devices is the sextant. This precision instrument is generally thought to be a device for celestial navigation but it can be very useful in piloting as well because of the precision with which it can measure vertical and horizontal angles. It can be used in determining vertical and horizontal danger angles and to determine the distance from objects of known height (both discussed in Chapter 5).

2.2.4. Anemometers, Knotmeters and Speed Curves. An anemometer measures the combined effect of real wind and the apparent wind caused by movement of the vessel. Knotmeters and speed curves, when combined with elapsed time, are used to determine distance traveled. Small boat knotmeters, or speedometers, are notoriously inaccurate. Some are very accurate at the high end of the scale and very inaccurate at the low end. Others are just the opposite. Some are good through most of the range but fall off at the high and low ends. When using a knotmeter it's important that it be calibrated; that is, that its readings be compared to known speeds through out the range. Speed curves are described in detail in Chapter 3. They are made for individual boats and provide speed through the water under the full range of available power settings. Provided trim and loading are not grossly different from that at the times the curves were made, they are quite reliable and accurate.

2.2.5. Depth Sounders. Depth finders are a navigator's tool as well. Comparing depth finder readings with charted depths can provide that final piece of information that allows the navigator to locate himself with precision and confidence. Depth finders are a form of sonar. A signal is sent from a transducer located on the hull to the bottom and is reflected back to the transducer. The mechanism of the depth finder converts the time involved to depth. Obviously, the actual depth requires the addition of the distance below the water line of the transducer while water under the keel requires subtraction of the distance of the transducer above the keel. Because the measurement is based on reflection of a sound signal, the bottom condition affects the accuracy of the reading. A hard bottom will reflect a strong signal, clearly defined as

a sharp line on a flashing depth finder. A soft bottom will reflect a softer signal, defined as a broad, possibly wavy line on the flashing depth finder. Digital depth finders, which display only numbers, will be affected in the same way by bottom conditions, but the instrument will not display a difference between solid and soft reflections.

2.2.6. The Three Basic Devices. Plotting equipment is a must. In fact, plotting equipment is required aboard any vessel offered for use as a USCG Auxiliary operational facility. Plotting equipment consists of a means of measuring and transferring distances, a means of transferring lines to and from compass roses while maintaining their directional orientation, and a means of drawing lines and making notations. We have defined the basic tools as dividers (or draftsman's compass), parallel rulers (or some form of plotter which can maintain or measure direction of lines, and pencils (which must be accompanied by erasers).

2.2.6.1. Dividers. Dividers require sharp points and must hold settings. If too loose, settings won't transfer without changes. If too tight, the dividers will spring and precise settings can't be made. A center mounted thumb wheel is often desirable for precise settings and thumb wheel dividers generally will hold their settings. A draftsman's compass is an acceptable, sometimes a preferred substitute, particularly if the pencil point can be sharpened. This is particularly true when circles of position (described in Chapter 4) are used.

2.2.6.2. Plotters. There are many types of plotters available at varying prices which can substitute for parallel rulers. Parallel rulers require care to make sure they are not turned when walking them to or from a compass rose or course line on the chart. Some plotters have built in protractors and a fixed straight edge which are used with meridian lines on the chart to measure direction. Other plotters have moveable straight edges which can be set to desired directions while maintaining the north orientation using meridians. Others are "walked" across the chart using little wheels to roll on while maintaining directional orientation. Still other navigators prefer to use a pair of triangles to move lines parallel to themselves.

2.2.6.3. Pencils and Erasers. Pencils should be sharp. The 0.5 mm mechanical pencils work particularly well because they remain sharp enough through out, a function of the thickness of the lead. HB lead is preferred because it is soft enough that it will not tear the chart and can be seen, and hard enough that it will not smear. A good, soft Ruby Red or art gum eraser will clean up chart work without excessive wear on the chart. There are soft white erasers that are mounted in a holder similar to a mechanical pencil which can be extended and retracted like a pencil lead which also work well. Filler erasers are available.

Whatever you use is a matter of personal choice. The point here is that the three basic devices in whatever form are required and must be aboard.

2-1. A(n) _____ diagram shows points of equal variation.

a. Napier
b. isogonic
c. isobaric
d. isomorphic

2-2. _____ is the angular difference between the geographical _____ and the magnetic _____.

a. Variation, north pole, north pole
b. Deviation, north pole, north pole
c. Compass error, variation, deviation
d. Variation, magnetic field, isogonic lines

2-3. _____ effects all of the compasses in a given area in the same manner and magnitude.

a. Variation
b. Deviation
c. Compass error
d. Dip

2-4. _____ is the combined effect of the _____ and the _____ working on the vessel's compass.

a. Variation, isogons, isobars
b. Deviation, heading, bearing
c. Variation, earth's magnetic field, vessel's magnetic field
d. Deviation, earth's magnetic field, vessel's magnetic field

2-5. The combined effect of deviation and variation is _____.

a. compass swing
b. compass compensation
c. compass error
d. compass point

2-6. When correcting headings from _____ to _____ to ____, deviation and variation are _____ when East, _____ when West.

a. true, magnetic, compass, subtracted, added
b. compass, magnetic, true, added, subtracted
c. true, magnetic, compass, added, subtracted
d. compass, magnetic, true, subtracted, added

2-7. East is least and west is best means deviation is East when the _____ is less than the _____.

a. compass bearing, magnetic bearing
b. magnetic bearing, compass heading
c. magnetic bearing, compass bearing
d. compass heading, magnetic bearing

2-8. Most small vessels, such as Auxiliary facilities, have only a _____ compass, observable from _____.

a. steering, anywhere
b. fluxgate, aft looking forward
c. hand bearing, anywhere
d. steering, aft looking forward

2-9.(True/False) Except at the magnetic equator, the earth's magnetic field has horizontal, vertical, and directional components.

2-10. (True/False) The location of magnetic north varies predictably. The amount of change can be found in the legend printed on navigational charts.

2-11. (True/False) The rhumb line is a reference line on the compass aligned with the keel to facilitate reading the compass.

2-12. (True/False) Modern compasses use a card with magnets attached to the underside and mounted within a teflon bowl.

2-13. (True/False) Vibration and rapid oscillation are damped, and friction is reduced through the use of a clear liquid, such as ethyl alcohol and water, in the compass bowl.

2-14. A _____ is a stand to hold and protect the compass. On large vessels it contains the adjusting devices, including _____ to adjust for roll and pitch and _____ to adjust for the dip of the earth's magnetic field.

a. pelorus, compensating magnets, a Flinder's Bar
b. binnacle, heeling magnets, a Flinder's Bar
c. binnacle, an inclinometer, heeling magnets
d. binnacle, a quadrantal sphere, a Flinder's Bar

2-15. Deviation can be determined when crossing ranges if the _____ compass is mounted so that it can be sighted across from positions other than directly aft of the compass.

a. hand bearing
b. fluxgate
c. steering
d. gyro

2-16. The essence of good navigation is systematic _____ and detailed _____.

a. observation, record keeping
b. watch standing, observations
c. time keeping, log entries
d. maintenance of navigation equipment, plotting

2-17. Two of the most basic and important means of fixing position are _____ _____ and _____ of events.

a. keeping a good lookout, accurate timing
b. advancing lines of position, detailed observation
c. an accurate compass, detailed logging
d. loran, recording

2-18. It naturally follows that two of the most important navigational aids are good _____ and a good _____.

a. communications, depth sounder
b. parallel rulers, pencil
c. charts, navigators' tool kit
d. binoculars, watch

2-19. The preferred binoculars for navigational use are 7 x 50. The 7 refers to the _____ of the binocular, in this case 7 powers, and the 50 to the _____ in millimeters.

a. magnification, focal length
b. magnification, diameter of the focal lens
c. magnification, diameter of the objective lens
d. magnification, diameter of the eye piece

2-20. A _____, sometimes called a dumb compass, should be mounted so that _____.

a. pelorus, bearings may be taken from any direction
b. fluxgate compass, bearings may be taken from any direction
c. pelorus, bearings may be taken from aft looking forward
d. fluxgate compass, bearings may be taken from aft looking forward

2-21. If the card of the _____ is mounted so that 000° is toward the bow of the vessel, it can be used to determine _____.

a. fluxgate compass, true headings
b. pelorus, relative bearings
c. steering compass, compass headings
d. steering compass, compass bearings

2-22. A valuable navigational aid for determining bearings of objects which can't be sighted across the steering compass is the _____.

a. fluxgate compass
b. gyro compass
c. hand bearing compass
d. pelorus

2-23. (True/False) The sextant, usually thought of as a precision instrument for celestial navigation, is particularly useful in measuring horizontal and vertical angles used for danger angles or to determine the distance from objects of known height.

2-24. (True/False) An altimeter measures apparent wind, the combined effect of the real wind and that generated by movement of the vessel.

2-25. (True/False) The basic navigational tools remain the dividers, for picking off and transferring distances, parallel rulers or similar devices for transferring lines to or from compass roses to measure direction, and pencils with erasers.

PROBLEMS:

2-1. A vessel is heading 207° by compass on a range established by a "spider" (fixed, with skeletal structure) light and an onshore smoke stack. The charted bearing of the "range" is 210° Magnetic. The variation in this area is 7°E. What is the deviation? _____

2-2. Fill in the blanks:

	T 203°	V _____	M 212°	D 4°E	C_____
2-3.			M 063°	D 12°W	C_____
2-4.	T 357°	V 6°W	M_____		
2-5.	T_____	V 10°E	M_____	D 3°W	C 228°
2-6.	T 096°	V 8°W	M_____	D_____	C 111°

2-7. Variation is 10°W. Deviation on compass heading 045° is 12°E, on 060° it is 9°E, on 075° 3°E, on 090° 3°W. A vessel is heading 045° by compass when a tower is sighted to starboard bearing 075° across the steering compass. What is the true bearing of the tower? _____

2-8. In the Napier diagram on page A-15, Appendix A, what is the compass course to be steered to follow a magnetic course of 305°? _____

2-9. The compass bearing, using the steering compass, to a lighthouse is 097°. The correct magnetic bearing is 102°. What is the deviation? _____

2-10. The magnetic bearing to a radio tower is 224°. The steering compass shows the bearing to be 228°. What's the deviation? _____

2-11. Using the deviation table for the USCG Auxiliary Facility Helena, (page A-14) what is the deviation for 307°C? _____ For 307°M? _____

CHAPTER 3
DEAD RECKONING

3. Chapter 3.

3.1. INTRODUCTION: As stated in the introduction to this book, dead reckoning is the most basic of the navigational disciplines, yet without it, the others would not be possible. Very simply stated, dead reckoning is the determination of position by the direction and distance traveled from a known position. Dead reckoning does not consider current or other external influences acting on the vessel.

3.1.1. Definitions.

3.1.1.1. Dead Reckoning. A Navy and Coast Guard definition of dead reckoning says that "dead reckoning is the process of determining a ship's approximate position by applying to the last well-determined position a vector or series of vectors representing the run made since." To understand this definition you must first understand vectors, a term with which you will become increasingly familiar.

3.1.1.2. Vectors. Dutton's, on page 200, provides a definition of a vector, as follows: "A vector is a straight line indicating by its orientation the direction, and by its length the ratio of travel of a moving element, represented by the head of the vector, with respect to another element that is represented by the foot of the vector." A much simpler definition is that a vector is a line with direction and magnitude. It can represent forces that act on an object in various directions with varying amounts of effort (magnitude) and it can represent the distance (magnitude) and direction in which an object moves. A series of vectors representing course changes and new legs traversed can be combined in a process called vector arithmetic to determine the distance and direction from point of origin to point of destination. The solution vector is called the *resultant*. This process is very useful in determining the combined effect of changing surface winds over time and in solving current problems. Graphic solutions to vector arithmetic problems are best solved on a Maneuvering Board, described below.

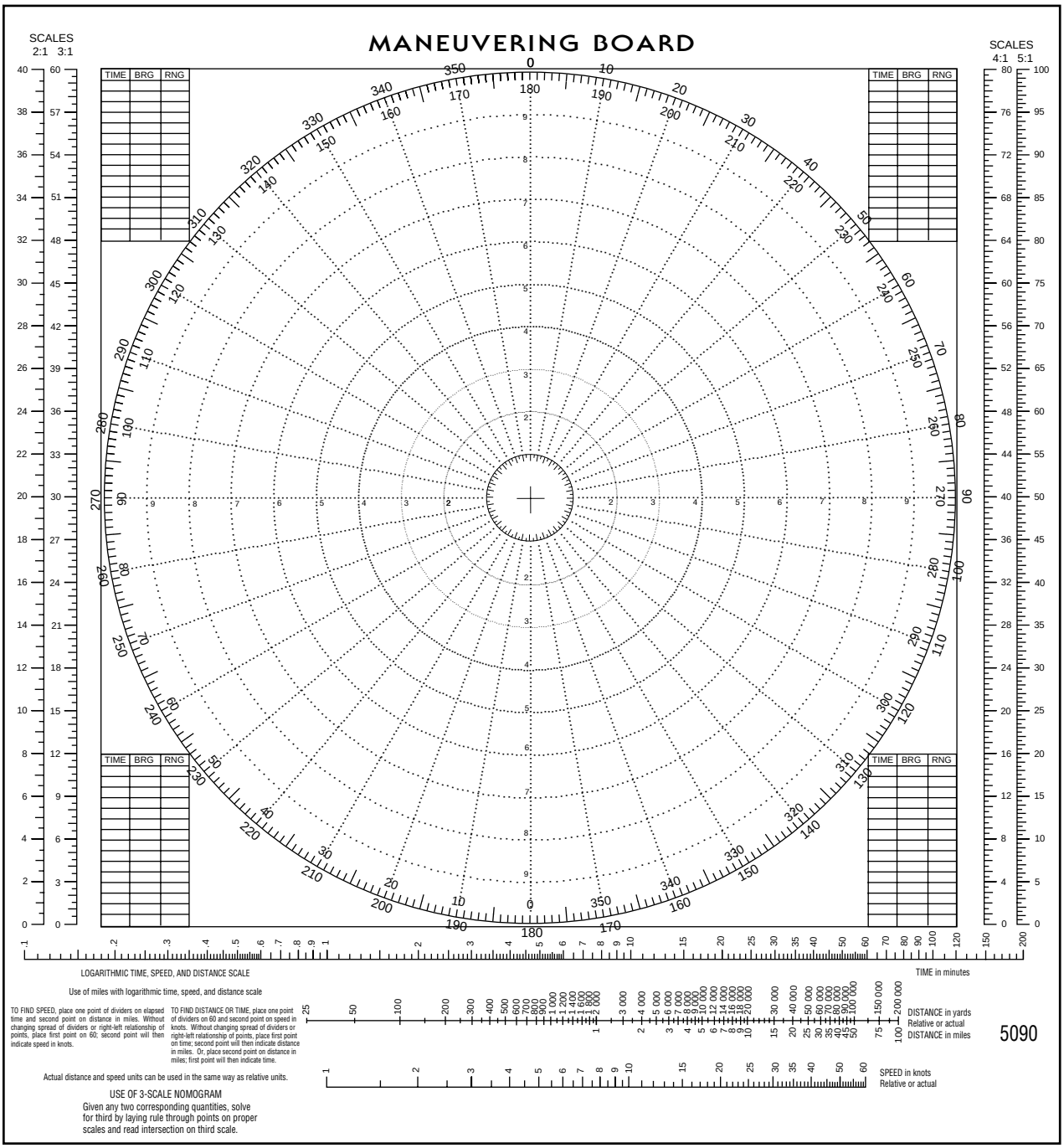
3.1.2. Maneuvering Board.

3.1.2.1. Description. Maneuvering Boards come in tablet form (see Figure 1) and consist of a series of ten concentric rings around an origin. Each ring has a radius 1/2" greater than the preceding ring and each ring after the first is drawn as 360

dots, each representing 1° in azimuth, or direction. Every ten degrees is marked by a dotted line or radial from the origin to the outer ring, each dot representing 1/10 of the distance between rings, and labeled from 0 at the top clockwise to 350. Using only the plotting area itself, the maneuvering board is scaled 1:1, 10:1, 100:1, 1:10, etc., in multiples of ten. That is, using a 1:1 scale each circle represents 1 mile or 1 knot; using a 10:1 scale each circle represents 10 miles or 10 knots; using 100:1 each circle represents 100 miles or 100 knots, etc.; and each dot on the radial represents 1/10, 1, 10, etc., miles, respectively. The board also has scales marked 2:1, 3:1, 4:1, and 5:1 which can be read as 20, 30, 40, or 50 to 1, as appropriate to make plots fit on the board. For example, if a vessel travels 44 nautical miles at 220°, the plot would be drawn on the 220° radial from the origin to the 4th dot beyond the fourth circle. Using the 2:1 scale as 20:1, pick off 44 with dividers spread from 0 to 4 plus an estimated 0.4 (4.4 x 10 = 44). Transfer to the 220° radial and mark the point where the leg of the dividers touches the radial (it will be 2 dots beyond the second ring). You can see how 44 could be laid out using each of the scales. Remember that you must use the same scale for every vector in the particular problem. The maneuvering board also has a logarithmic 3-scale nomogram along the bottom. This is used to solve time-speed-distance problems. By laying a straight-edge across any two known values, the third can be read directly. For example; a vessel travels for 15 minutes at 10 knots. Lay a straight-edge across the nomogram (or draw a line) from 15 on the "time in minutes" scale to 10 on the "speed in knots" scale. The line crosses the "distance" scale at 2.5 nautical miles (or 5000 yards - the scale is calibrated in both). Note that the nomogram can only be used with nautical miles (or yards) if knots are used. It can be used with mph and statute miles, but cannot be used with mph and yards (a vessel will travel 2.5 statute miles in 15 minutes at 10 mph but that is only 4400 yards, not 5000 as the nomogram would show).

3.1.2.2. Using the Maneuvering Board. The use of the maneuvering board is best illustrated with an example. The problem is to determine the course and speed made good after a series of turns. This is simply a case of finding the resultant (finding the end result of all the actions), or where you are, relative to where you started, after the series of course and speed changes.

To illustrate: You are heading 037° from a fix at 9 knots. After 40 minutes you turn to 085°, maintaining your speed of 9 knots. Twenty minutes later you reduce speed to 6 knots and continue on course 085° for another 30 minutes. You then increase speed to 10 knots and turn to course 116°, which you hold for 21 minutes. How far, and in what direction are you from the fix What is your speed made good? Proceed as follows (see Figures 3-2 and 3-3):



The Maneuvering Board
Figure 3-1

1. Lay parallel rulers (plotter, paraline plotter, etc.) from origin to 037° (7th tic mark beyond 30 on the outer circle) and draw light line.

2. Use nomogram or other means to determine distance traveled in 40 minutes at 9 knots (6 nautical miles). On 2:1 scale, pick off 6 miles (O to 6) with dividers.

3. Put one point of dividers at the origin, mark where the second point tics the line drawn through 037°. Once the line has been marked with the distance traveled it becomes a vector with direction (037°) and magnitude (distance, 6 miles).

4. Lay parallel rulers from origin to 085°. "Walk" to tic mark on the 037° line and draw the second line from the tic mark.

5. Determine distance traveled in 20 minutes at 9 knots (3 miles). On the 2:1 scale pick off 3 miles with the dividers.

6. Put the point of the dividers at the head of the first vector (the tic mark on the 037° line and mark where the second point tics the 085° line. This is the second vector.

7. The third vector is also 085° so it is an extension of the line already drawn. Thirty minutes at six knots is also 3 miles. Mark it off from the head of the second vector (the tic mark on the 085° line where the second divider point tics the extended 085° line. This is the third vector.

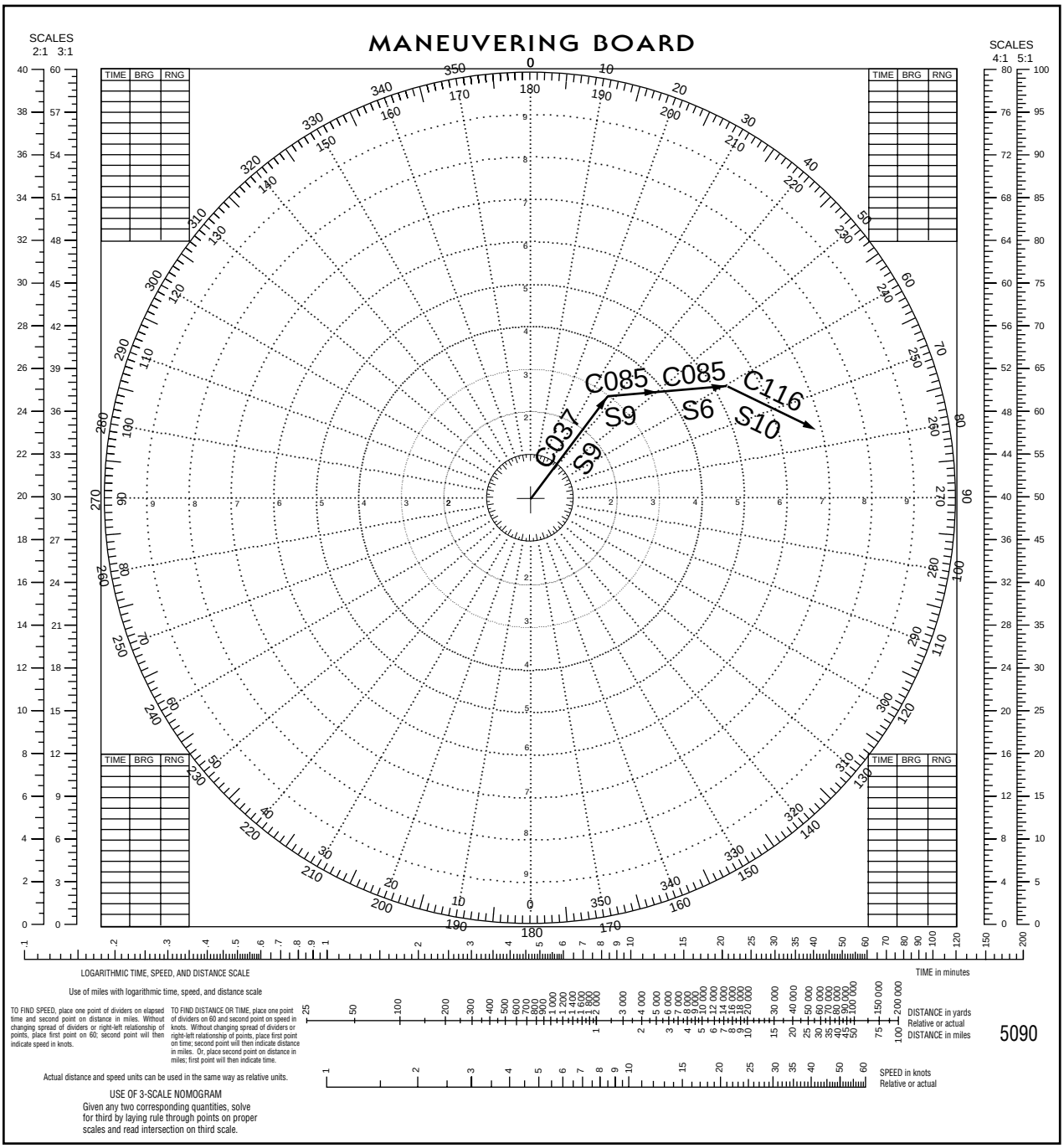
8. Use the parallel rulers to draw a line 116° from the head of the third vector. Lay off 3.5 miles (21 minutes at 10 knots) with the dividers on the 116° line. Where the second point tics the line is the head of the fourth vector.

9. Draw a line from the origin to the head of the fourth vector and mark where the straight edge crosses the outer circle. Use the dividers to pick off the distance from the origin to the head of the fourth vector. Place one point of the dividers on the 0 of the 2:1 scale and read 13.3 miles where the second point falls.

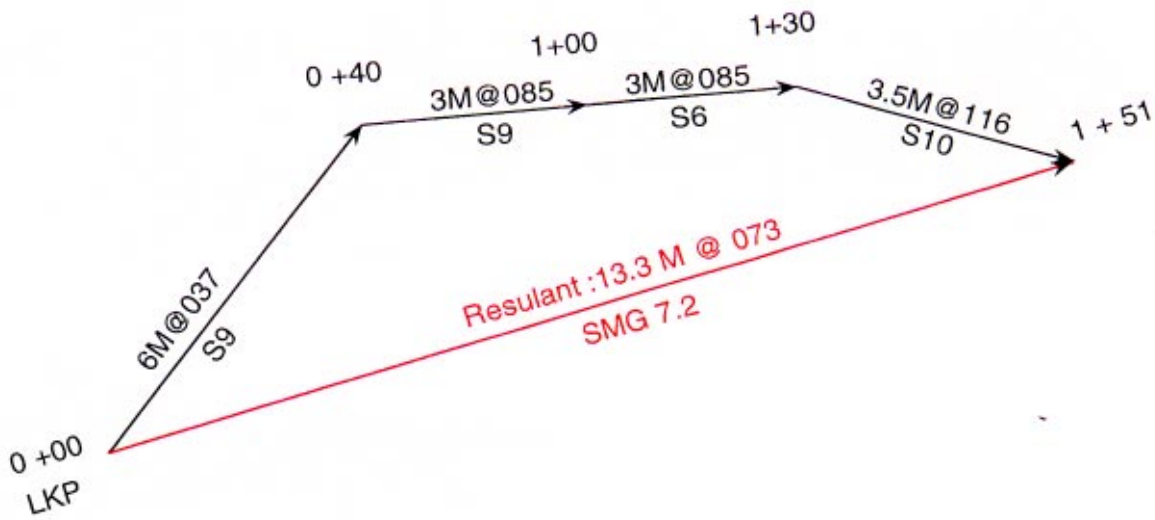
10. You are 13.3 miles away from the starting fix at 073°. Your speed made good is 7.2 knots (13.3 miles in 1 hour and 51 minutes).

3.2. DEAD RECKONING CONVENTIONS.

3.2.1 Terms. The definitions of dead reckoning terms provided below are those used in the preferred reference texts for this course. It's important to note, and somewhat disconcerting, that many terms have two meanings depending on usage. For example,



Course Vectors Plotted
Figure 3-2



track means path of intended travel; it also means the path actually traveled over the ground). Note also that these terms are not applicable to dead reckoning alone and some are more applicable to piloting or current sailing, both of which are discussed in some detail in subsequent chapters.

3.2.1.1. Dead Reckoning Plot (DR Plot). The desired path of the vessel laid out on the chart with the presumed location of the vessel at prescribed intervals marked, along with the times of planned turns. The plot starts from a known position, a fix, identified by a circle around the dot marking the position). (See Figure 3-4. page 3-11). The conventional charting symbols are:

3.2.1.1.1. Course line labeled with the direction of travel above the line, in True degrees, and the speed of the vessel beneath the line, as $\frac{0935}{060}$. Note that no designator was used to indicate True direction. <u>The convention says that unless otherwise specified, direction is always true</u>. If magnetic or compass directions are used the designator would be C126M or C126C.

3.2.1.1.2. Dead Reckoning (DR) Position: A dot on the course line at the position, inside a semi-circle above the line and marked with the time of occurrence or anticipated occurrence.

3.2.1.2. Line of Position (LOP). A line determined by observation of a charted object. The LOP may be obtained by visual bearing or by a range (two charted objects in line with the observer), radar bearing, distance from an object (usually called a Circle of Position or COP), or other means. A vessel is on the LOP or COP at the time of the observation. Where on the line may not be known but the vessel is on it, somewhere. That is the key to piloting, discussed in the next two chapters. The LOP or COP is labeled with the time of the observation above the line and the bearing below, as . Note that once again the convention says that if the type of bearing is not designated, it's true. If it were magnetic it would have been labeled 067M.

3.2.1.3. Estimated Position (EP). When only one LOP is obtained the only thing that is known is that the vessel is somewhere on the LOP. The convention says that the vessel is probably at the point closest to the DR position of the vessel at the time the LOP was taken. The symbol for an EP is a dot at the position on the LOP closest to the DR position, surrounded by a square and labeled with the time.

3.2.1.4. Fix. A fix may be determined by crossing two or more LOPs, COPs, or combination of LOPs and COPs, obtained at the same time. If the vessel is on each LOP at the time of the observation, and the observations are taken at the same time, then the vessel is at the point where the LOPs cross; hence, its position is fixed. The symbol for a fix is a dot at the position of the vessel, surrounded by a circle and labeled with the time. Some texts say that fixes determined electronically are marked with a triangle instead of a circle; however, the most respected texts, those considered standards (Dutton's, and Bowditch), say that the triangle is used when a fix is determined by two means simultaneously such as visual and radar and that it sometimes *may* be used for electronic fixes.

3.2.1.5. Running Fix (RFIX). Sometimes visibility precludes obtaining two LOPs at the same time. A second observation taken of the same or a different object at a substantially later time can be used. The first LOP is advanced the distance traveled between sightings in the direction of travel and labeled with the time of its original sighting and the time of the second observation above the line and its direction below, as:

$$\frac{0935–0953}{067}$$

The second LOP is labeled normally, as $\frac{0953}{138}$. The point where the second LOP and the advanced first LOP cross is the running fix and is labeled with the dot inside the circle and RFIX 0953.

3.2.1.6. Most Probable Position (MPP). A probable position which is better defined than an EP and not as well defined as a fix. It requires more information than an EP, such as a sounding or anything else which may be helpful, or is based all or in part on floating aids to navigation which may or may not be off station. It is marked with the EP symbol, a dot inside of a square.

3.2.1.7. Grid. True courses on a Mercator chart are determined from lines of latitude and longitude printed on the chart. These lines constitute a grid. Consequently, grid directions and true directions are the same thing when using Mercator projections. We will not deal with grid directions in this course. They are special purpose uses, usually for security reasons; if you can handle geographic coordinates, you can handle grid designations and grid directions.

3.2.1.8. Heading (Hdg). The direction in which a vessel points, or heads, at any given instant. In reality, heading changes constantly as the vessel is affected by sea conditions and steering errors.

3.2.1.9. Course (C). A rhumb line direction. The direction of travel measured in degrees clockwise from a reference direction; true, magnetic, or compass North. Unless specifically designated magnetic (M) or compass (C), the course is understood to be true (T).

3.2.1.10. Course Line. The graphic representation of the course laid out on a chart. It is used in laying out a dead reckoning plot.

3.2.1.11. Course Made Good (CMG). Shufeldt says that course made good defines "the path a vessel actually made good relative to the earth". As stated in Chapter 1, the Dutton's and Bowditch definition that CMG is the single resultant direction and distance from point of origin to current position is used here.

3.2.1.12. Track (Tr). The Shufeldt definition of CMG agrees with the Dutton's and Bowditch definitions of track. Neither Dutton's nor Bowditch define track as course made good. Bowditch defines track made good (TMG) with the exact definition used by Dutton's for CMG.[27] All three sources use the word "track" to describe the path over the ground, the path actually traveled. Dutton's also uses course over the ground (COG) to define the actual path traveled. Sorting this all out, all three references agree that track has the following meanings:

[27] Bowditch, p. 64.

3.2.1.12.1. Desired direction of travel. May differ from course when the course is changed to compensate for current or other external forces. For example; the course may be 167° in order to track 180° when a westing current is flowing. The current will move the vessel to the right (west) of the track so it must be steered to the left (east) of the track in order to follow the track. This is covered in great detail in Chapter 6.

3.2.1.12.2. Path of intended travel drawn on the chart (same as Course Line).

3.2.1.12.3. Actual path over the ground. This includes all of the turns and maneuvers which occurred. It is <u>not</u> the same as CMG.

3.2.1.13. Intended Track. Sometimes used to make it clear that the first definition is meant, rather than the third.

3.2.1.14. Speed (S). Rate of travel of a vessel through the water. Unless specified otherwise, speed is always shown in knots. If another unit, such as MPH, is used, that unit must be shown on the plot.

3.2.1.15. Speed made good (SMG). Dutton's and Bowditch define SMG as the speed along the course made good.[28] That is, the distance along the CMG is divided by the total time required to travel from the start point to the end point. That is the definition we will use.

3.2.1.16. Speed over the ground (SOG). The actual vessel's speed with respect to the earth along the COG.[29]

3.2.1.17. Speed of advance (SOA). Shufeldt, Dutton's, and Bowditch all define SOA as the average speed which must be maintained to arrive at the destination at the desired time. Dutton's and Bowditch also define it as the intended (anticipated, desired) speed to be made along the track.[30]

3.2.1.18. Distance (d): The linear measurement between two points on the earth's surface represented by two points on a chart. Distance is usually expressed in nautical miles (M). If other units are used, they must be identified.

3.2.2. Labeling. The conventions used in labeling DR plots will be used throughout this course. Whenever true course or bearings are used they will be identified only by the three-digit azimuth direction; i.e., 312, 036, 004. Course

[28] Dutton's, p. 178; Bowditch, p. 63
[29] Dutton's, p. 178.
[30] Dutton's, p. 178; Bowditch, p. 63.

directions on a plot will be preceded by the letter "C" as: C312, C036, C004. Whenever magnetic or compass course or bearings are used they will be followed by the letter "M" or "C", as C337M, C059C, 222C, 010M. Relative bearings will be followed by the letter "R" as 015R, 349R. The letter "T" will not normally be used. In the same vein, speed is always in knots (nautical miles per hour). Miles per hour refers to statute miles and will not be used in this text, except in discussion. Note, also, that the degree symbol is not used on the plots. This is to avoid confusion if the navigator happens to make his symbol too large.

3.2.3. Charting Conventions. Page 83 of Shufeldt lists eight conventions to ensure that DR plots can be read by others. Using charting conventions is a good practice which avoids confusion and increases understanding. The eight conventions are repeated below:

1. Right after drawing a line or plotting a point, label it legibly.

2. The label for a point on a line should angle out from the line, not lie along it.

3. The label for the line itself should lie over and along it and consist of three numerals meaning true course.

4. When magnetic courses are being plotted, *M* follows the numerals.

5. The label indicating speed (S) should appear along the line and beneath it (*Editorial comment* : directly beneath the line label). If for some reason (ICW passage) statute miles are being used, MPH must be appended, or else knots will be understood.

6. The label of any point on a DR plot consists of a semicircle over a point with a time in four figures beside it.

7. A fix is indicated by a full circle around a dot, and the time numerals.

8. Twenty four hour time notation is used, eliminating the need for A.M. and P.M. labels. 1 P.M. is 1300, and so on. If seconds are of consequence, which is seldom the case in dead reckoning, six numerals are used, such as 011526 for 15 minutes and 26 seconds past 0100 (*Editorial comment* : The six digits are also used to express date-time groups (DTG)). In this case the same six digits would mean 1526 hours on the 1st of the month (designated after the figures, as: 011526Z Dec, where the Z represents the time zone, Greenwich Mean Time. Other time zones are designated by identifying label such as an R for EST in the United States. Sometimes the letter designator is omitted for local times). This notation may appear in tide and current worksheets when boundary event times occur the day before or the day after the time of interest or

on DR plots when the plot starts before and continues after midnight.)

3.2.4. Plotting Rules. The Navy and Coast Guard have established rules for maintaining a DR plot which bear repeating. They call for a DR position to be plotted (see Fig 3-4, from Shufeldt, Figure 10-3, page 84):

1. Every hour on the hour (for this course we will use every half-hour on the half-hour).

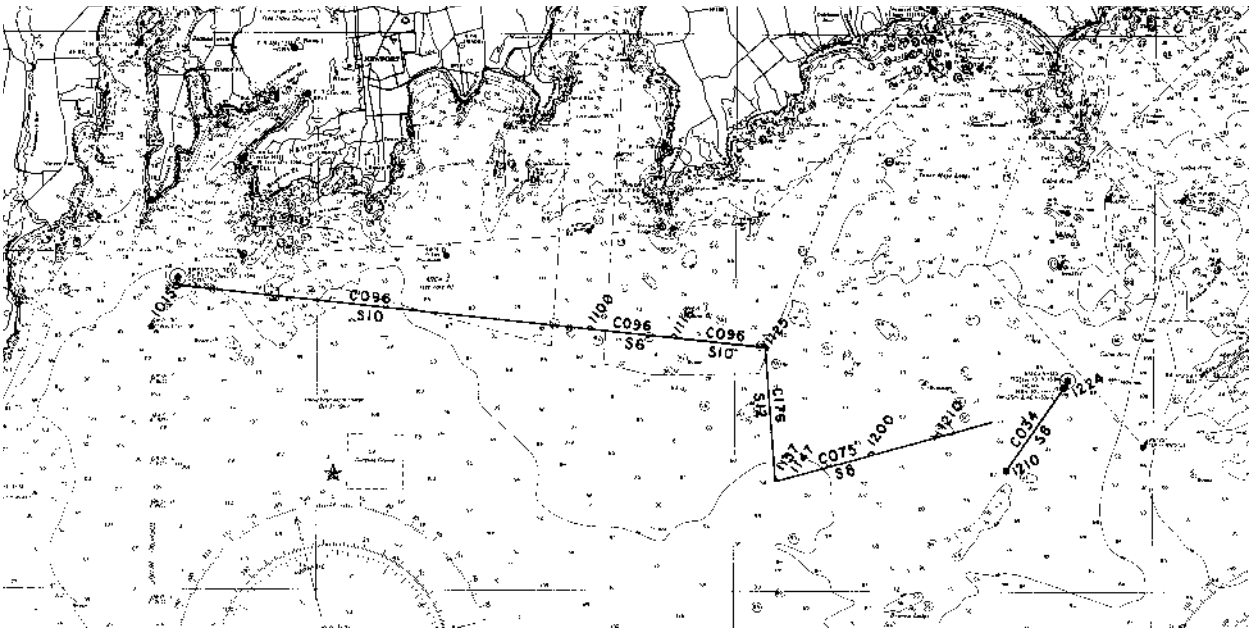
2. At the time of every course change.

3. For every speed change.

4. At the time of each fix or running fix.

5. At the time of obtaining a single LOP.

The rules can be used before the voyage to preplan and to preplot the intended track, indicating the planned times of departure, arrival at destination, positions at prescribed elapsed times, and times when turns should be made. They can be used during the voyage to show actual courses steered and times of events as they occurred.



Dead Reckoning Plot
Figure 3-4[31]

[31] Shufeldt, Fit. 10-3, p. 84

3.2.5. Fixes While Running a DR Plot. Whenever a fix or running fix is obtained, the DR plot is continued from that point. It may also be continued from a most probable position, but not from an estimated position; however, if the EP indicates a possibility that the vessel is standing into danger, action must be taken to reduce or eliminate the possibility. Since the EP is based on one LOP and the vessel could be anywhere on the LOP, the most prudent action is to stop until more information can be obtained to change the EP into a MPP or fix. If visibility is not a factor and it is known that a second observation can be obtained before the minimum time in which the vessel could encounter the danger, then a running fix can resolve the issue of potential danger.

3.3. SPEED CURVES. Since Dead Reckoning is the extension of the last known position (the last fix or point of origin) by distance and direction, there must be a means of determining distance. It's also important to note that dead reckoning will be most needed when LORAN and GPS are not working. Boats and ships don't have odometers so distance is determined by multiplying the speed of the vessel by the amount of time it traveled at that speed. How do we determine the speed? Speedometers and speed logs for small vessels such as used by the USCG Auxiliary are notoriously inaccurate through at least part of their range. Some are fairly accurate at high speeds and grossly inaccurate at low speeds. Others are just the opposite. Some are inaccurate throughout the range. All are subject to fouling of the impeller wheel. Consequently, it's desirable to have a speed curve on any small boat and imperative on those without a speedometer.

3.3.1. Developing the Curve. To establish a Speed Curve for a vessel one must first pick two precisely charted objects on a waterway with a straight run between them. Run between them at the lowest rpm setting which provides steerage (allows steering control), recording the time with a stop watch. Turn around and run the other way between them at the same rpm setting, again recording the time. Repeat the process for incremental increases in rpm up to maximum speed. After the times are recorded in each direction for each selected rpm setting, determine the speed in each direction (the distance between the objects are determined from the chart, the times from the runs). Average the speeds for each rpm setting to determine the speed through the water of the vessel at that particular power setting. IT IS IMPORTANT THAT SPEEDS BE AVERAGED. Averaging times, then determining the speed, will provide incorrect values. It also should be apparent that two people are required, one to operate the vessel, one to determine when the charted objects are exactly abeam and to start and stop the timer. The speeds determined for each power setting are valid as long as the trim and load conditions under which the speeds were determined remain constant. If the loads or trim vary, the speeds will also. This is particularly true with outboard and smaller inboard - outboard engine powered boats. While true of larger inboard engine powered vessels, the effect of changes in load or trim are not nearly as apparent. The equation for determining speed is:

$$ST = 60D$$

where S = speed in knots
T = time in minutes
D = distance in nautical miles

and 60 is a conversion factor to allow the use of minutes and miles directly in the equation. To determine the speed, use:

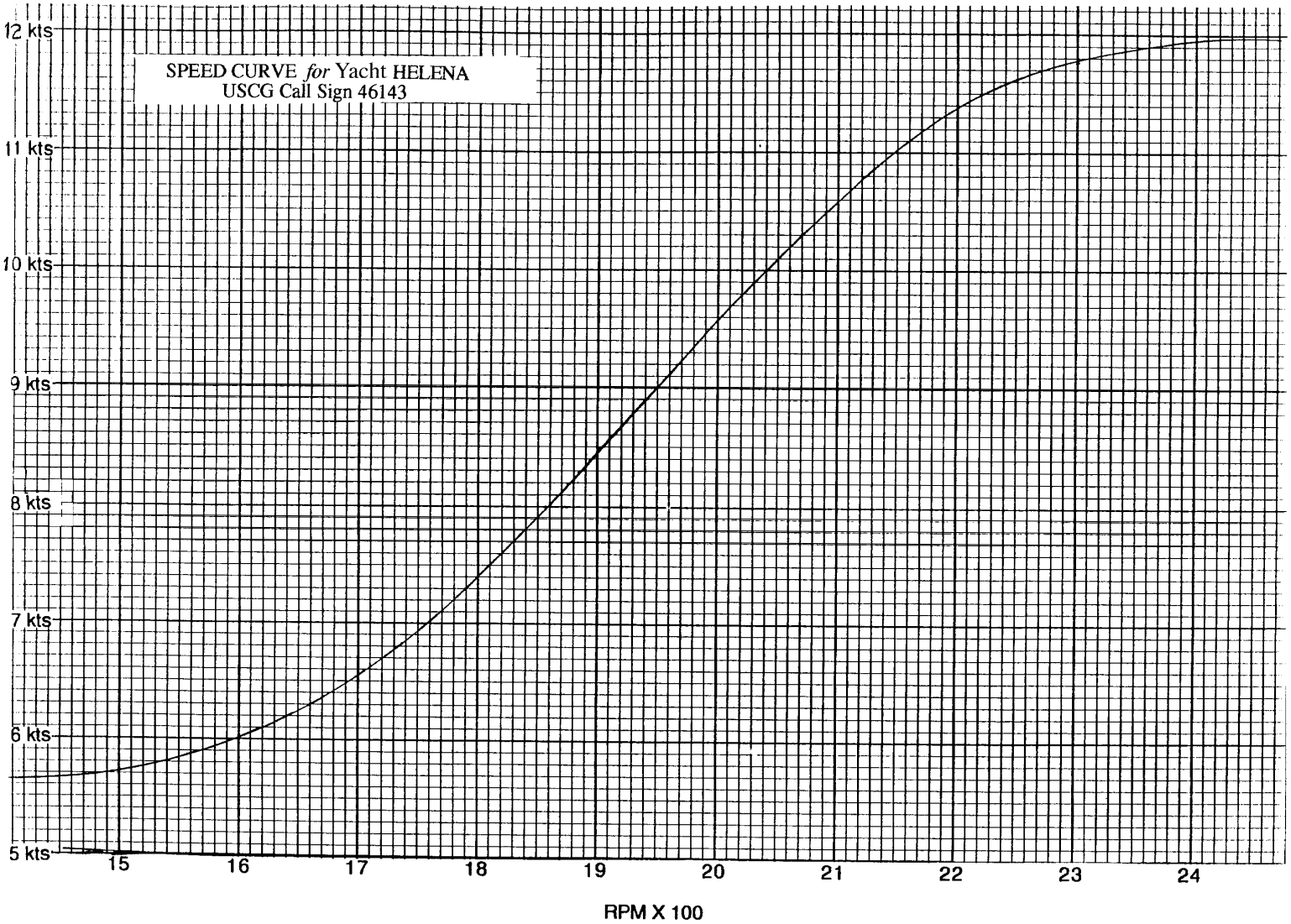
$$S = \frac{60D}{T}$$

3.3.2. Speed Table. The time measurements are entered into a table from which the speed curve is plotted (distance between objects is 1.0M), as follows:

	Out			Back	
rpm	time out	spd out	time back	spd back	Avg Spd
1400	29:37	2.03	6:28.2	9.27	5.65
1500	28:34	2.10	6:25.2	9.35	5.72
1600	25:13	2.38	6:14.4	9.62	6.00
1700	20:29	2.93	5:54.0	10.17	6.55
1800	15:52.2	3.78	5:26.4	11.02	7.40
1900	12:25.2	4.83	4:58.2	12.07	8.45
2000	10:04.2	5.96	4:33.0	13.20	9.58
2100	8:30.0	6.98	4:13.2	14.22	10.60
2200	7:42.6	7.78	3:59.4	15.02	11.40
2300	7:21.0	8.16	3:54.0	15.40	11.78
2400	7:12.0	8.33	3:51.0	15.57	11.95
2430	7:10.8	8.36	3:52.8	15.60	11.98

The times above indicate a digital wrist watch with a stop watch feature that indicates tenths of a second for times below 20 minutes. To determine speeds, the time, in minutes and seconds (indicated by the colon after the minutes) must be converted to minutes (by dividing the seconds by 60 and adding the resulting decimal fraction to the minute integer (the whole number of minutes) and dividing the result into the 1.0 nautical mile distance between the objects.

3.3.3. Speed Curve. The speed curve resulting from the above data is shown in Figure 3-5 on page 3-14. Notice that with the curve, the navigator can quickly determine the speed through the water for rpm between the data points.



Speed Curve
Figure 3-5

3-1. _____ is the basic discipline of navigation.

a. Dead Reckoning
b. Piloting
c. Celestial navigation
d. Electronic navigation

3-2. Dead reckoning is the determination of position by _____ from a _____.

a. speed and time, fix
b. distance and heading, most likely position
c. CMG and SMG, last known position
d. distance and direction, last known position

3-3. Dead reckoning does not consider _____ or _____ forces acting on the vessel.

a. water motion, wind
b. current, other external
c. current, wind
d. wind, internal

3-4. A vector is a line which has direction and _____; therefore, a _____ plot consists of a series of vectors.

a. magnitude, dead reckoning
b. force, traverse sailing
c. strength, actual track
d. distance, course

3-5. (True/False) The solution of a vector arithmetic problem is called the resonance.

3-6. (True/False) The maneuvering board is laid out in ten concentric circles ten units apart which allows direct readings of speed or distance in multiples of two.

3-7. (True/False) The maneuvering board contains four additional scales of 2:1, 3:1, 4:1, and 5:1 each of which can be expanded in multiples of two.

3-8. (True/False) The nomogram in the bottom margin of the maneuvering board allows direct solution of speed, time, and distance problems.

3-9. (True/False) A line of position is a line on which the vessel is located, someplace, based on observation or measurement. When based on measurement (distance) from a charted object the line of position can also be called a circle of position.

3-10. A ___ is an accurate position determined from two or more _____, or _____, or combinations determined almost simultaneously.

a. running fix, lines of position, circles of position
b. fix, horizontal angles, vertical angles
c. fix, lines of position, circles of position
d. running fix, horizontal angles, vertical angles

3-11. A _____ is a position determined from two _____ determined at different times.

a. running fix, lines or circles of position
b. fix, horizontal or vertical angles
c. fix, lines or circles of position
d. running fix, horizontal or vertical angles

3-12. A running fix is determined by crossing LOPs observed at substantially different times by advancing the first LOP _____ to the ____ of the second LOP. The position is where the two LOPs (the redrawn first, and the second) _____.

a. perpendicular to itself for the distance traveled, time, intersect
b. parallel to itself for the distance traveled, time, coincide
c. in the direction and for the distance traveled, bearing, intersect
d. in the direction and for the distance traveled, time, intersect

3-13. _____ is the direction the vessel points at any given instant.

a. heading
b. course
c. track
d. bearing

3-14. _____ is the direction of travel, expressed in true degrees unless otherwise specified.

a. heading
b. course
c. track
d. bearing

3-15. _____ is a graphic representation of the vessel's course plotted on a chart. It is used in the construction of a _____ plot and is the same thing as _____.

a. Course line, dead reckoning, course made good
b. Dead reckoning, course line, intended track
c. Course line, dead reckoning, desired track
d. Course line, dead reckoning, track

3-16. Course made good is the resultant _____.

a. of a series of fixes
b. of courses between the origin and the current position
c. direction and distance from point of origin to current position
d. of all forces acting on the vessel as it travels from origin to present position

3-17. _____ is the series of courses actually traveled.

a. Course
b. Course over the ground
c. Course made good
d. Course line

3-18. Track has several meanings:

* Desired _____ (in this sense the meaning is the same as course).

* _____ travel drawn on the chart.

* _____ over the ground.

a. direction of travel, path of intended, actual path
b. heading, path of intended, speed and direction
c. direction of travel, path of intended, desired path
d. course line, actual, desired path

3-19. (True/False) Intended track is used to make sure desired direction of travel is meant rather than the opposite meaning: actual path over the ground.

3-20. _____ is the rate of travel through the water.

a. Acceleration
b. Speed
c. Vector
d. Velocity

3-21. _____ is the average speed over the _____. It is determined by dividing the straight line _____ between points A and B by the total elapsed time it took to get from point A to point B.

a. Speed made good, course made good, direction
b. Speed of advance, course over the ground, distance
c. Speed of advance, course made good, distance
d. Speed made good, course made good, distance

3-22. _____ is the average speed that must be maintained to arrive at the destination at a given time.

a. Speed of advance
b. Speed made good
c. Speed over the ground
d. Speed of resolution

3-23. A dead reckoning plot always starts from a known position, identified by a _____ labeled with the ____ of departure, called a fix.

a. square around a dot, direction
b. square around a dot, time
c. circle around a dot, direction
d. circle around a dot, time

3-24. (True/False) Course lines, or vectors are plotted and labeled with the course above the line and the time below.

3-25. (True/False) DR positions are determined for every hour on the hour (every half hour for Auxiliary purposes), at the time of course or speed changes, when LOPs are established, and when most probable positions are reached.

3-26. (True/False) Speed curves are desirable on all small vessels and are essential when the vessel has no tachometer or speed log.

3-27. (True/False) In making a speed curve, two timed runs are made in opposite directions, the speeds are determined for each direction, and are averaged for the given RPM setting. Times are not averaged.

3-28. (True/False) Distance traveled is usually determined as a function of direction traveled at a given speed.

PROBLEMS

St. Albans is 12.8 NM from Westcott at 083°. Idle Rock lies across the straight line path between the two ports. Because of Idle Rock and shoal waters, the track between Westcott and St. Albans consists of a series of legs. The USCG Auxiliary vessel Helena, call sign 46143, left Westcott at 1015 on a course of 083°, speed 12 knots. At 1035 she changed course to 040° and slowed to 9 knots. At 1058, Helena turned to course 108° and resumed 12 knots. At 1125 a final course change and speed adjustment was made to 083° and 10 knots. Helena arrived at St. Albans at 1134.

3-1. What was the average speed through the water? _____

3-2. What was the length of the path over the ground? _____

3-3. What was the speed of advance? _____

3-4. What was the speed made good? _____

3-5. What was the course made good? _____

3-6. A speed curve is being developed. A run is made at 2500 rpm between two fixed points exactly one nautical mile apart in 3 minutes and 41 seconds. A second run is made at the same rpm in the opposite direction in 5 minutes and 29 seconds. What is the speed through the water of the vessel for a power setting of 2500 rpm? _____

A vessel travels 3.7 NM on course 148° in 13 minutes. It turns to course 088° while slowing to 14 knots. It reaches its destination in 19 more minutes.

3-7. What is the course made good? _____

3-8. What is the speed made good? _____

3-9. How is the course line for the first leg labeled? _____
_____

3-10. How far does a vessel travel in 45 minutes at 9 knots? _____

3-11. A vessel tracks 066° for 43 nautical miles (M). It then tracks 093° for 18 M, then tracks 037° for another 36.5 M. How far is it, and in what direction from the starting point? _____

CHAPTER 4
PILOTING I

4. Chapter 4.

4.1. PILOTING, THE DISCIPLINE. Piloting is navigation by reference to visible, charted objects. The visibility can be electronic, as with radar, or by eye. Of all the navigational disciplines, piloting is the one requiring the greatest experience, most sound judgment, and quickest reaction; that is, piloting requires an ability to determine past, present, and future conditions quickly and accurately. This probably seems paradoxical when one considers the complexities of celestial navigation. Consider, though where the two disciplines are employed.

4.1.1. Open Waters. Celestial navigation is used in open waters, out of sight of land, with long times between sights. Dead reckoning positions are sufficient sometimes for several days of continuous running without creating undue anxiety. There is usually plenty of time to catch and correct errors.

4.1.2. Coastal Waters. Piloting is the required discipline in coastal waters where shoal conditions and dangerous waters abound. An error that is small on the high seas can be immense in piloting waters where grounding and collision with objects is always a possibility (avoiding collision with other vessels is a skill of seamanship). The coastal navigator, or pilot, must be constantly vigilant, mentally alert, with a thorough knowledge of the principals involved.[32]

4.2. LINES OF POSITION (Vectors and Lines). A course line is a vector. It has direction and magnitude; i.e., it extends in the direction the vessel travels to a defined destination or turning point. A line of position (LOP) is a line. It has “to” and “from” characteristics. That is, if an object bears 060° from a vessel, then the vessel bears the reciprocal, 240°, from the object. These two true bearings define the same line. It is easier, therefore, to think of direction to the object from the vessel and not concern yourself with reciprocals. Bearings are taken from the vessel. These can be laid off on the chart using the measured bearing and the nearest compass rose, moved to the object with parallel rulers or similar device, and drawn from the object back towards the vessel.

4.2.1. Ranges. A range is established when any two charted objects are aligned. This LOP is labeled with the time of sighting only, because the range itself determines its direction.

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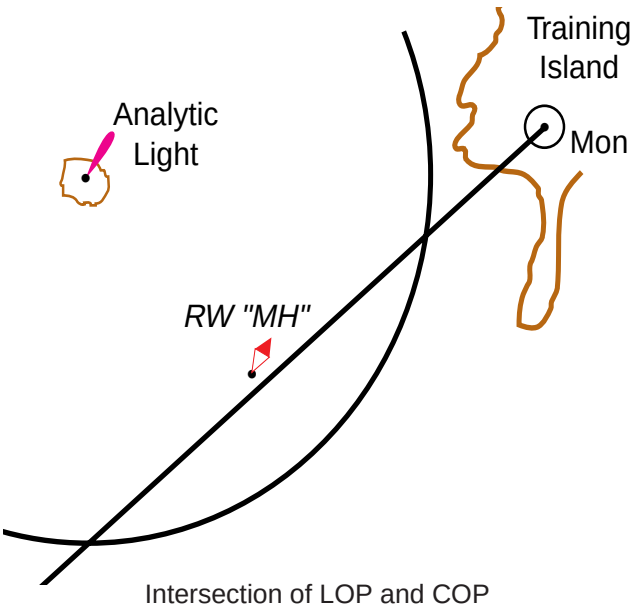
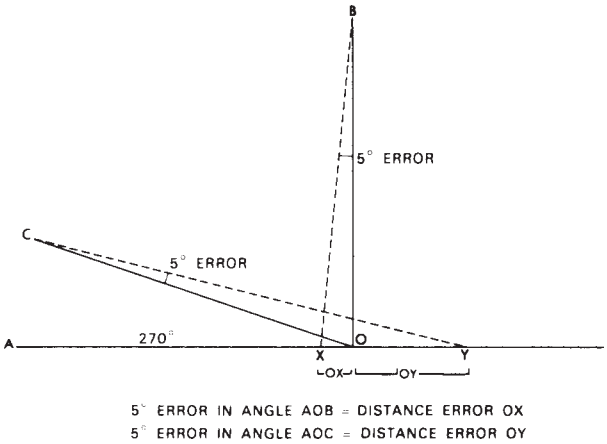
[32] Dutton’s, p. 158.

4.2.2. Circles of Position. A circular line of position, or circle of position (COP) is defined by the distance to the object. It has a characteristic that can cause confusion when establishing a fix with another LOP or COP. The circle and the line, or the two circles can intersect at two points. When this occurs, more information is needed. A third LOP or COP will usually serve to define the fix more precisely. One can also note the presence of an object near the LOP when taking the sight. A sure means of eliminating one intersection is if it occurs on land. In Fig 4-1, the pertinent arc of the circle of position is drawn around Analytic Light. A line of position is projected from the monument on Training Island. Note that the LOP crosses the COP in two places. Note also that the buoy RW "MH" lies slightly to the left of the LOP from the west most "fix". If the vessel is at the east most "fix", the observer won't see the buoy. If at the western "fix", he or she will. That additional piece of information turns "fix" into fix.



Intersection of LOP and COP
Figure 4-1

4.2.3. Angles of Intercept. Fig 4-2 illustrates a very important point. We are conscious of the need to have the angle at which two LOPs intersect each other as close to 90° as possible, at least between 60° and 120°, because of the error which can be introduced if they cross at shallow angles. This diagram shows the importance of having the bearing of the LOP in the same relationship to the heading of the vessel. Small boat navigation is a constant balancing of heading swings of five or more degrees either side of the course. Add to that the error introduced because we can't consider the deviation of a hand-bearing compass and our probable inability to hold the course to much closer than ± 5° its easy to see that the additional errors introduced by shallow angles can cause really inaccurate fixes.



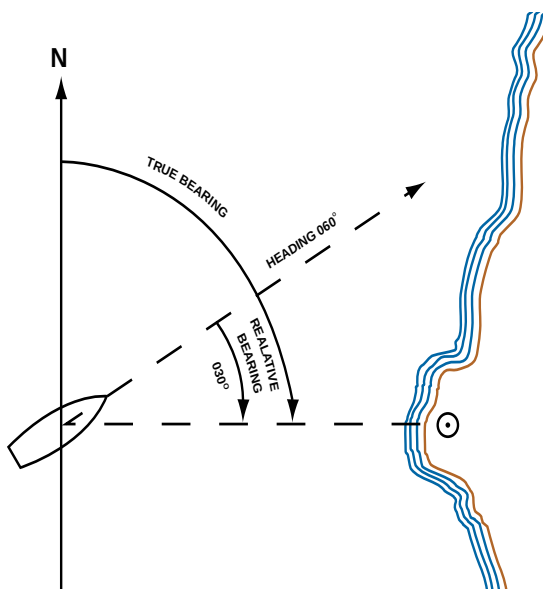
Intercept Angle Impact
Figure 4-2[33]

[33] Shufeldt, Fig. 11-11, p. 95

4.3. BEARINGS.

4.3.1. Deviation. Although deviation is not considered when using a hand-bearing compass, it must be remembered that it exists. It's wise to try to find a spot on the vessel as far removed from engines, electronics, and other equipment or characteristics that define the vessel's magnetic field, as possible. This will minimize the error induced by ignoring deviation. It is also important to remember that if the steering compass is used to take bearings the deviation for the heading of the vessel must be used, not the deviation corresponding to the bearing.

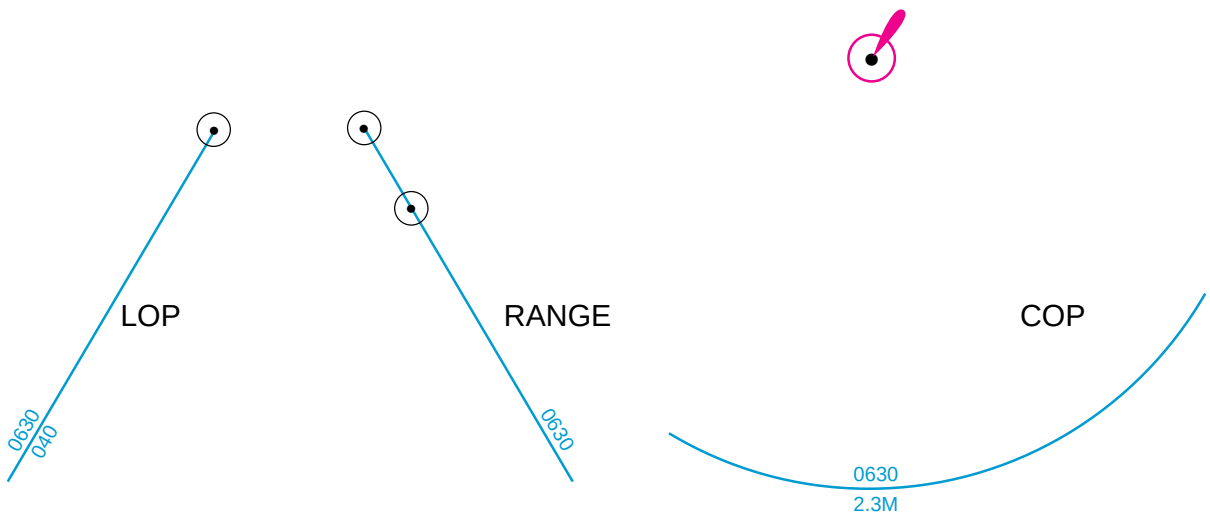
4.3.2. Relative Bearings. Bearings can be, and often are relative. That is, they are measured clockwise from straight over the bow as 000°. All bearings taken by radar are relative. The true bearing is determined by simply adding the relative bearing to the true heading of the vessel. Remember, convert the compass heading to true, taking into account variation and deviation, then add the relative bearing. Do not add the relative bearing to the compass heading and then apply variation and deviation. There is nothing wrong with this method if the navigator remembers that deviation for the heading, and not the bearing, must be applied; however, it is too easy (and too common) to apply deviation for the bearing.



Relative Bearings
Figure 4-3[34]

[34] Shufeldt, Fig. 1-9, p. 95

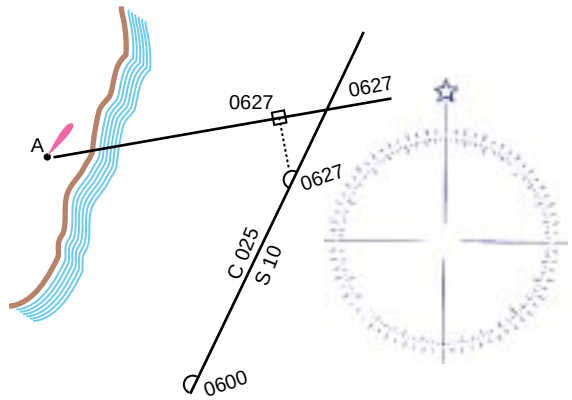
4.3.3. Defining LOPs. A LOP is defined by its bearing from the vessel to the sighted object. The accepted convention is to label the LOP with the time of sighting above the line and the true bearing to the object below the line. COPs are labeled in a similar manner with the time above and the distance from the object below the arc of the circle. The bearing defines the line and the distance defines the circle. Ranges are defined solely by the two objects through which the LOP is drawn; therefore, they are labeled with the time, only.



Labeling LOPs and COPs
Figure 4-4

4.4. POSITIONS.

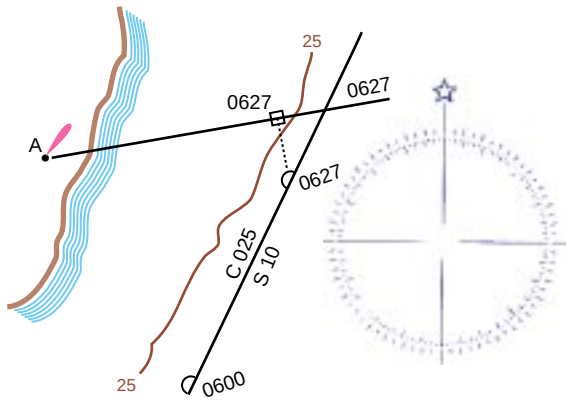
4.4.1. Estimated Position. An estimated position is determined when information is not good enough to determine a fix. The most common example occurs when one LOP is all that can be obtained. It is used with the DR plot. See Figure 4-5 on page 4-5. The DR position for the time of the LOP is plotted. The estimated position is determined by dropping a perpendicular from the DR position to the LOP. The point at which the perpendicular intersects the LOP is the estimated position (EP), labeled with a square around the point. This method puts the EP at the point on the LOP which is closest to the DR position, the location of the vessel if no external forces had acted upon it. There is no assurance that the vessel is at the EP. All that is known, still, is that the vessel is somewhere on the LOP. The EP amounts to an educated guess about the most probable location on the LOP. It can be wrong.



Determination of Estimated Position
Figure 4-5[35]

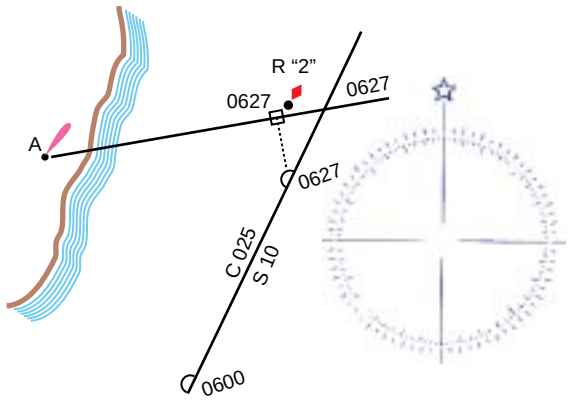
4.4.2 Most Probable Position

4.4.2.1. LOP and Sounding. A most probable position (MPP) is the result of better information than used for an estimated position but not as good as used for a fix. Soundings can be used to help establish position, particularly when used in conjunction with LOPs. It's important to remember that the depth finder's transducer is some (known) distance below the water line and the soundings on the chart are based on datum; that is, mean low or mean lower low water. Depth readings will be a function of height of tide applied to datum, and depth of the transducer. This is an imprecise means of determining position. Results require extreme care in interpreting. Even so, they fit an estimated or most likely position rather than a fix. If soundings alone are used, the position is, at best, an estimated position rather than a most probable one.



MPP Based on Sounding
Figure 4-6

[35] Shufeldt, Fig. 12-13, p. 106



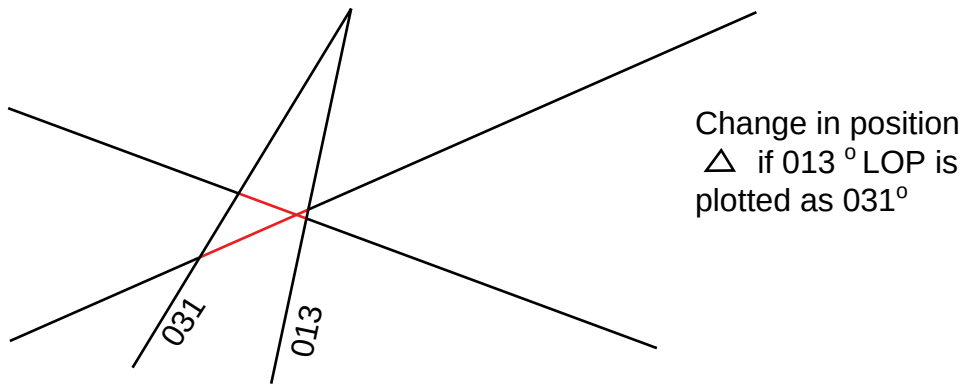
MPP Based on Floating Aid
Figure 4-7

4.4.2.2. LOPs on Fixed and Floating Objects. A bearing on a floating aid to navigation, combined with a bearing on a fixed aid, would result in a MPP because of the possibility of the floating aid being off station.

4.4.3. Fixes.

4.4.3.1. Intersection of LOPs. A fix is a known position. We know that, at the instant a bearing on a charted object is taken, we are somewhere on the LOP defined by the bearing. It follows, then, that if two or more LOPs are defined at that instant, we are somewhere on each of the LOPs. This can only be true if we are at the point where all of them intersect. In practice, when more than two LOPs are defined, the intersection becomes a small triangle. The fix is at the center of the triangle. Three LOPs are always preferred to two. In fact, the Coast Guard requires three LOPs to establish a fix in cutter navigation. Two LOPS define an Estimated Position in this case. Two LOPs to define a fix are allowed only in small boat navigation. Since Auxiliary facilities are small boats by definition (under 65 feet in length), this course will define a fix as a position established by the intersection of two or more LOPs (including ranges and COPs as special cases of LOP).

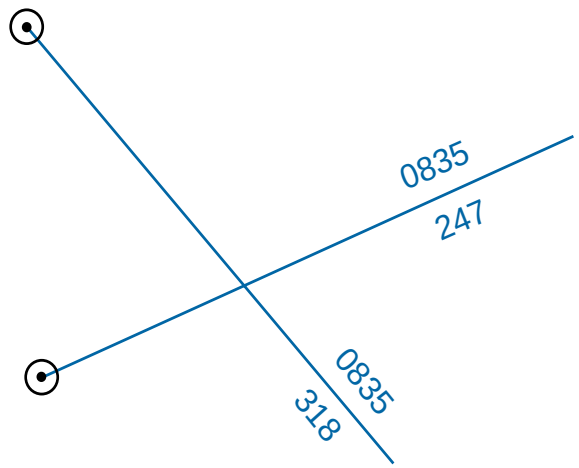
4.4.3.2. Position Triangle. The triangle formed with three LOPs plays an important role. If the bearings are taken nearly simultaneously, and if they were accurately measured and recorded, the triangle will be quite small. A relatively large triangle is an indication that the bearings were taken over too long a time, one or more measurement of bearing was inaccurate, or one or more bearings were improperly recorded (see Fig. 4-8 for the effect of transposed numbers in recording a bearing). If only two LOPs are used, the possible errors may very well be undetected, resulting in an inaccurate fix, the results of which could be disastrous.



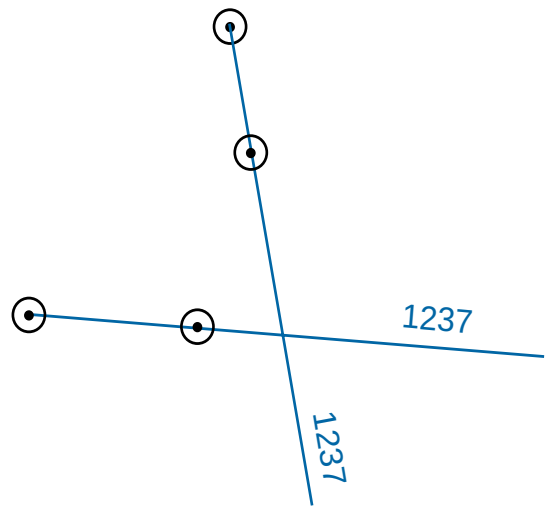
Position Triangle
Figure 4-8

4.4.3.3. LOP Combinations. There are several ways in which LOPs intersect to establish a fix, as follows:

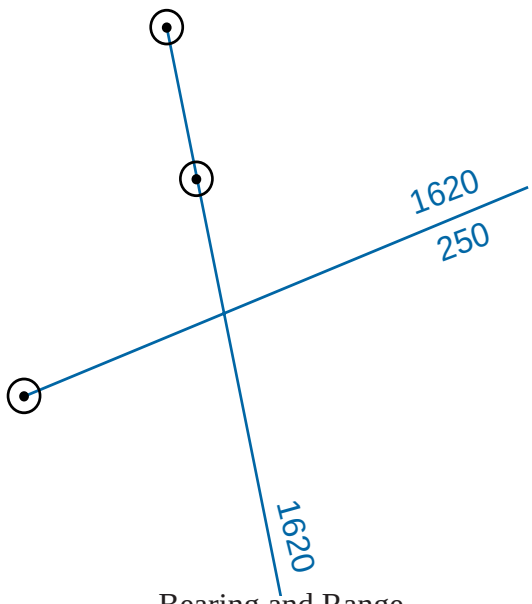
* Cross bearings
* Cross ranges
* Bearing and range
* Bearing and distance from different objects
* Bearing and distance from the same object
* Distances from different objects



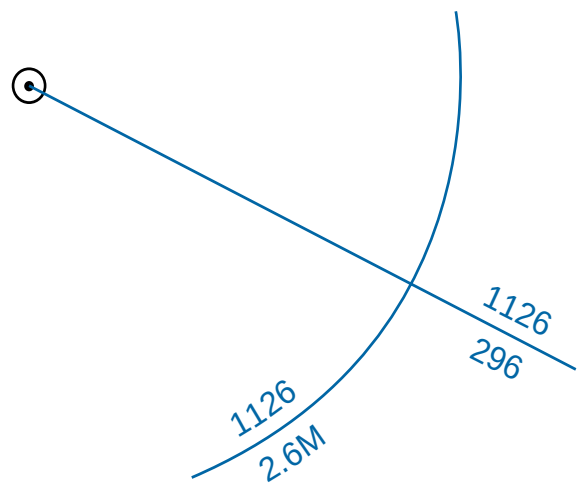
Cross Bearings
Figure 4-9



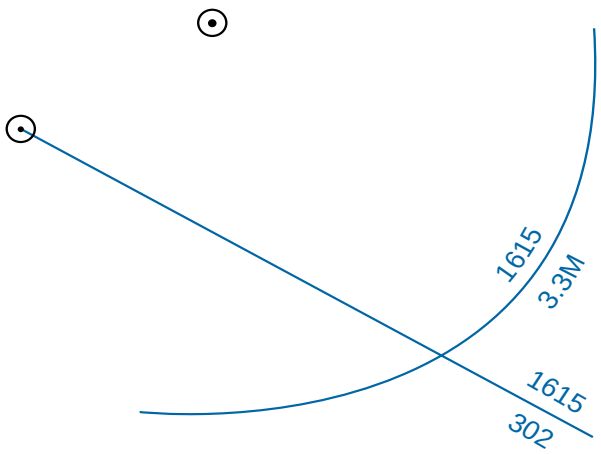
Cross Ranges
Figure 4-10



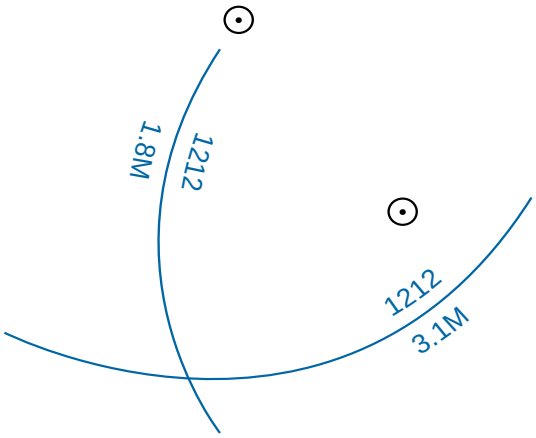
Bearing and Range
Figure 4-11



Bearing and Distance - Same Object
Figure 4-12



Bearing and Distance - Different Objects
Figure 4-13



Distance From Different Objects
Figure 4-14

4.5. SUMMARY. It is physically impossible for a navigator, working alone, to make two observations simultaneously. For this reason its important that an object who's relative bearing is changing the slowest be observed first, saving the one with the fastest change for last. Because a fix depends upon near simultaneity, the good navigator must be capable of fast, accurate visual observations. Fast, accurate plotting is necessary if the observations are to be of real use. Skillful navigation requires practice, practice, practice. If the Auxiliarist practices in fair weather to where he is comfortable and proficient, he will be able to apply his skills in foul weather and periods of restricted visibility with confidence.

4-1. Piloting is the most demanding discipline of navigation, requiring the greatest experience, soundest judgment, and _____.

a. best equipment
b. finest electronics
c. quickest reaction
d. best training

4-2. The coastal navigator must be constantly vigilant, mentally alert, and have _____ to avoid grounding or collision with objects.

a. operating radar
b. thorough knowledge
c. experience operating in reduced visibility
d. well briefed and positioned lookouts

4-3. (True/False) A line of position runs to and from an object. The object lies on a bearing from the vessel, the vessel lies on the refractional, the bearing from the object to the vessel. Both bearings define the line of position.

4-4. When using a _____, deviation is not considered.

a. fluxgate compass
b. gyro compass
c. steering compass
d. hand-bearing compass

4-5. When using the _____ compass to determine the bearing to objects, the deviation of the compass for the _____ at the moment of the sighting is considered.

a. steering, bearing to the object
b. hand-bearing, bearing to the object
c. steering, heading of the vessel
d. hand-bearing, heading of the vessel

4-6. When using relative bearings to determine the bearings to objects, the deviation of the steering compass for the _____ at the _____ _____ is considered.

a. heading of the vessel, moment of sighting
b. bearing to the object, moment of sighting
c. heading of the vessel, time of range crossing
d. bearing to the object, time of range crossing

4-7. _____ should cross each other at angles between _____.

a. Circles of position, 60° and 120°
b. Ranges, 90° and 150°
c. Lines of position, 60° and 120°
d. Reciprocal bearings, 60° and 150°

4-8. (True/False) Bearings to objects, to be used as LOPs, should fall between 60° and 120° to the vessel's course.

4-9. (True/False) When only one LOP can be established, one fact is known: the vessel lies somewhere on the course line.

4-10. (True/False) A single LOP is used in conjunction with the DR plot to determine a fix.

4-11. A range is the alignment of _____.

a. a large visible object and a charted object
b. the keel of the vessel and a charted object
c. a small object in front (closer) and a large object in the rear (further away)
d. two charted objects

4-12. Most probable positions result from information better than that for _____ but not as good as that for _____.

a. an estimated position, a fix
b. a range, a fix
c. a fix, an estimated position
d. a fix, a position triangle

4-13. A fix is the _____ of two or more LOPs, COPs, ranges, or combinations.

a. resection
b. precession
c. juxtaposition
d. intersection

4-14. (True/False) The intersection of three LOPs forms a fix. The fix is at the point where the three LOPs intersect.

4-15. A position determined through soundings, alone, should be called an _____ instead of a _____.

a. most probable position, estimated position
b. most probable position, fix
c. estimated position, most probable position
d. estimated position, fix

4-16. A position established through a proximity to a floating aid, or through bearings to the floating aid and a fixed aid is a(n) _____.

a. fix
b. most probable position
c. estimated position
d. running fix

4-17. (True/False) Because a navigator cannot sight two objects at the same time (except for a range), the first sighting should be taken on the object whose change in relative bearing is fastest, saving the one whose change is slowest for last.

4-18. (True/False) Fast, efficient plotting is the sign of a good navigator.

PROBLEMS

In the following problems, use the deviation table and the speed curve for the USCG Auxiliary Facility Helena (pages A-14 and A-16). Variation in the area is 10°W.

4-1. A vessel is heading 057°C. The relative bearing to a light house to starboard is 062°. What is the true bearing of the light house? _____

4-2. A vessel is heading 126°M. An object is sighted bearing 237° across the steering compass. What is the true bearing of the object? _____

At 0926 Helena is heading 304°C with throttles set to 2100 rpm. One observer sights a charted monument bearing 015° across the steering compass. A second observer sights a tower bearing 082° by hand-bearing compass.

4-3. What is the true bearing of the monument? _____

4-4. What is the true bearing of the tower? _____

4-5. How far will Helena have traveled in 23 minutes? _____

CHAPTER 5
PILOTING II

5. Chapter 5.

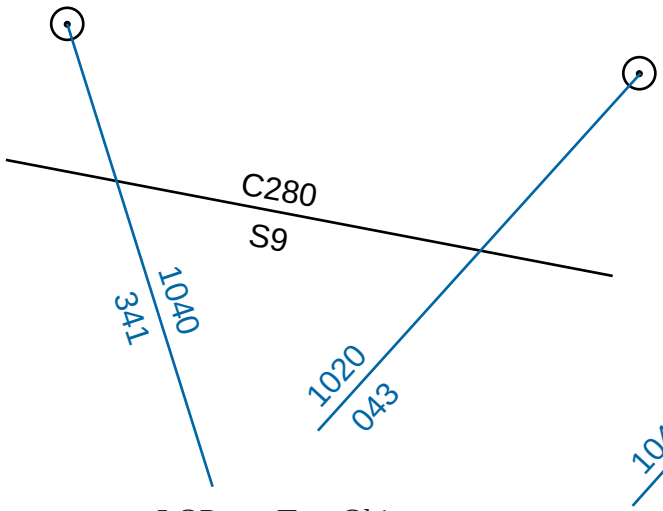
5.1. RUNNING FIX.

5.1.1. What Is It? It is often impossible to obtain sightings on two objects at the same time, a requirement to establish a fix, a known position. This usually occurs when the fix is needed the most, during times of limited visibility. A technique called a running fix allows the navigator to establish his position using a second sighting on the same or a different object at a later time. This chapter will treat several ways of determining running fixes. Unlike fixes, running fixes can use two sightings of the same object.

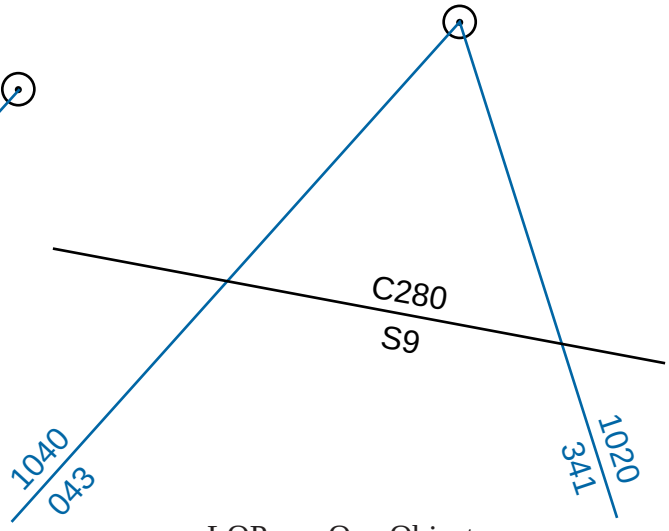
Running fixes are often taught as occurring along a straight course line without regard for external influences. It is a given, though, that the longer the time between sightings, the greater the influence of external forces. Consider that in 15 minutes a one knot current will have moved a vessel a quarter of a mile away from its corresponding DR position. Failure to consider this phenomenon could be disastrous. In addition to external forces, conditions prevailing in the area in which a vessel is operating could cause the Captain to follow a DR plot requiring course changes. Course changes could be required, also, to avoid collision. The navigator must be able to handle the real conditions with which he or she is faced. That means he must be able to quickly determine position from a second sighting when intervening events have occurred since the first sighting. Running fixes involving currents will be presented in Chapter 6, Current Sailing.

5.1.2. Advancing a LOP. Running fixes are developed by advancing an LOP taken on an object to intersect an LOP taken on the same or a different object sometime later. Figure 5-1 shows two LOPs taken 20 minutes apart on different objects. Figure 5-2 shows two LOPS taken 20 minutes apart on the same object. Figure 5-3 shows how to advance the first LOP to intersect the second. The principles and methods are identical whether one object or two are used for the LOPs. The first LOP is advanced by redrawing it, parallel to itself, in the direction, and at a distance from itself equal to the direction and distance traveled between the two observations. The course line is drawn in Figures 5-1 and 5-2 purely as a reference and as a tie-in to procedures with which most Auxiliarists are comfortable. The course and speed must be known to establish a running fix, the course line does not need to be plotted on the chart; in fact, it’s better if it’s not. This is shown in Figure 5-3. It’s also important to remember that

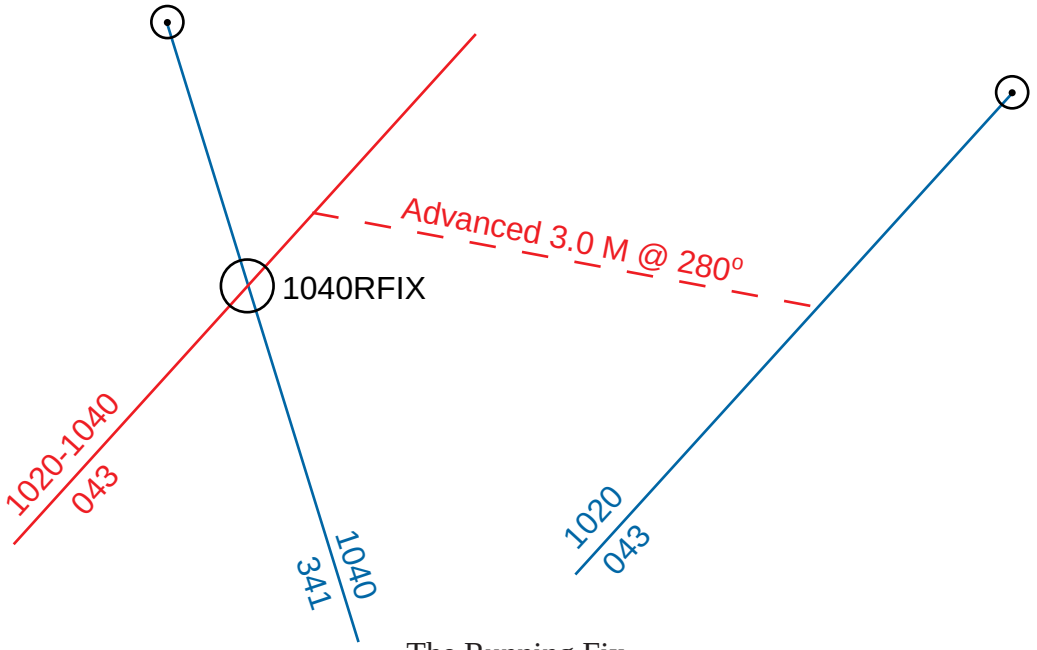
the plotted intersection of the advanced first LOP and the new LOP may be off because of the effect of current in the intervening time. This highlights the need to learn how to handle running fixes under different circumstances.



LOPs on Two Objects
Figure 5-1



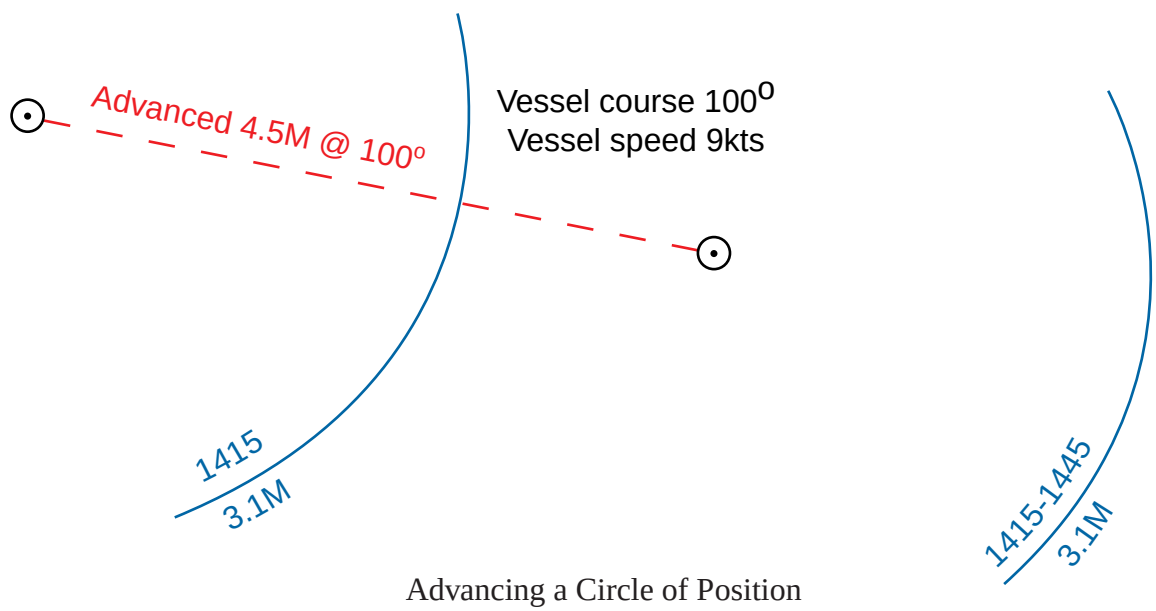
LOPs on One Object
Figure 5-2



The Running Fix
Figure 5-3

5.1.3. Method of Advancing the LOP. The most common error in developing a running fix is the direction in which the first LOP is advanced. Many people try to move it in a direction perpendicular to itself. It must be advanced in the direction the vessel is traveling for a distance equal to that traveled by the vessel between sightings. That is, it is moved parallel to itself at a constant angle to the DR plot, which is the same as along the course line. Advancing the LOP merely means redrawing it parallel to itself. The trick is determining where to redraw it. Select any point on the line of position. Through that point lay out a line parallel to the course. Scale a distance equal to that traveled by the vessel between sightings and mark that on the line. For example, if the second sighting occurs 20 minutes after the first and the vessel is running at 9 knots, it will have traveled 3 miles between sightings. Mark the point on the line a distance representing 3 miles. Draw a line through that point parallel to the LOP. The LOP (first sighting) was marked with the time, say 1620, above the LOP and the true bearing, say 212°, below. The redrawn LOP is marked with the original time and the time of the second sighting, as 1620 - 1640, above and the true bearing, 212°, below the line. The running fix is where the second LOP crosses the redrawn first LOP.

5.1.4. Advancing a COP. A circle of position may be advanced also. The procedure is a little different in that the navigator may not use any point on the circle, as he can with a line. To advance a COP, the center of the circle must be advanced in the direction of travel for the distance traveled. The circle (or arc of the circle) is redrawn with the same radius, the distance from the object, as before.



Advancing a Circle of Position
Figure 5-4

5.1.5. Running Fix with Course Changes. Course changes can occur between sightings. When this happens it must be taken into account. The process is the same. Advance the first LOP in the direction of travel for the distance traveled until the turn. Then advance it in the new direction for the distance traveled between the turn and the second sighting (or next turn, as the case may be). The easiest way to handle this, particularly if there is more than one turn, is to determine the resultant of the vectors representing the courses and distances traveled after the first sighting, using a maneuvering board (see Chapter 3). The resultant is the Course Made Good (CMG) between the two sightings. A prudent navigator will continue his DR plot between sightings. This will usually be from the DR position at the time of the sighting since one LOP can contribute only to an estimated position and DR plots are continued in those instances. From the DR position at the time of the first sighting, use the course made good for the straight line distance between that DR position and the DR position at the time of the second sighting. This represents the resultant. Advance the LOP in the direction, and for the length (distance) of the resultant (in the direction of the CMG for a distance equal to the straight line distance between the two DR positions). Redraw the LOP as described earlier. If the DR plot is continued from a point, any point, on the LOP, the point on the DR plot representing the second sighting is the point through which the LOP is redrawn. It doesn't matter which procedure is followed; the redrawn LOP will lie in the exact same place. Where it intersects the second LOP is the running fix.

TABLE 7

Distance of an Object by Two Bearings

Difference between the course and second bearing	Difference between the course and first bearing													
	20°		22°		24°		26°		28°		30°		32°	
°														
30	1. 97	0. 98												
32	1. 64	0. 87	2. 16	1. 14										
34	1. 41	0. 79	1. 80	1. 01	2. 34	1. 31								
36	1. 24	0. 73	1. 55	0. 91	1. 96	1. 15	2. 52	1. 48						
38	1. 11	0. 68	1. 36	0. 84	1. 68	1. 04	2. 11	1. 30	2. 70	1. 66				
40	1. 00	0. 64	1. 21	0. 78	1. 48	0. 95	1. 81	1. 16	2. 26	1. 45	2. 88	1. 85		
42	0. 91	0. 61	1. 10	0. 73	1. 32	0. 88	1. 59	1. 06	1. 94	1. 30	2. 40	1. 61	3. 05	2. 04
44	0. 84	0. 58	1. 00	0. 69	1. 19	0. 83	1. 42	0. 98	1. 70	1. 18	2. 07	1. 44	2. 55	1. 77
46	0. 78	0. 56	0. 92	0. 66	1. 09	0. 78	1. 28	0. 92	1. 52	1. 09	1. 81	1. 30	2. 19	1. 58
48	0. 73	0. 54	0. 85	0. 64	1. 00	0. 74	1. 17	0. 87	1. 37	1. 02	1. 62	1. 20	1. 92	1. 43
50	0. 68	0. 52	0. 80	0. 61	0. 93	0. 71	1. 08	0. 83	1. 25	0. 96	1. 46	1. 12	1. 71	1. 31
52	0. 65	0. 51	0. 75	0. 59	0. 87	0. 68	1. 00	0. 79	1. 15	0. 91	1. 33	1. 05	1. 55	1. 22
54	0. 61	0. 49	0. 71	0. 57	0. 81	0. 66	0. 93	0. 76	1. 07	0. 87	1. 23	0. 99	1. 41	1. 14
56	0. 58	0. 48	0. 67	0. 56	0. 77	0. 64	0. 88	0. 73	1. 00	0. 83	1. 14	0. 95	1. 30	1. 08
58	0. 56	0. 47	0. 64	0. 54	0. 73	0. 62	0. 83	0. 70	0. 94	0. 80	1. 07	0. 90	1. 21	1. 03
60	0. 53	0. 46	0. 61	0. 53	0. 69	0. 60	0. 78	0. 68	0. 89	0. 77	1. 00	0. 87	1. 13	0. 98
62	0. 51	0. 45	0. 58	0. 51	0. 66	0. 58	0. 75	0. 66	0. 84	0. 74	0. 94	0. 83	1. 06	0. 94
64	0. 49	0. 44	0. 56	0. 50	0. 63	0. 57	0. 71	0. 64	0. 80	0. 72	0. 89	0. 80	1. 00	0. 90
66	0. 48	0. 43	0. 54	0. 49	0. 61	0. 56	0. 68	0. 62	0. 76	0. 70	0. 85	0. 78	0. 95	0. 87
68	0. 46	0. 43	0. 52	0. 48	0. 59	0. 54	0. 66	0. 61	0. 73	0. 68	0. 81	0. 75	0. 90	0. 84
70	0. 45	0. 42	0. 50	0. 47	0. 57	0. 53	0. 63	0. 59	0. 70	0. 66	0. 78	0. 73	0. 86	0. 81
72	0. 43	0. 41	0. 49	0. 47	0. 55	0. 52	0. 61	0. 58	0. 68	0. 64	0. 75	0. 71	0. 82	0. 78
74	0. 42	0. 41	0. 48	0. 46	0. 53	0. 51	0. 59	0. 57	0. 65	0. 63	0. 72	0. 69	0. 79	0. 76
76	0. 41	0. 40	0. 46	0. 45	0. 52	0. 50	0. 57	0. 56	0. 63	0. 61	0. 70	0. 67	0. 76	0. 74
78	0. 40	0. 39	0. 45	0. 44	0. 50	0. 49	0. 56	0. 54	0. 61	0. 60	0. 67	0. 66	0. 74	0. 72
80	0. 39	0. 39	0. 44	0. 44	0. 49	0. 48	0. 54	0. 53	0. 60	0. 59	0. 65	0. 64	0. 71	0. 70

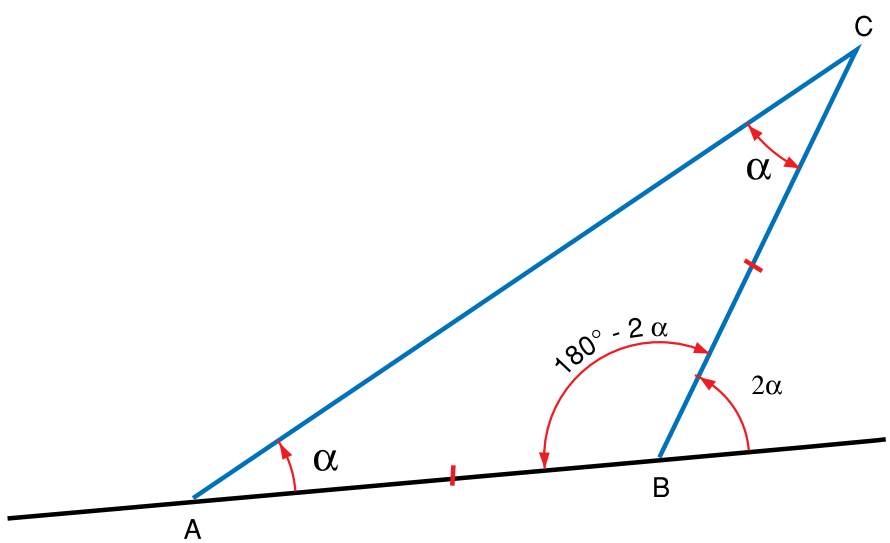
Extract from Table 7 from Bowditch, Vol. 2, 1981

Figure 5-5

5.1.6. Mathematical Solutions

5.1.6.1. Angles Off the Bow. The table in Figure 5-5 provides the distance from the object at the second sighting as a function of the angles off the bow of both sightings (the first number in each column multiplied by the distance run between observations). It also provides the distance when abeam (the second number, also multiplied by the distance traveled).

5.1.6.2. Doubling the Angle on the Bow. This table, which is not likely to be aboard an Auxiliary facility, is not necessary for a mathematical solution to advancing a position. A special case, called doubling the angle on the bow, is based on geometric principles that are simple to understand. The process uses the geometry of an isosceles triangle. In the diagram in Figure 5-6, angle A equals α. Angle B is 2α, double angle A. A triangle consists of 180°, as does a straight angle. The straight angle formed by angle B and the interior angle of the triangle equals 180°. Therefore the interior angle equals $180° - 2\alpha$. Angle C, then, must equal α ($\alpha + \alpha = 2\alpha$ and $180° - 2\alpha + 2\alpha = 180°$). The sides opposite the equal angles of an isosceles triangle are equal; therefore, side AB equals side BC. Side AC represents the first sighting, 30° off the port bow. Side BC represents the second sighting of the same object, 60° off the port bow. Side AB represents the course and distance traveled between the two sightings. Since sides AB and BC are equal, the object is as far from the vessel at the time of the second sighting as the vessel traveled between the two observations. This



The Geometry of Doubling the Angle on the Bow
Figure 5-6

is true no matter what angles are used as long as the second angle is twice the first. Therefore, it is possible to determine the running fix of the second sighting merely by measuring a distance on the second LOP from the object equal to the distance traveled between the sightings (speed and time between sightings).

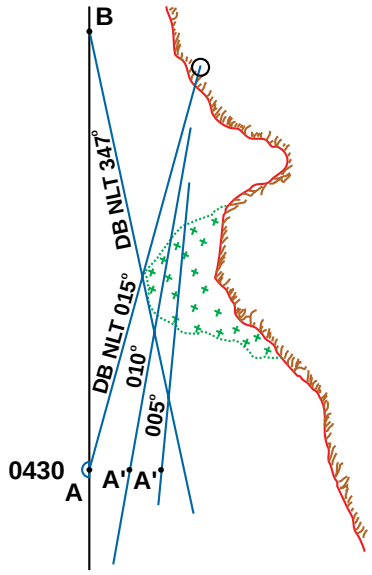
5.1.6.3. Seven Eighths and Seven Tenths Rules. Some sets of doubled angles possess special properties. The 22.5° - 45° case meets the Seven-Tenths Rule; that is, when abeam the distance to the object will be 0.7 times the distance traveled between sightings. The 30° - 60° case meets the Seven-Eighths Rule. The object is 7/8 (0.875) the distance traveled between sightings when the vessel is abeam.

5.1.6.4. Use of the Pelorus. Doubling the angle on the bow is a good, precise method of establishing a running fix but it's not practical unless the vessel has a good pelorus and, for a small vessel, is not practical at all for any combination involving fractions of degrees. The best way to accomplish this procedure is to preset the first angle, mark when the object is sighted across the pelorus, starting a stop watch at that instant. Preset the second angle. Mark when the object is sighted across the instrument, stopping the stop watch at that instant. The stop watch time times the speed will give the distance traveled which is the distance from the object at the time of the second sighting. The distance from the object plus the LOP on the bearing of the second object establish the fix.

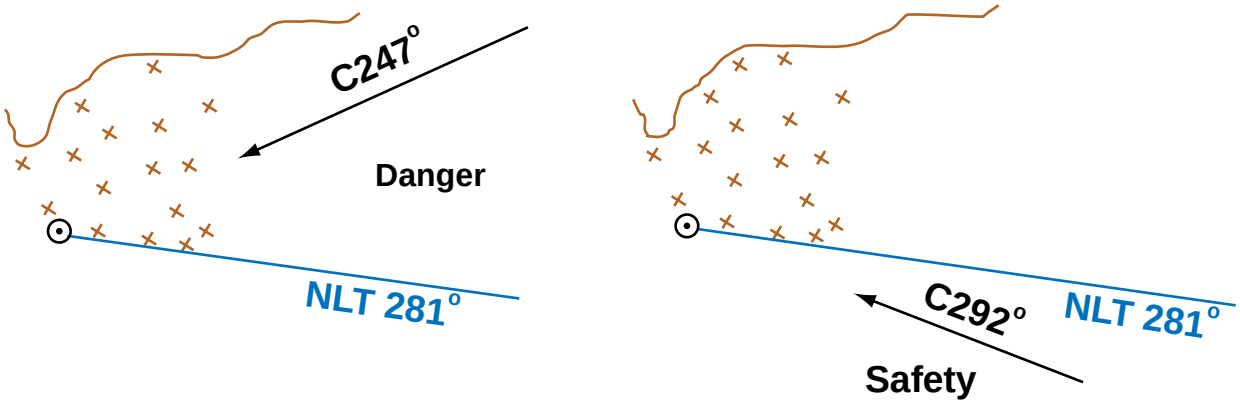
5.2. DANGER BEARINGS.

5.2.1. Running Past Reference. Danger bearings are a very common and easy to use means of avoiding trouble, of staying well clear of dangerous waters. The concept is very much misunderstood. Figure 5-7 [36] discusses one aspect of danger bearings. Figure 5-7 shows that the danger bearing to lighthouse Oscar is not less than (NLT) 015°. That means that if the relative bearing to the lighthouse is 015° or less from the DR plot and the present heading of the vessel, the vessel is standing into the shoal water. It would actually be somewhere closer to shore than position A where a course of 000° could take it into the shoal water. If the relative bearing to the lighthouse is more than 015°, it is heading through safe water. CAUTION: if the vessel is further back on its course line, that is, the DR plot is incorrect and it has not yet reached point A, the lighthouse could bear 010° and the vessel still be safe on course 000°.

[36] Shufeldt, Fig. 12-9



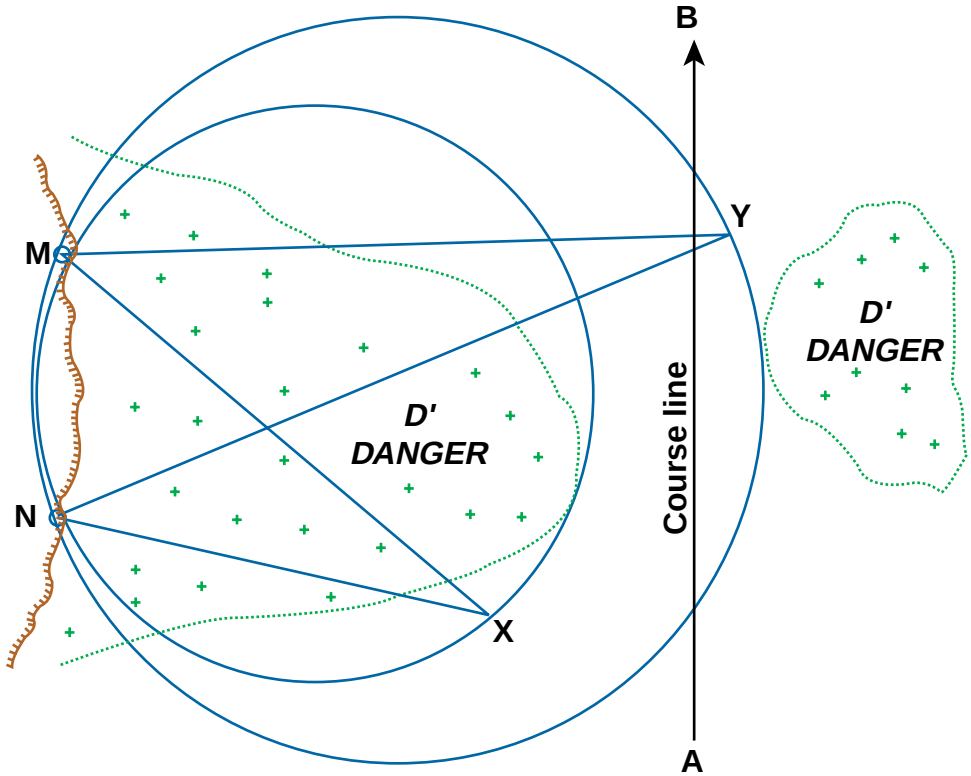
Danger Bearings for Point B
Figure 5-7



Danger Bearings
Figure 5-8

5.2.2. Running Towards the Reference. If point B, the destination or intermediate waypoint, is a visible charted object such as a buoy, a better approach to staying out of the shoal water is to determine the danger bearing for point B, in this case (Figure 5-7) 347°. Is it more than or less than 347°? If a vessel heads for point B at 340° it is headed through the shoal water. Consequently, any heading bearing to point B less than 347° stands the vessel into danger and the danger bearing is designated NLT

347° (not less than 347°). Any heading greater than 347° assures the vessel of passage through safe water. Figure 5-8 shows that a heading to the reference object less than 281° is dangerous while a heading greater than 281° to the object is safe.

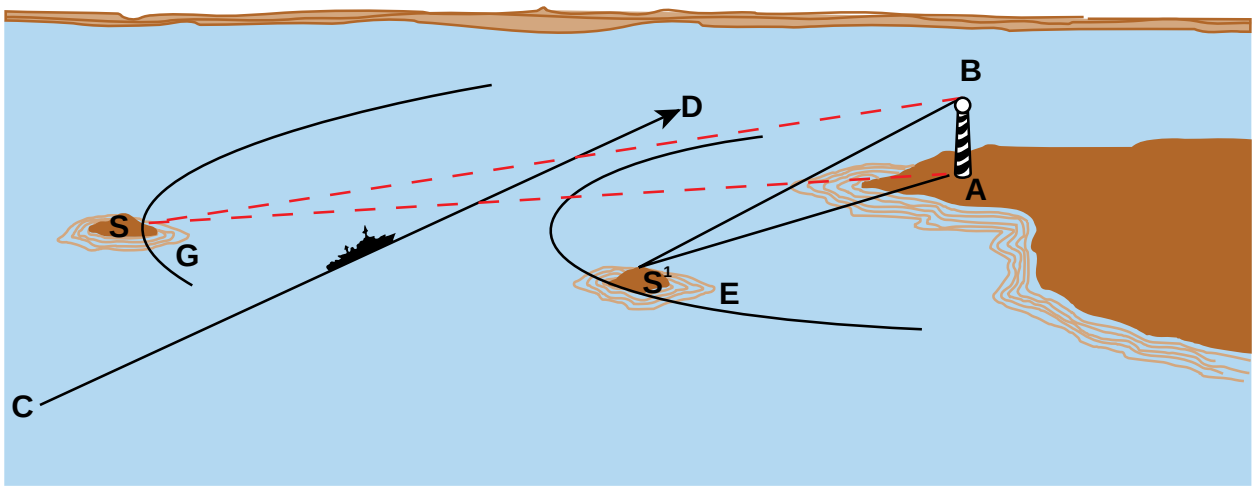


Horizontal Angles to Determine Danger
Figure 5-9[37]

5.2.3. Danger Bearings by Horizontal or Vertical Angles.

5.2.3.1. Horizontal Danger Angles. The angles formed by the end points of a circle segment (points M and N in Figure 5-9) and any points on the circumference of the circle (point X, a moving point) are equal. If the angle increases, point X is inside the circumference. If it decreases, the point is outside. The circle is constructed by drawing chord MN (the straight line connecting M and N) and chord MX or NX, where X can be any point on the circle outside of arc MN. Construct a perpendicular bisector through each chord. The center of the circle is where the perpendiculars intersect.

[37] Shufeldt, Fig. 12-11, pg. 104



Vertical Angles to Determine Danger
Figure 5-10[38]

5.2.3.2. Vertical Danger Angles. Vertical angles are used to determine distance from an object of known height by measuring the angle between the top and bottom of the object (to the center of the light housing for lighthouses and other large fixed lights). Using the formula:

$$d = \frac{h}{6076 \tan ø}$$

where d = distance in miles
h = height of the object in feet
ø = the angle measured by sextant from the bottom to the top of the object

6076 is the number of feet in a nautical mile, the constant necessary to convert the height of the object in feet to distance in miles. As long as the vertical angle is constant, the distance to the object is constant. If the angle increases, the observer (the vessel) is closer. If the angle decreases, the vessel is further away. It should be clear that the safe course between objects S and S' (Figure 5-10) is one where the angle to the object is ≤ AS'B and ≥ ASB.

[38] Shufeldt, Fig. 12-12, pg. 105

5.3. NAVIGATING WITHOUT A FIX.

5.3.1. Constant Bearing Towards an Object. It is possible to navigate without fixes and to ensure that you remain in safe water. If a charted object is visible, and if the direct course to the object is through safe water, a navigator may follow that direct course, keeping the object in sight. As long as the bearing (heading) does not change, the vessel is on that path through safe water. If the vessel keeps heading for the object and the heading decreases, the vessel has drifted to the right of the course line. Conversely, if the heading increases, the vessel has drifted to the left of the course line. Remember, left turns decrease the heading, while right turns increase it. If the vessel has drifted to the right and is still headed for the object, the situation is the same as a left turn (It is, in fact, a left spiral).

5.3.2. Running Ranges. Ranges can be navigational ranges, set up for the sole purpose of helping a vessel stay in the center of a channel. They can also be the simple alignment of two charted objects. It doesn't matter which. If two objects in alignment mark a course through safe water, the vessel may proceed on that range and be assured of safe passage. If the vessel drifts to the right, the forward object comprising the range will move to the left, if the drift is to the left, the forward object will appear to move to the right.

5.3.3. Soundings. In areas where there are no obstructions and bottom contour (lines of equal depth) lines are fairly smooth, it is possible to follow a bottom contour line using the depth sounder. As long as the depth sounder shows a relatively constant depth, the vessel is following the contour. Drift to the right or left can be determined by changes in the depth as shown by the depth sounder, used in conjunction with the chart. A position determined by soundings alone can be considered to be no better than an estimated position, only slightly better than a DR position.

5-1. A running fix is established when _____ of two objects is impossible or impractical.

a. intersection
b. near simultaneous observation
c. juxtaposition
d. bearings

5-2. (True/False) Moving the LOP along the course line at a constant angle to the DR plot and moving the LOP parallel to itself along the course line mean the same thing.

5-3. (True/False) In establishing a running fix, the first LOP is moved perpendicular to itself in the direction the vessel travels between sightings.

5-4. (True/False) An important difference between a fix and a running fix, besides the time difference between observations, is the fact that both observations may be of the same object.

5-5. The advanced LOP is labeled with _____ above the line and the ____ _____ below.

a. bearing, time of second sighting
b. time of the first and second sightings, course
c. time of the first and second sightings, bearing
d. time of second sighting, bearing

5-6. A running fix can be determined by advancing circles of position. This is done by moving _____ in the direction of travel a distance equal to that traveled between observations and redrawing the circle segment.

a. a point on the circumference of the circle
b. the radius of the circle
c. the chord of the arc of the circle perpendicular to the DR plot
d. the center of the circle

5-7. (True/False) When course changes are made between observations, the first LOP is moved parallel to the course line for a distance equal to that traveled between the first observation and the course change. It is then moved parallel to the new course line for a distance equal to that traveled between the turn and the second observation or the next turn.

5-8. Another method of advancing the first LOP is to move it parallel to the _____ of all the course changes and time between observations.

a. resultant
b. reciprocal
c. refraction
d. sum

5-9. This is done by advancing the LOP in the direction of the CMG between the _____ at the time of the first sighting and the _____ at the time of the second sighting, and for a distance equal to the distance between the two.

a. intersection of the LOP and the course line, DR position
b. fix, fix
c. DR position, DR position
d. estimated position, estimated position

5-10. A mathematical solution to advancing a position is a technique called _____.

a. running the block
b. doubling the angle on the bow
c. rotating the isosceles triangle
d. seven-eighths rule

5-11. This technique is based on the geometric principal that the sides of a triangle that are _____ equal angles of the triangle _____.

a. opposite, are opposite
b. next to, are equal
c. equal to, are equal
d. opposite, are equal

5-12. (True/False) In applying this technique, the governing principal is that when the object is observed at an angle off the bow that is double the angle at the first sighting, the object is as far from the vessel as the vessel traveled from the second sighting.

5-13. (True/False) The seven-tenths rule means that when the object is abeam of the vessel it's distance from the vessel will be seven-tenths of the distance from the object at the first sighting.

5-14. Doubling the angle on the bow is a good, precise method of _____ _____ but is not practical without a _____.

a. establishing a running fix, good pelorus
b. establishing a fix, fluxgate compass
c. establishing a running fix, fluxgate compass
d. establishing a fix, good pelorus

5-15. A bearing used to keep a vessel clear of an offshore area of shoal water that must be passed closely is a danger bearing. Danger bearings should be based on _____ that can be seen far ahead.

a. a lighthouse
b. a range
c. a reference
d. hazards

5-16. A danger bearing is marked NLT 180°. This means that a vessel headed for the reference object on a heading of 175° is standing ____ danger.

a. into
b. out of
c. clear of
d. don't know, not enough information is provided

5-17. Danger can be indicated by horizontal or vertical angles. Horizontal danger angles are based on the geometric principal that all angles formed between the _____ of an arc of a circle and points any where _____(outside of the arc, itself) are _____.

a. ends, on the circumference, equal
b. center, on the circumference, clear of danger areas
c. ends, outside of the circle, equal
d. circumference, on the circumference of the circle, equal

5-18. A vessel which measures a larger angle than the horizontal danger angle is _____ the circle, in the danger area. A smaller angle means the vessel is in safe water, _____ the circle.

a. outside, inside
b. outside, on
c. inside, outside
d. inside, on

5-19. (True/False) A vertical angle between the top and bottom of an object of known height is used to estimate the distance to the object and forms a circle of position.

5-20. (True/False) A vessel wants to pass between two dangerous areas. Vertical angles representing the distance from the dangerous areas to a prominent object can be determined. A vessel can safely pass between the two dangerous areas if angles measured from the vessel are less than the predetermined angle for the off shore area **and** greater than the angle for the near shore area.

5-21. (True/False) A vessel is navigating without fixes by steering to objects seen ahead. If the heading decreases the vessel has drifted left of the course line.

5-22. (True/False) A less precise means of determining position is to use soundings. This method produces an estimated position, which is slightly better than a DR plot.

PROBLEMS

5-1. A lighthouse bears 330°R. What is its relative bearing when the angle on the bow is doubled? ____

5-2. The USCG Auxiliary facility Helena is on course 212° at 10 knots. At 1406 Osprey Point Light is observed bearing 177°. Thirteen minutes and twelve seconds later the light bears 142°. How far away is the light? ____

5-3. At 1019, while on course 068°, speed 15 knots, a navigator sights a monument bearing 294°R. At 1027 the vessel turns to course 089°, still maintaining 15 knots. At 1033 she turns to 110° and slows to 10 knots. At 1051 the navigator sights a radio tower bearing 303°R. In what direction is the first LOP moved to establish a running fix? ____

5-4. How far is the first LOP advanced? ____

5-5. A yacht is heading 273° at 20 knots. At 1047 she sights an antenna bearing 30° off the port bow. At 1111, while still heading 273° at 20 knots, the antenna bears 60° off the port bow. How far away will the antenna be when the relative bearing is 270°? ____

5-6. The danger bearing to the lighted buoy marking the eastern end of Marl Bank is NMT 288°. A vessel approaches from the Southeast on heading 312°. The buoy bears 000°R at 1.6M. The vessel turns to heading 325°. Is she standing into danger? _____.

5-7. The chart shows Jessica Point Light to be 112 feet high with a nominal range of 24M. A navigator measures the angle from the base of the light to the center of the light housing with a sextant. She determines the angle to be 22'. How far away is she from the light? ____

5-8. How far can Jessica Point Light be seen by an observer whose eye is 14 feet above the water? ____

5-9. How high would the eye of the observer have to be to see the light for its nominal range if the atmospheric conditions are normal? ____

CHAPTER 6
CURRENT SAILING

6. Chapter 6.

6.1. CURRENT.

6.1.1. The Current Mind Set. Common usage defines current as the horizontal movement of water (differentiated from the vertical movement - tide). This is only one aspect of current as the term is used in current sailing and coastal navigation. It is important that the difference between current as used in navigation, and current as used in water movement be thoroughly understood. Chapter 8, Tides and Current - Current, will deal with the movement of water usage. This chapter deals with the navigational usage. Dead reckoning treated the determination of position as the extension of the last known position by direction and distance of travel without regard for any external influences. Current, which in the navigational sense is the sum of <u>all</u> the external influences, was disregarded. Piloting continued the no current mind set through determination of fixes which involves almost simultaneous observations of charted objects. Chapter 5 introduced the element of time through the development of running fixes, where a second observation of the same or another object occurs some time after the first. This new element, time, forces us to consider the external influences called current, because it is current acting over time that causes our vessel to be somewhere (the fix or running fix) other than where we expected it to be (the DR position). Current, the external influences, include:

1. Water current
2. Leeway
3. Wave and swell action
4. Inaccurate steering
5. Compass errors
6. Speed curve inaccuracies
7. Knot meter, speedometer, or speed log inaccuracies
8. Fouled hull or propeller
9. Vessel, engines (outboard), or sails out of trim

10. Propeller slip

11. Other influences on vessel speed or heading

6.1.2. Definitions.

6.1.2.1. Current Sailing. Current sailing is the art of selecting course and speed through the water, making due allowance for the effect of a predicted or estimated current, so that upon completion of travel, the intended track and the actual track will coincide, and you will have arrived at your desired destination. Primarily, current sailing is the application to the intended track of the best available information about the current to determine what course and speed to use. Additionally, however, the term is expanded to include the determination of actual current - by comparison of DR positions and fixes - and the prediction of anticipated track if course and speed are specified. [39]

6.1.2.2. Water Movement Current. Although current, in the navigational sense, consists of all the external factors working on a vessel, the greatest of these is the movement of water. There are two basic types of water movement current, tidal and non-tidal. Non-tidal include ocean, wind-driven, and river currents.

6.1.2.3. Ocean Currents. Ocean currents are well defined and extend over a large area. These currents, such as the Gulf Stream, the Japanese Current, etc., are well-known, charted, and predictable. They have a great influence on vessels crossing, following, or opposing them. They are important to ocean navigators but have little or no effect in coastal navigation (piloting).

6.1.2.4. Wind-driven Currents. Wind-driven currents are caused by steady winds over long fetches for a prolonged period of time, over 12 hours. They usually do not impact coastal navigation. Wind currents are not leeway. Wind currents and leeway are both caused by wind action but leeway is the effect of the wind on a vessel as a sail (the entire aspect area of the vessel acts as a sail. The aspect area is the exposed portion of the vessel against which the wind blows and is called sail area). It literally blows the vessel in the direction the wind is blowing. The leeway velocity of the vessel never equals the wind velocity. The leeway velocity is a function of the area of the vessel exposed to the wind (sail area), and the resistance the vessel offers through hull design and displacement (wetted area). Although not a wind-driven current in the sense of movement of water, leeway is one of the external forces that makes up current in the navigational sense. Leeway does impact coastal navigation.

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[39] Dutton's, p. 177

As an aside, it's interesting to note that a given wind will not yield a specific height of waves. A 25 knot wind blowing for a period of time will cause 4 foot seas. Double the amount of time and the seas can increase to 10 or 12 feet, even though the wind speed remains 25 knots. If the wind is blowing with a current (water movement) the seas are not nearly as high or as violent as wind blowing steadily into the current.

6.1.2.5. River Currents. River current is a special movement-of-water case that directly effects a vessel in obvious ways.

6.1.2.6. Tidal Currents. Tidal currents do impact coastal navigation. Tidal currents are, as would be expected, caused by tidal action. In harbors and estuaries they are reversing in nature, as in ebb and flood; along the coast they tend to be rotary. This will be treated further in Chapters 7 and 8.

6.1.3. Actual Current. Actual current is the current encountered by a vessel, the result of all the external forces at work on the vessel. It can only be determined by accurate measurement of the distance and direction of an accurate fix from the DR position of the vessel for that same time.

6.1.4. Set and Drift

6.1.4.1. Set of the Current. Auxiliarists are used to the reporting of wind direction as the direction the wind is blowing from; that is, an East Wind is blowing from the east to the west and a 227° wind is blowing from 227° towards 047°. It is important to remember that the *set* of a current is just the opposite. It is the direction toward which the current is flowing or the vessel is displaced; that is, if the set of the current is 035°, a vessel's actual position (fix) will be 035° from the DR position for that time.

6.1.4.2. Drift of the Current. The speed of the current is called *drift.* It is measured in knots, therefore, any distance a vessel is moved over time must be converted to nautical miles per hour.

6.2. CURRENT SAILING.

6.2.1. Current Problems and Use of the Maneuvering Board. The term "current problems" refers to the determination of currents encountered, the determination of the action of currents on vessels, or the action of vessels to compensate for known or anticipated currents. Current problems are solved through vector arithmetic and are best done graphically using a maneuvering board. The maneuvering board is a convenient, easy way to solve current problems. It will allow a current problem to be laid out at a larger scale than can be done on a chart, thereby providing greater accuracy,

and helps to keep the chart clean. Bitter experience has taught us, the hard way, that a cluttered chart can lead to serious navigational errors such as heading off on the wrong course. The maneuvering board is described in Chapter 3, along with a traverse sailing problem to illustrate its use.

Use of the Maneuvering Board to Solve Current Problems. A simple exercise will illustrate the use of the maneuvering board in solving current problems. The Captain wishes to travel 248° at 8 knots. A foul current is flowing 140° at 2.3 knots. What course must be steered and what speed must be made through the water to track the desired course and speed?

1. On the maneuvering board lay out a vector from the origin to the eighth circle on the 248° radial (draw a light line from the origin through the tic mark for 248° and mark, or put an arrow head at 8 knots - the eighth circle). This is the track vector. Its tail is at the origin and its head is 8 knots away at 248°.

2. Place the parallel rulers so the edge passes through the origin and the 140° mark on the outer circle. "Walk" this setting to the head of the track vector and draw a line which crosses the head of the track vector.

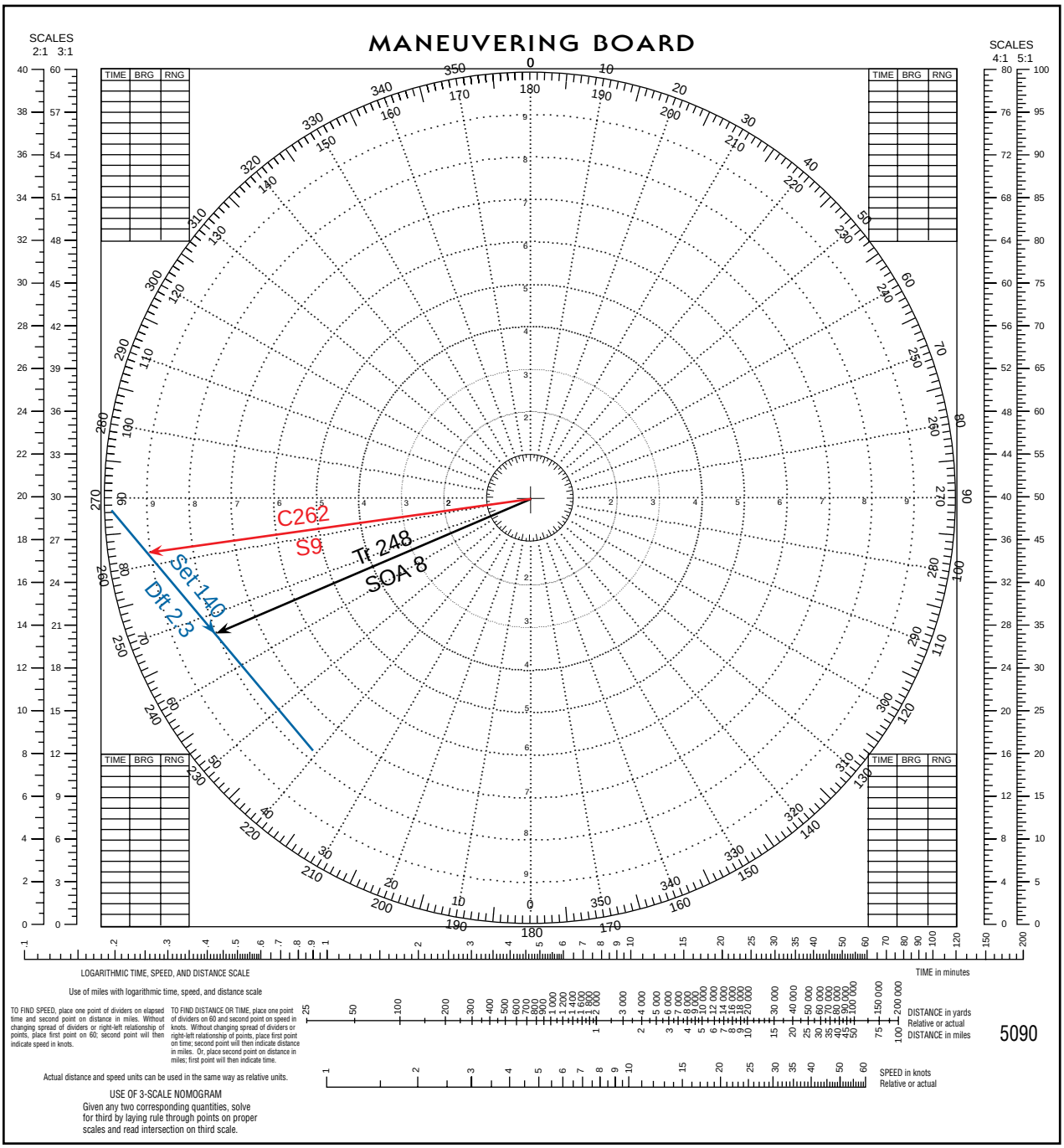
3. Using dividers, scale off 2.3 knots (from the origin to the third dot past the second circle on any radial).

4. Consider what the current does to the vessel. You are traveling south westerly and the current is moving south easterly. The current will be moving you off course to the south, so you must steer to the north to compensate.

5. Lay off the 2.3 knots on the 140° line on the north side of the line. That is, the point of the divider at the head of the track vector represents the head of the current vector and the tic mark 2.3 knots away is the tail of the vector.

6. Draw a line from the origin to the tail of the current vector and mark where its extension crosses the outer circle. The direction (262°) is the course which must be steered and the length of the vector (9 knots) is the speed that must be maintained to track 248° at 8 knots.

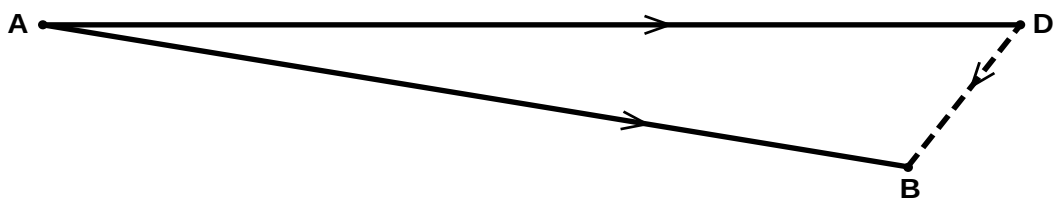
7. If the problem had been to determine the track and speed of advance if you were steering 248° at 8 knots, the current vector would have been drawn with its tail at the head of the course vector in the direction 140°. The track would have been 232° and the speed of advance 7.6 knots.



Solution of Current Problem on the Maneuvering Board
Figure 6-1

6.2.2. Relation of Vectors. Notice in the current example and its variation, that the tail of the current vector coincides with the head of the course vector and its head with the head of the track vector. Except for one special case, this condition will always prevail.

6.2.3. The Current Triangle. Figure 6-2 [40] presents the current triangle diagram. It can be used to solve any current sailing problem the coastal navigator might encounter.



PART	USING ESTIMATED CURRENT	USING ACTUAL CURRENT
Point A	Present position (fix) of vessel	Previous position (fix) of vessel
Point D	Future DR position of vessel	Present DR position of vessel
Point B	Future estimated position of vessel	Present position (fix) of vessel
Side AD	Course and speed vector	Course and speed vector
Side AB	Intended track and SOA	Actual track and SMG
Side DB	Anticipated or expected current	Actual current encountered

Points D and B are always at the same time in both cases

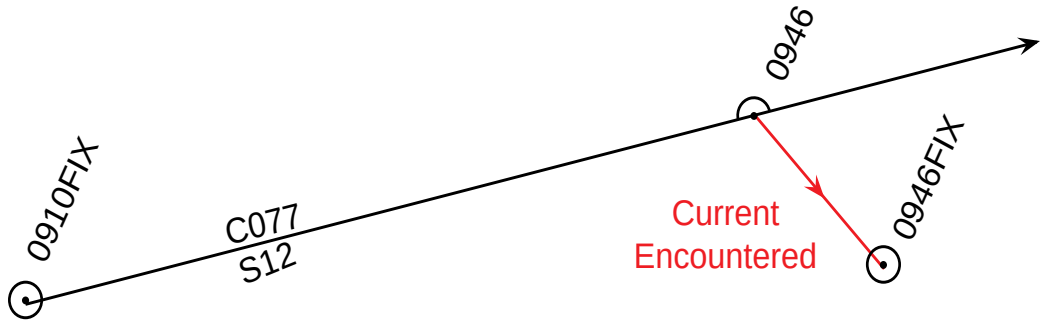
The Current Triangle
Figure 6-2

6.2.3.1. Constructing the Current Triangle - A Convention. In constructing current triangles, the current vector (side DB) can be drawn to the head or from the tail of the track vector (side AB) or it can be drawn from the head or to the tail of the course vector (side AD). To eliminate confusion and to simplify understanding, we will use a standard convention, the current vector will be drawn to or from the head of the track or course vectors. There is one exception to this rule, which will be discussed below. There are certain aspects of current and its effects that you must be familiar with:

6.2.3.2. Types of Current Problems - Cases

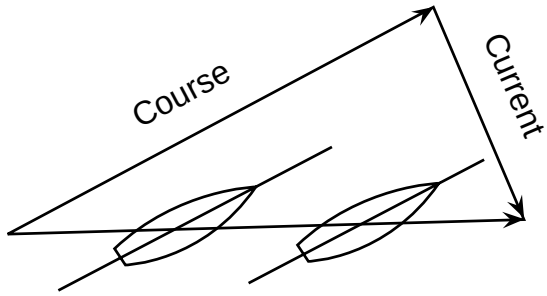
[40] Dutton's, Fig. 1208, p.180

6.2.3.2.1. Case 1: Fix is not at the DR position. You are not where you expected to be (DR position). Why not? Dead reckoning, as you know, is the extension of the last known position (LKP) by course and distance without regard for external influence. When a fix puts you somewhere other than where you expected to be, external influence (current) is the cause. The direction from the DR position to the fix is the set, or direction of the current. The distance between the two, divided by the time from the LKP, will give the drift, or speed of the current. This particular situation is plotted on the chart.



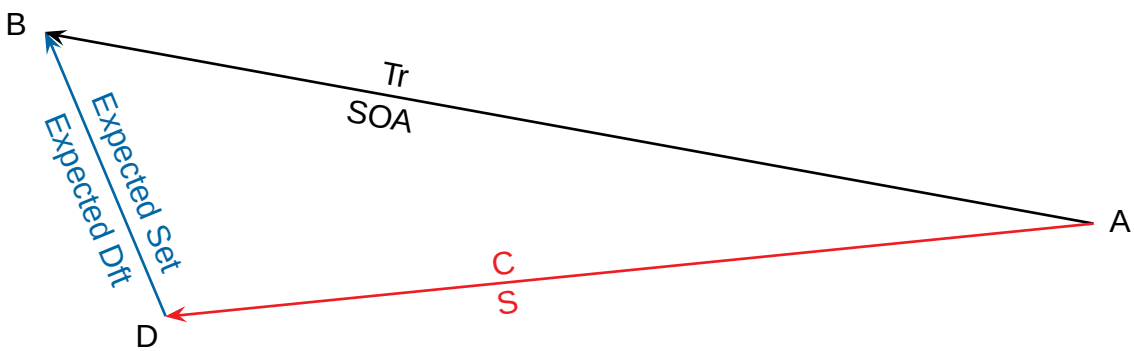
Case 1: Fix is Not at the DR Position
Figure 6-3

6.2.3.2.2. Case 2: Course to steer to follow desired track. You want to follow a given track at a specified speed of advance in the face of an anticipated current. What course must you steer and at what speed to do this? In this situation, the current will move you away from your intended track so you must steer into the current to compensate. A fair current will push you faster and a foul current will slow you down so you must also adjust your speed to compensate. The track vector (AB) is drawn on the maneuvering board. Remember, a vector has direction (the direction of the track you want to follow) and magnitude (the SOA). The current vector (DB) is drawn to the head of the track vector (the heads of the two vectors are at the same point). Its direction is the set of the current and its magnitude is the drift. The course vector (AD) is drawn from the origin to the tail of the current vector. Its direction is the course that must be steered and its magnitude (length) is the speed that must be made through the water (rpms required or speedometer reading) to compensate for the expected current. It's important to recognize that you are not traveling in the direction you are steering. You are trav-



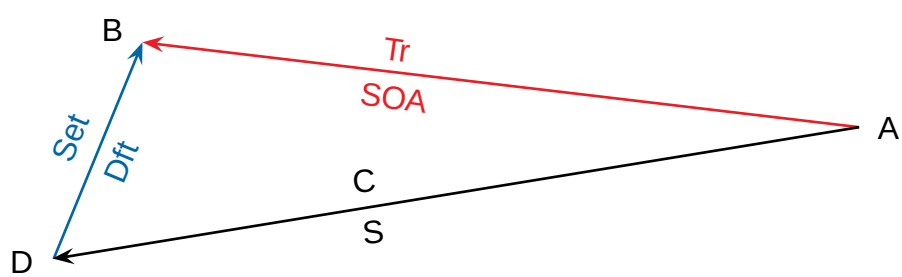
Crabbing to Track
Figure 6-4

eling the track line while steering the given course. This is known as crabbing into the current and is illustrated in Figure 6-4.



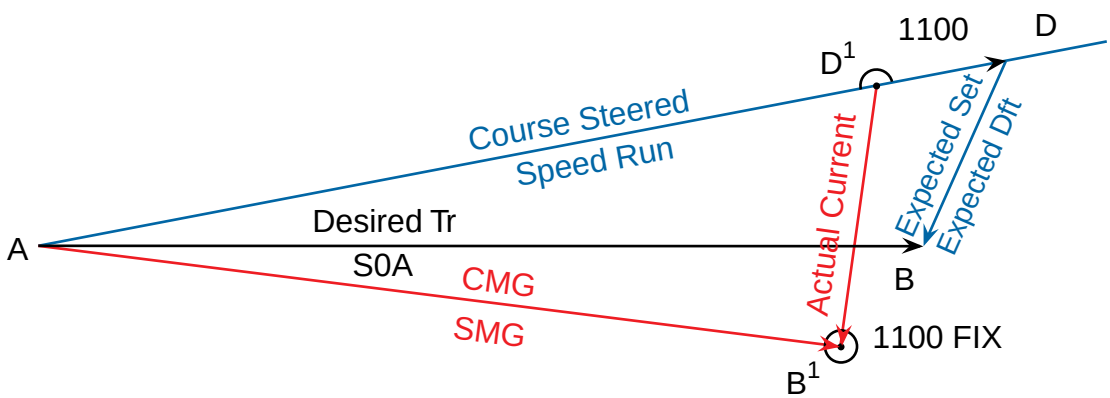
Case 2: Course to Steer to Follow Desired Track
Figure 6-5

6.2.3.2.3. Case 3: Hold course and speed in the face of current. You want to steer a given course and run at a given speed through the water (rpms required or speedometer reading), letting an anticipated current carry you where it will. The current will move you off the course line in the direction of the set for a distance appropriate to the drift and the time involved. The current vector (DB) is drawn from the course vector (AD) (the tail of the current vector coincides with the head of the course vector). The track vector (AB) is drawn from the origin (tail of the course vector) to the head of the current vector. Its direction is the expected track (CMG) and its length is the expected SOA.



Case 3: Hold Course and Speed in the Face of Current
Figure 6-6

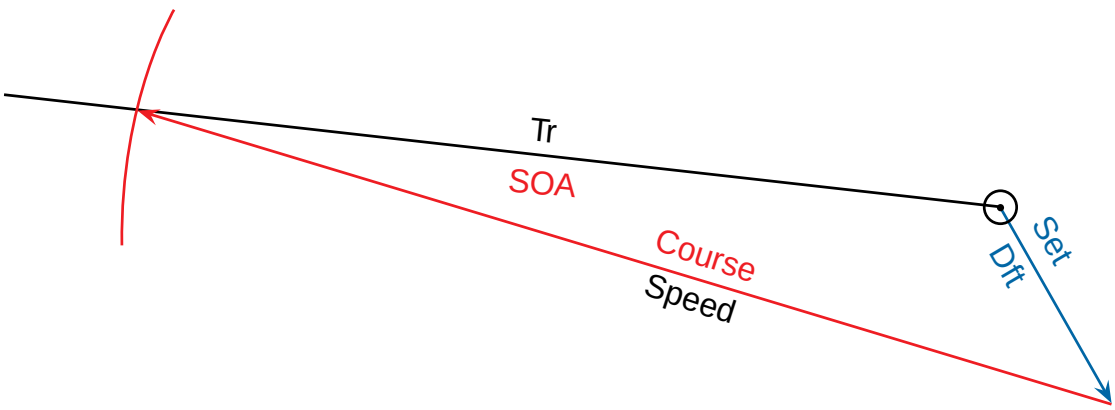
6.2.3.2.4. Case 4: Inability to track as desired after compensating for current. You want to follow a given track and make good a stated speed, compensating for an expected current. You establish a fix off the track. What was the actual current? What were the CMG and the SMG? This situation is one that trips up many navigators. It should be worked using both the chart and the maneuvering board. The course to steer and the speed through the water are determined as in situation 2. The fix and the DR position for that time, using the course actually steered and the speed actually run, must be plotted on the chart. The direction from the DR plot to the fix is the set of the actual current; its drift is a function of the time involved and the distance between the DR position and the fix.



Case 4: Inability to Track as Desired After Compensating for Current
Figure 6-7

6.2.3.2.5. Case 5: Track at specified turns (speed through the water). You want to follow a given track at a stated speed through the water, maybe because your vessel is more economical or rides better at a specific rpm setting. The current is known. What course do you steer and what is your SOA along the given track? This is the special case where the current vector is drawn from the tail of the track line (the origin, or center, of the maneuvering board). Note the use of track line instead of track vector. This is because the line has only direction, its magnitude is unknown at this point. The track line is laid out on the maneuvering board. The current vector is drawn from the origin (the tail of the track line); the two tails coincide. A drawing compass is opened to a distance representing the speed of the vessel through the water. This is the course magnitude but there is no course vector because the direction is unknown. Using the head of the current vector as the center, swing an arc. Where the arc intersects the track line is the head of the now defined track vector (the magnitude, speed, is established as the distance from the tail to the head. The course vector is also

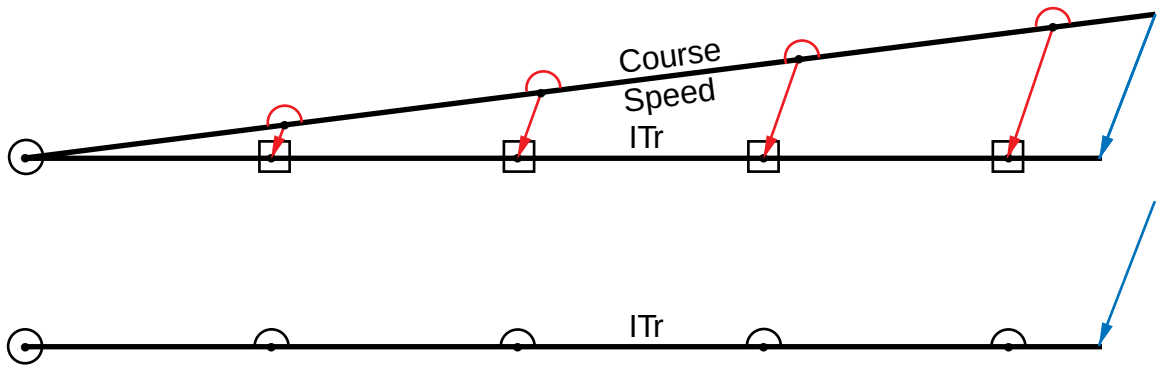
defined with its tail coinciding with the head of the current vector and its head with the head of the track vector. The direction of the vector is the course to steer.



Case 5: Track at Specified Turns (Speed Through the Water)
Figure 6-8

6.2.3.2.6. Case 6: Revised DR plot based on course and speed to compensate for current. You plan a voyage from St. Albans to Westcott, laying out the desired track and plotting DR positions for every half hour on the half hour. You anticipate a current and steer a course at a speed intended to compensate for it. Does the DR plot change? If so, how? This situation is a special case similar to case 4. The desired track is drawn and DR positions are plotted on the chart. Remember, DR plots ignore current. Once you steer a course different from the track and run at a speed different from the SOA along the track the original DR plot is no longer valid. A new plot must be made based on what you are actually doing (steering a course at a given speed through the water), not what you wanted to do (follow a track at a given SOA). The DR positions on the original plot become Estimated Positions (EP) in the new plot. A new DR plot is made on the course line.

In Chapter 4, EPs were defined as the point on a single LOP closest to the DR position for that time. In this case EPs are defined as the position displaced from the DR position by an estimated current. The common thread is that the EP is based on only two things, a DR position and one piece of additional information (the LOP or the current). Keep in mind that a current is *everything* that acts on the vessel, including sloppy steering, and its easy to appreciate how imprecise it is. Nevertheless, it is based on information and it does introduce the effect of forces acting on the vessel over time. Therefore, an EP based on an anticipated current is likely to be closer to the truth than an EP based on a pure DR plot.

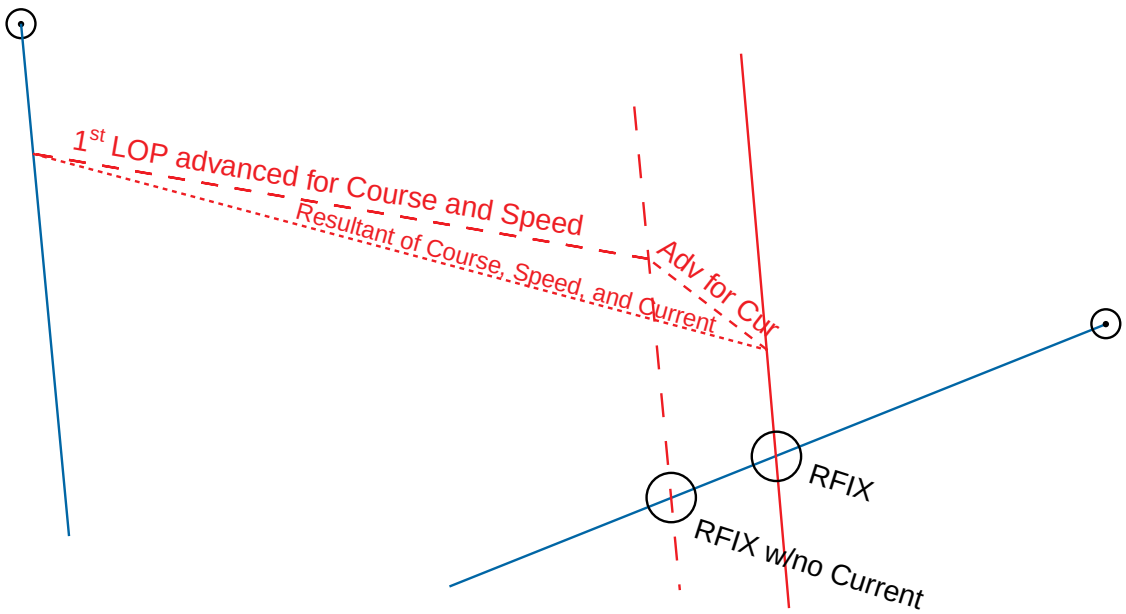


Case 6: Original DR Positions Become Estimated Positions
When Compensating for Current
Figure 6-9

6.3. RUNNING FIXES IN THE FACE OF CURRENT. Chapter 5 introduced the idea of current acting on a vessel between observations of a running fix. To appreciate the effect, consider that in 30 minutes, a two knot current will move a vessel one mile. The stronger the current and the longer the time, the greater the effect. It's quite obvious that a true fix cannot be established if much time has intervened between observations unless the effects of current are considered. Since fixes are used to update the navigation by providing true locations from which to plan future actions, the inaccuracy introduced by external forces acting over time, as in a running fix, cannot be accepted. Figure 6-10 lays out a method of handling current in a running fix. The one thing that must be remembered in dealing with running fixes is that the vessel is somewhere on the second LOP. It can't be anywhere else, so whatever is done to improve the accuracy of the (running) fix must show the vessel on that LOP.

6.4. CURRENT CONSIDERATIONS.

6.4.1. Current Changes Constantly. Consider, again, the listed elements of current in paragraph 6.1.1, plus any others you might think of. Since current is *everything* working on the vessel, including wind and weather, movement of water, and steering errors, it follows that current will not remain constant during a voyage. Nor will current reported by one vessel be the same current encountered by another in the same area at the same time (conditions of wind and weather and movement of water may be the same, but steering errors, condition of hull and propeller, trim, and the like will differ from vessel to vessel). Tidal currents change over time and from location to location. The inexperienced navigator is quite likely to ignore

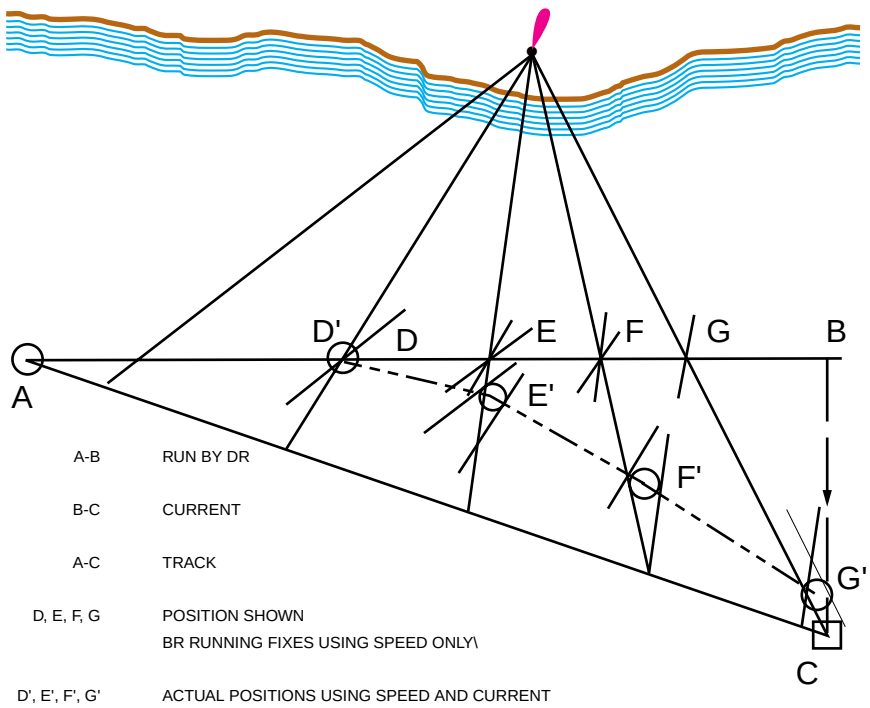


Running Fix Considering the Effect of Current
Figure 6-10

the effects of current, apply them (the effects) incorrectly, or assume current will remain constant throughout the voyage. It should be readily apparent that frequent fixes are required to ensure safe passage through coastal waters. Two, or more, simultaneous observation fixes should be taken whenever possible. When not possible running fixes should be taken as often as possible. Figure 6-11 shows a plot of running fixes based on sequential observations of the same object.[41]

6.4.2. Leeway. Leeway, one element of current, is the response of a vessel to the wind. The wind affects all vessels but the effects are much more apparent on small boats such as Auxiliary facilities. Obviously the vessel will not move to leeward as fast as the wind is blowing. The hull above the water line and superstructure act as a sail while the wetted area (the hull area in the water) offers resistance. A vessel's leeway is a function of sail area vs. wetted area and other characteristics such as weight, speed, and wind speed and aspect. The Auxiliary Search and Rescue Specialty Course provides a graph (Figure 6-12) which gives a rough approximation of leeway for varying wind speeds for different groupings of vessels. The graph is useful in determining drift and set of a disabled vessel and provides insight to the effects of wind on various types of vessels; however, the prudent navigator will, over time and through experience, determine the leeway characteristics of his own vessel under varying conditions of load, speed, and wind.

[41] Dutton's, Figure 1213b, p. 186

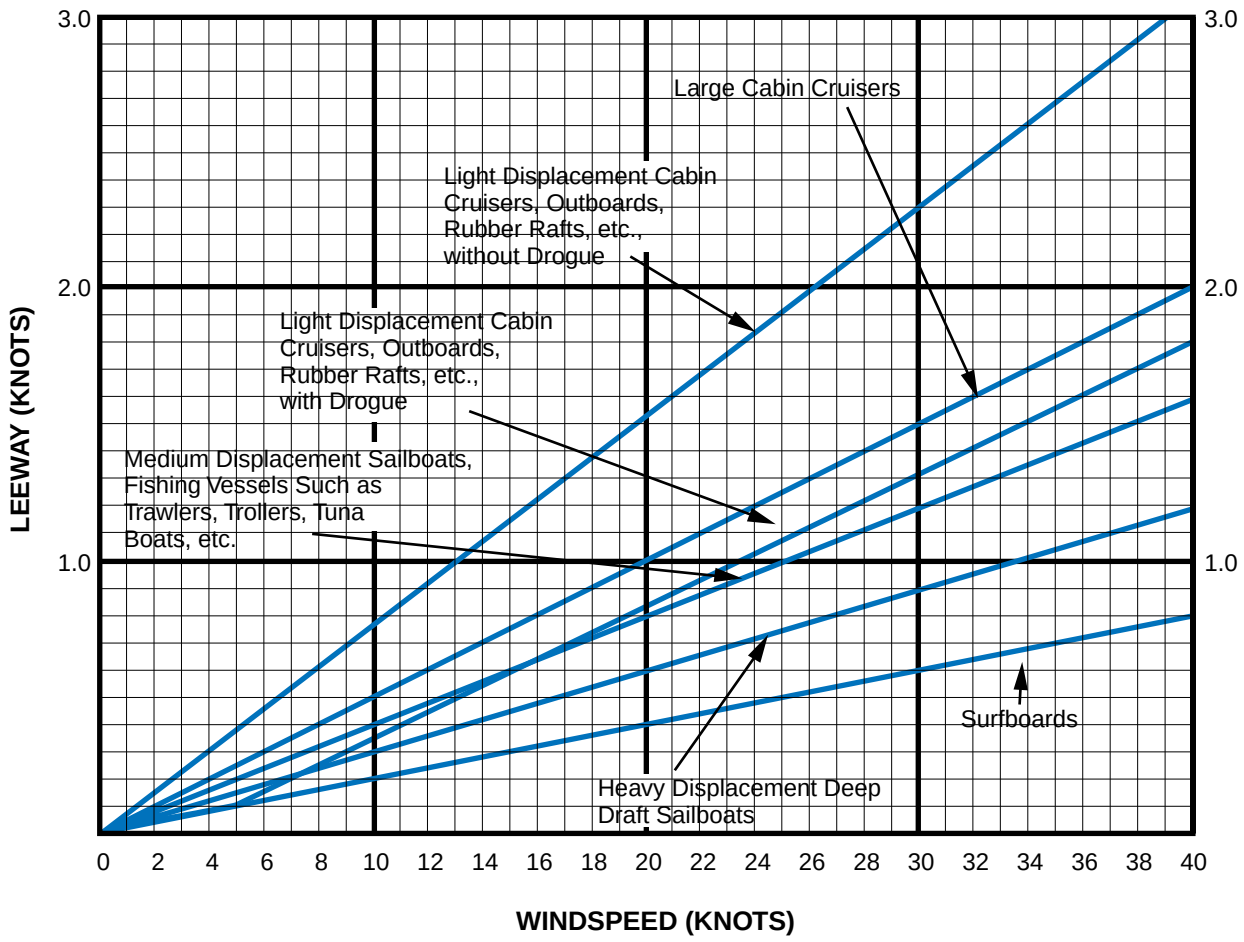


Sequential Running Fixes Cinsidering Current
Figure 6-11

6.4.3 Tidal Water Currents. Tidal currents change constantly. The drift of reversing currents is in a constant state of flux even though set can remain constant throughout the ebb or the flood (it will generally differ between ebb and flood). Both the set and drift of rotary currents change constantly. Wind can increase or decrease the drift of a tidal current depending on whether it blows with or against the current. Wind against the tidal current will create more chop, which, in itself, is an element of navigational current, because of its impact on vessels traversing it.

6.4.4. Other Considerations. Different helmsmen can change the steering error element. Poor steering is often the source of apparent current. [42] It should be obvious that current conditions change constantly and often rapidly. This is particularly true when taking running fixes in current infested waters. Such positions must be looked at askance. They can indicate safety when danger is the true case. The prudent navigator is aware of this and is constantly alert for opportunities to more firmly establish his position. In any case, when there is any question as to actual location, he or she should assume worst case positions and make course alterations accordingly.

[42] Shufeldt, p. 114



Leeway Graph
Figure 6-12

6-1. Current is the _____ working on a vessel.

a. water movement
b. wind and leeway
c. external forces
d. internal forces

6-2. Some of the factors comprising current are:

a. _____
b. _____
c. _____

d. _____
e. _____
f. _____
g. _____
h. _____
i. _____
j. _____
k. _____

6-3. Although many factors make up current, the greatest is the _____.

a. wind and leeway
b water movement
c. hull and propeller fouling
d. steering errors

6-4. (True/False) Ocean currents are well-defined, predictable, charted, and extend over large areas; they have significant impact on coastal navigation.

6-5. (True/False) Wind-driven currents are caused by steady winds over long fetches for at least ten hours.

6-6. (True/False) Leeway is caused by the ratio of the sail area to the wetted area of the vessel as impacted by the wind.

6-7. (True/False) A given wind will not yield a given sea state. This is determined by the length of time the wind blows.

6-8. ___ is the direction _____ which the current flows.

a. Drift, towards
b. Drift, from
c. Set, towards
d. Set, from

6-9. _____ is the velocity of the current.

a. Drift
b. Set
c. Speed
d. Acceleration

6-10. Current problems are solved using _____ arithmetic, usually on _____ _____.

a. vector, the chart
b. simple, a maneuvering board
c vector, a maneuvering board
d. simple, the chart

6-11. The maneuvering board helps prevent _____ the chart, which can lead to serious navigational errors.

a reading
b. tearing
c. losing
d. cluttering

6-12. The _____ vector is drawn to the head of the _____ vector and from the head of the _____ vector.

a. track, current, course
b. course, track, current
c. current, course, track
d. current, track, course

6-13. _____ causes a vessel to be in a location other than where it was predicted to be on the DR plot.

a. Current
b. Wind
c. Leeway
d. Inaccurate charts

6-14. The current triangle is used to solve six basic cases of current problems; including, the _____ to make good the intended track when running through the current at a given speed, and second, finding the _____ required in a current to arrive at the destination on time.

a. course to steer, speed of advance
b. speed of advance, course
c. course to steer, course and speed
d. heading, speed

6-15. (True/False) You lay out an intended track and plot dead reckoning positions on the track line. You are aware of a current running which will impact your progress. You plot this information to determine a course to steer and a speed to run to make good your intended track and arrive at your destination on time. The DR positions on

the intended track become estimated positions and a new DR plot is made on the course line.

6-16. (True/False) A course and speed to run in order to make good an intended track and time of arrival at the destination are determined based on an estimated current. A fix is obtained. The actual current set is the direction of the fix from the DR position plotted on the course line and the drift is the distance from the DR position divided by the time since the last fix.

6-17. (True/False) The current vector is drawn from the tail of the track line (origin of the maneuvering board) when determining the course to steer to make good the intended track at a specified speed (number of turns, or rpm) through the water.

6-18. Steering into the current to follow an intended track is called _____.

a. trolling
b. trawling
c. slipping
d. crabbing

6-19. When a running fix is determined, the vessel is on the _____ established at the time of the fix. The salient fact when allowing for current in determining the vessel's position is that the vessel is still on the _____.

a. LOP, DR plot
b. LOP, LOP
c. course line, course line
d. DR plot, LOP

6-20. (True/False) The inexperienced navigator is likely to make certain errors in working with current: making no allowance for it, applying the allowance incorrectly, or expecting a demonstrated current to change.

6-21. (True/False) Small craft are more susceptible to wind-driven currents than heavy, deep-draft vessels.

6-22. (True/False) For a given size vessel, the more freeboard and top hamper relative to draft, the greater the leeway potential.

6-23. _____ is sometimes the real source of apparent current.

a. Water temperature
b. Poor steering
c. Freeway
d. Propeller pitch

6-24. _____ taken in current infested waters must be viewed with skepticism for they can give the impression of having room to spare when there is none.

a. Running fixes
b. Estimated positions
c. Fixes
d. DR positions

PROBLEMS

6-1. A vessel leaves point A at 0900 and sails on course 100° at 9 kts. At 0940 a fix places the vessel 6.8M from point A at 113°. What is the set and drift of the current encountered? _____, _____

6-2. Same situation, except speed is 6 kts and time of the fix is 1000. _____, _____.

6-3. The navigator of a vessel wishes to track 160° to arrive at a destination 14M away in two hours. A current is running 280° at 2.2 kts. What course must be steered and at what speed in order to make good the desired track and arrive at the destination on time? _____, _____

6-4. A skipper determines that the vessel's most economical power setting is 2200 rpm which produces 9 kts through the water. The desired track is 317° at that power setting. A 1.8 kt current is setting 085°. What course must be steered and at what speed of advance along the intended track? _____, _____.

6-5. A navigator intends to track 233° with a SOA of 5 kts. A 1 kt current is reported running 022° in the area. In order to make good the desired track and speed 228° is steered at a speed of 5.9 kts. One hour and 17 minutes after departure a fix places him 7 miles out, bearing 217° from the departure point. What was the actual current encountered? _____, _____

6-6. A radio antenna on a promontory is located 5.0 miles from a vessels last known position (LKP), bearing 300°. The vessel is steaming on course 235°, speed 9 kts. At 0900 the antenna is sighted bearing 333° from the vessel. At 0930 it is observed again, now bearing 023°. A 2.4 kt current is running 270°. What is the position of the vessel relative to its LKP? _____

6.7. What would its position have been if there was no current? _____

CHAPTER 7
TIDES AND CURRENTS - TIDES

7. Chapter 7.

7.1. INTRODUCTION. Most texts include tides and currents in one chapter. This text breaks them into two chapters for ease of instruction and because we have found that both tides and currents cannot be adequately covered in a normal two hour instruction period. Determination of sunrise and sunset is also included in this chapter.

7.2. TIDE TABLES

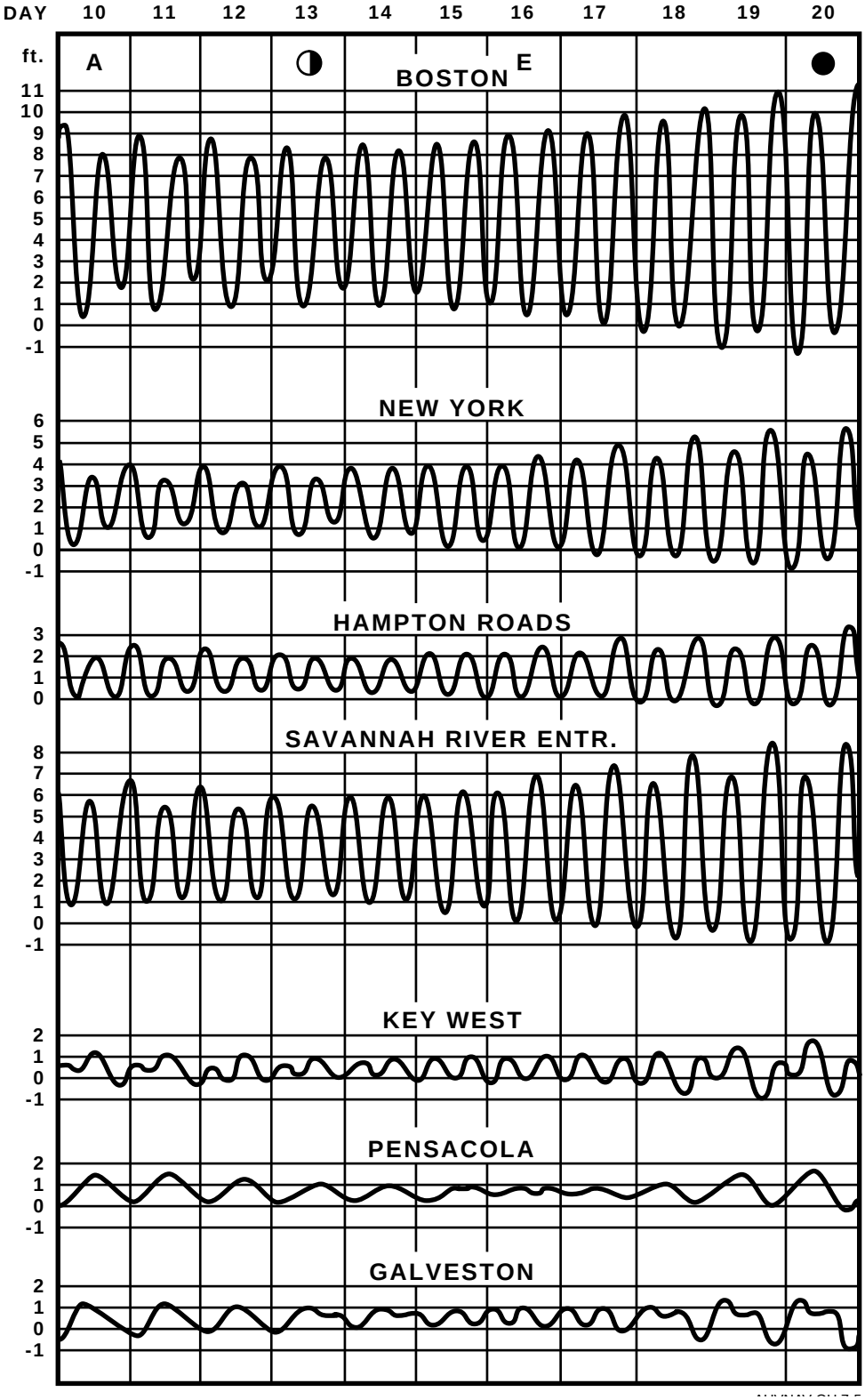
7.2.1. Description. Tide information is contained in the Tide Tables published by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce. The Tide Tables are published periodically in four volumes: Vol. 1, Europe and West Coast of Africa including the Mediterranean Sea; Vol. 2, East Coast of North and South America including Greenland; Vol. 3, West Coast of North and South America including the Hawaiian Islands; and Vol. 4, Central and Western Pacific Ocean and Indian Ocean. The four volumes include data for 198 reference ports and differences and constants for about 6500 stations. Volume 2, which was used in the preparation of the text and this workbook, covers 50 reference ports and about 2500 stations (the Introduction indicates 48 reference stations, but 50 are listed).

7.2.2. Tables. The Tide Tables comprise 8 separate tables, three pertaining to tides, three to sun and moon rise and set, one for the conversion of feet to centimeters, and one to demonstrate the accuracy of predictions. Each separate table includes instructions in its use. The pertinent instructions for each table are included in the extracts provided with this text and with the examination.

7.2.3. Diurnal and Semidiurnal Tides. Page 7-2 is from page 3, NOAA Tide Tables 1994. Gulf coast tides, as represented by Pensacola and Galveston, are called diurnal because there is one high tide and one low tide in each lunar day. East and west coast (of the United States) tides, represented by Boston, New York, Hampton Roads, and Savannah River, are called semidiurnal because there are two high tides and two low tides in each lunar day. Datum for diurnal tides is obviously mean low water, a moving average low depth of water taken over a period of 18.6 years. Datum for semidiurnal tides is the moving average depth of water at the lowest of the two daily low tides over a similar 18.6 year period.

Moving average means that the earliest data is dropped when the newest is added so that the height of tide is always based on the latest 18.6 year period preceding the

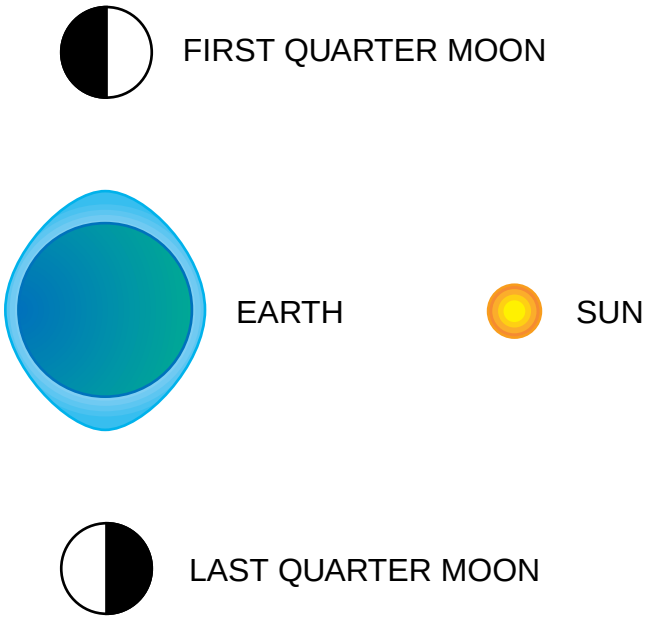
TYPICAL TIDE CURVES FOR UNITED STATES PORTS



date of the Tables. There is a special case of semidiurnal tide, called a mixed tide, that occurs in many locations around the world. In this tide, the difference between the two lows is great while the difference between the two highs is slight (or the reverse where the difference between the two highs is great and the lows is slight; however, this condition is relatively rare). Key West tides are mixed. The diurnal tides at Pensacola and Galveston change to mixed tides as the lunar cycle progresses through the month.

7.2.4. More on Datum. Some fairly recent texts say that datum for charts of the Atlantic and Gulf coasts of the United States is Mean Low Water (MLW). This remains true for the Gulf coast but datum for the east coast and the Caribbean Islands was changed to Mean Lower Low Water (MLLW) effective 1 January 1989 as a result of the "National Tidal Data Convention of 1980," Federal Register, vol. 45, No. 207, Thursday, Oct. 23, 1980, p 70296 - 70297.[43] This course will consider east coast datum to be Mean Lower Low Water.

7.3. SPRING AND NEAP TIDES.



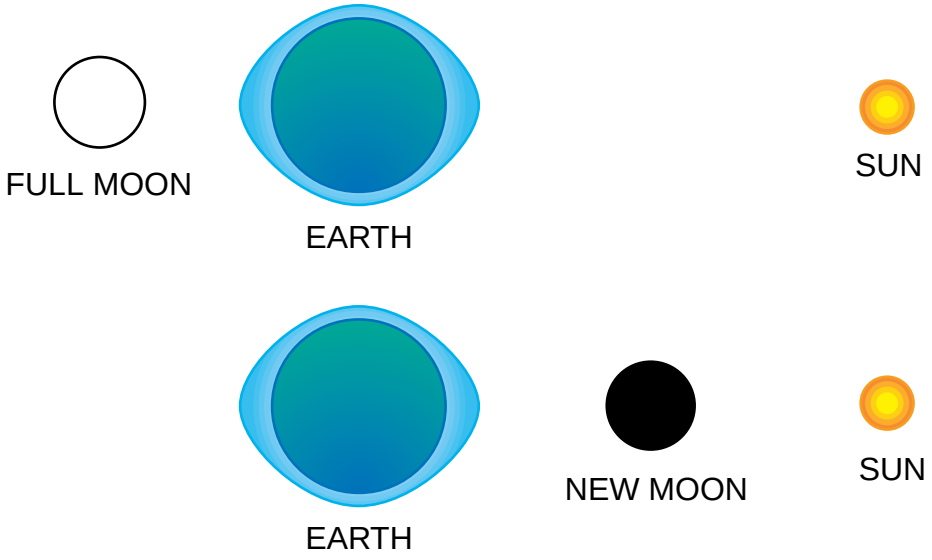
Position of Earth, Sun, and Moon at Neap Tides
Figure 7-1[44]

[43] Tide Tables, 1994, National Ocean Service, National Oceanic and Atmospheric Administration, US Dept. of Commerce, issued 1993

[44] Dutton's, Fig. 903c, p. 126

7.3.1. Neap Tides. The condition of the sun and moon under which neap tides occur is called quadrature and takes place with the first and third (last) quarter moons. This condition occurs when the sun and moon are at right angles to each other relative to the earth. During this condition, the range of the tide, that is, the difference in height of tide between adjacent high and low waters, is the least.

7.3.2. Spring Tides. Spring tides take place with new and full moons when the sun, moon, and earth are aligned. It doesn't matter whether the moon is on the same side of the earth as the sun (new moon) or the opposite side (full moon), the gravitational pull of the two bodies work together to cause tides of the greatest range.



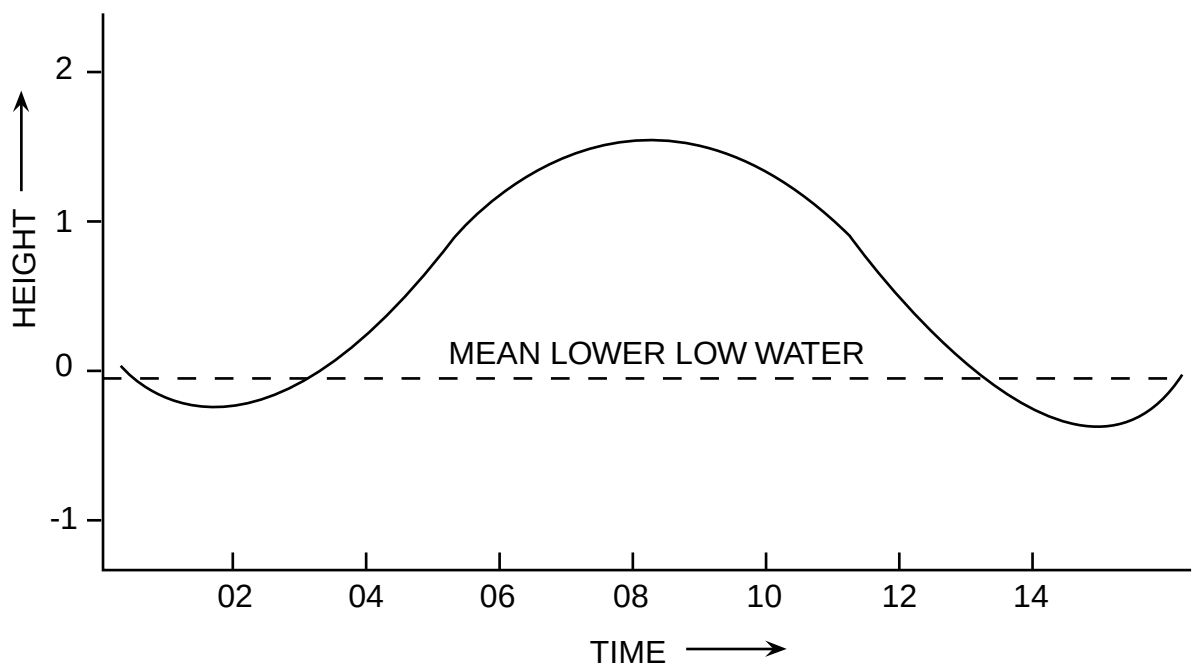
Position of Earth, Sun, and Moon for Spring Tides
Figure 7-2[45]

7.3.3. Cyclical Nature of Tides. Tides and tidal currents are fairly easy to understand when you consider that they are cyclical as is shown in the diagrams on page 7-2 and in Fig 7-3 on page 7-5; that is, they follow a natural phenomena which can be mathematically modeled as a sine wave, or S curve. Cyclical means that they continuously go from a high to a low to a high to a low to a high to a ..., forever. This should be obvious when you consider that the relative positions of the sun and moon move from alignment on the same side of the Earth, to quadrature, to alignment on opposite sides, to quadrature on the other side, etc. The lunar day has 24h 50m. Therefore, a diurnal tide, which normally has a high and a low each day, will occasionally have one or the other in a calendar day, but not both. A semidiurnal tide, with two highs and lows each day, will occasionally have two of one and one of the other.

[45] Dutton's, Fig. 903b, p. 126

7.4. SUNRISE AND SUNSET.

7.4.1. NOAA Tables. Before going into the determination of heights of tide at various locations and times, let's consider determination of sunrise and sunset and moonrise and moonset. Moonrise and moonset are used in celestial navigation. There is little practical use for such data in coastal piloting; it will not be considered in this text. Sunrise and sunset are of interest to both the celestial and the coastal navigator; however, the celestial navigator requires a much greater degree of precision. Table 4 of the NOAA Tide Tables provides the time of sunrise and sunset for every 5th day and every 5° of latitude from the equator to 30° N and 30° S and every 2° of latitude from 30° N or S to 76° N and 60° S. This is sufficient for piloting. The time is local mean time at the given latitudes which is the time at the standard or time meridian for each time zone. (Extracts of these tables are included in Appendix A).

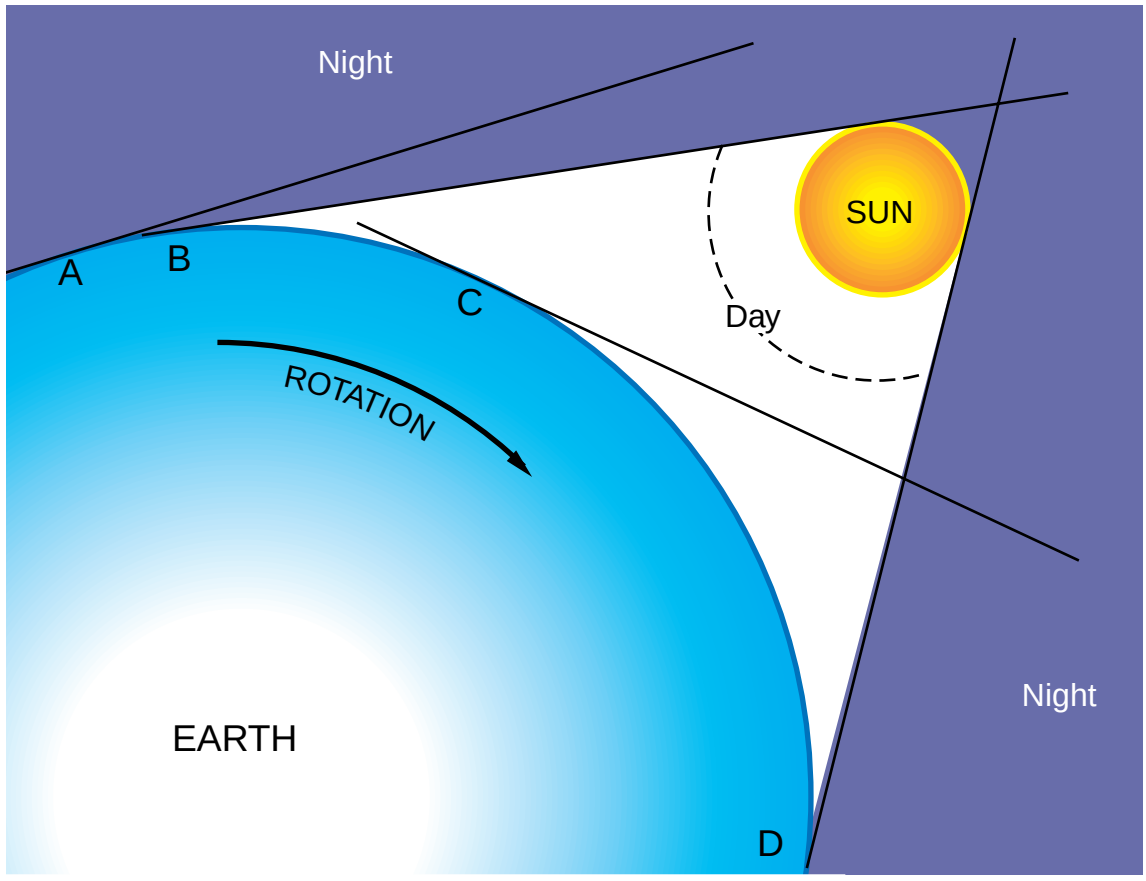


The Cyclical Nature of Tides
Figure 7-3

Table 5 provides the corrections for locations east or west of the standard (time) meridian.

7.4.2. Apparent Motion of the Sun. Figure 7-4 illustrates the difference in time of either sunrise or sunset, disregarding morning and evening twilight. Both sunrise and sunset occur when the *upper limb* of the sun appears tangent to the earth at the observer's position. That is, when the very top of the sun's disc, as it appears to the observer, is all that can be seen on the horizon. Motion of the sun is apparent; it appears to rise and move across the sky and set at a rate of 15° per hour (equal to 15' per minute). The motion of the sun is apparent because, as we all know, the sun does not move. The earth rotates from west to east about its axis which makes the sun appear to move. Figure 7-4 shows that an observer at point A sees a night sky. As the earth rotates so the observer is at point B, the upper limb of the sun just becomes visible. It is sunrise at that point. When the earth rotates so that the observer is at point C, he or she sees a day sky. When the earth's rotation places the observer at point D, only the upper limb can be seen again and it is sunset.

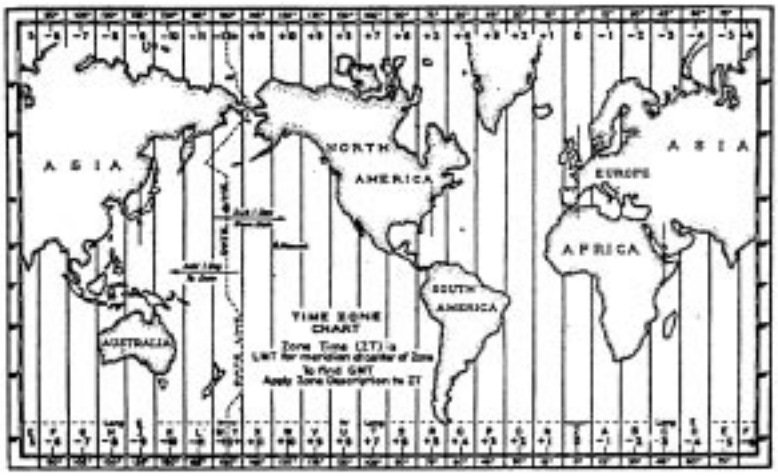
7.4.3. Standard or Time Meridians. To look at it another way, assume that the time meridian (075° W longitude for Eastern Standard Time, 090° W for Central,



Time of Sunrise or Sunset at Various Locations
Figure 7-4

105° W for Mountain, and 120° W for Pacific Standard Time) passes through Point B. It is sunrise at that point. Sunrise has already occurred at point C, to the east, and is yet to occur at point A, to the west. The time meridians, also known as standard meridians, are the central meridians of each time zone, which are exactly 15° wide (local use may cause legislated variations in time zone boundaries). This is illustrated in Figure 7-5.

7.4.4. Interpolation Not Required. The "Explanation of Table" for Table 4 says that interpolation of dates or latitudes is not necessary when using the table because of "sensible variations"[46] in time of rising or setting caused by elevation of the observer and changes in refraction. <u>That means that the navigator should use the data for the closest date and the closest latitude in determining time of sunrise or sunset.</u> The worksheet on page 7-8, below, will be helpful in using the tables. Copies are in Appendix C.



Time Zones
Figure 7-5[47]

7.4.5. An Example. As an example, determine the time of sunrise at New Bedford, Massachusetts, on 7 April. From the extract from Table 2 in Appendix A, determine the latitude of New Bedford (position latitude) to be 41° 38' N and the longitude to be 70° 55' W. Enter this data in the worksheet:

Position latitude:	<u>41° 38' N</u>
Date:	<u>7 April 1994</u>
Position longitude:	<u>70° 55' W</u>

From Table 4, determine the nearest date to be 6 April, the nearest latitude to be 42° N, and the time of sunrise to be 0535. Enter this data:

[46] Tide Tables 1994, p. 243
[47] QM3 Maritime Calculations, US Coast Guard Pamphlet No. D33713 (05/94), Fig. 3-1, p. 3-3

TIME OF SUNRISE OR SUNSET WORKSHEET

Location: _____

Position latitude: _____ Date: _____
Position longitude: _____

From Table 4 - Nearest date: _____ Nearest latitude _____
Time of sunrise or sunset at nearest date and latitude: _____

Longitude of time meridian: _____
Position longitude: _____
Difference in longitude: _____

From Table 5 - Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): _____

Time of sunrise or sunset at position: _____

Note: If local meridian is east of standard (time) meridian (longitudinal difference is - in the western hemisphere, + in the eastern), subtract the correction (event occurs earlier). If local meridian is west of standard meridian, add the correction.

Table 5 says to subtract or add corrections to local mean time. Local mean time in each time zone is the time of the standard meridian as given in Table 4; therefore, applying the correction provides the time of the event at the local meridian (position).

For Daylight Savings Time, add one hour to the time.

From Table 4 - Nearest date: 6 Apr. Nearest latitude: 42° N
Time of sunrise or sunset at nearest date and latitude: 0535

From Table 1, the time (standard) meridian is identified as 75° W. The next step is to determine the difference in longitude. Remember, 75° W can be written as 75° 00' W, which is the same as 74° 60' W for the purpose of subtraction or addition.

Longitude of time meridian:	75° 00' W
Position longitude:	70° 55' W
Difference in longitude:	- 4° 05'

The final step is to determine the correction from Table 5 and calculate the time of sunrise at New Bedford. Enter the table at the row for 3° 53' to 4° 07' and read the correction to be 16 minutes. Since the longitude of New Bedford is less than the longitude of the time meridian (the difference is minus), New Bedford lies to the east of the time meridian and sunrise occurs there 16 minutes before it does at the time meridian. Enter this data in the worksheet.

From Table 5 - Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): 16

The time of sunrise at New Bedford on 7 April is 0535 - 16, or 0519 EST. If daylight savings time is in effect (it changes on the first Sunday in April), the time is 0619 EDT. The completed worksheet looks like this:

TIME OF SUNRISE OR SUNSET WORKSHEET

Location: New Bedford
Position latitude: 41° 38' N Date: 7 April
Position longitude: 70° 55' W

From Table 4 - Nearest date: 6 April Nearest latitude: 42° N
Time of sunrise or sunset at nearest date and latitude: 0535

Longitude of time meridian:	75° 00' W
Position longitude:	70° 55' W
Difference in longitude:	- 4° 05'

From Table 5 - Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): 16

Time of sunrise or sunset at position: 0519

Time if Daylight Savings Time (it is on 7 April) 0619

7.5. HEIGHT OF TIDE

7.5.1. Tide Tables. The tide tables provide a means of determining the height of tide at several thousand locations around the world. Volume 2, used for this text, provides data for some 2500 locations along the east coasts of North, South, and Central America, including the Gulf of Mexico and all of Greenland.

7.5.2. Depth of Water. It is important to remember that height of tide and depth of water are not the same. Charted depth of water is at datum, which is Mean Low Water or Mean Lower Low Water, depending on the location. The height of tide is arithmetically added to the charted depth to determine the depth at any given time. This means that a negative height of tide is subtracted from datum, while a positive height is added to datum (adding a negative value is the same as subtracting). Remember also that the Mean Low or Mean Lower Low is an average of all lows or lower lows over more than 18 years. Consequently, the depth of water during an ebb (outgoing) tide and at low water at any given time is often shallower or deeper than datum. Depending on the draft of the vessel, it is easy to see why determination of height of tide can be very important. It is also important to note that clearances under bridges are based upon Mean High or Mean Higher High Water. This information is particularly important to sail boats.

7.5.3. Height of Tide Worksheet. The Coast Guard Auxiliary's public education course in Advanced Coastal Navigation, Second Edition, provides an excellent worksheet for determining height of tide; however, the worksheet goes so far in explaining each entry that a user never has to develop an understanding of tides and tidal actions. Since a Navigation Specialist is *ipso facto* qualified to teach ACN, it is important that he or she be able to determine a height of tide and depth of water through understanding and knowledge of the process. The Navigation Specialty Course uses the worksheet from Shufeldt, slightly modified to include depth of water, reproduced on page 7-12. Additional copies are provided in Appendix D.

7.5.3.1. Definitions. Before using the worksheet and the tide tables to determine height of tide or depth of water at various times and locations, it's important to understand the terms used.

Height of tide: The difference in depth of water from datum.

Depth of water: Datum plus the height of tide (height of tide is subtracted from datum if it is a negative (-) value.

Datum: Charted depth of water based on moving average (mean) low waters or lower low waters.

Range of tide: Difference in height of tide between high water and the adjacent low water at the station (place) of interest or between low water and the adjacent high water (adjacent is the next tide before or after).

Duration of rise Time from high water to low water or from low water to high water at the place of interest. Starting at low water, time for the tide to come in (flood), or starting at high water, time for the tide to go out (ebb).

Time from nearest high water or low water: The time between the desired time and the time of the high or low water at the place of interest closest to that time.

Ebb The outgoing tide. Begins at high water and ends at low water when the tide starts flooding.

Flood The incoming tide. Begins at low water and ends at high water when the ebb begins.

7.5.3.2. Illustrative Example. To illustrate the use of the tables to predict height of tide at given location let's consider New Bedford again. What is the height of tide at 1712 hours on 3 Apr.? What is the depth of water if the charted depth is 8 feet? Using the extracts of the tables in Appendix A, we find that New Bedford is "on Newport, p. 40" (table 2, page A-3). That means that New Bedford is a subordinate station to Newport, RI, the data for which begins on page 40 of Table 1, in Tide Tables 1994. Table 2 provides differences for the subordinate stations. Differences in time tell us how much earlier or later the high or low water occurs at the subordinate station than it does at the reference station. Differences in height tell us how much higher or lower the corresponding high or low water is at the subordinate station than it is at the reference station.

Notice that height differences in the Table 2 extract (page A-3) is asterisked for both high and low water. <u>The asterisk means that the difference is a ratio and the height of tide at high and low water at the reference station is multiplied by the asterisked number</u> (for New Bedford this is 1.05 for both high and low water). If the asterisked number is more than 1, the difference in height of tide is greater at the sub station, if it's less than one, the height is less. This can get tricky. If the reference station value is (-), as it is for 0505 hours, 1 April (table 1, page A-2), then the low water at New Bedford at the time corresponding to 0505 hours is (-0.3)1.05 or -0.315 ft below datum at New Bedford; the difference is greater, the height of tide at low water is lower (to be practical, the -0.315 would be rounded to -0.3 for no real difference). If the height difference is shown as a + value, the water at the substation is deeper than at the reference station by that amount. If a - value, the water is shallower and the value is subtracted.

HEIGHT OF TIDE WORKSHEET

Substation _____ Date _____

Reference Station _____

HW time difference _____ Diff. in height of HW _____

LW time difference _____ Diff. in height of LW _____

Ref. Sta. _____ Sub Sta. _____

LW _____ _____ _____ _____
HW _____ _____ _____ _____
LW _____ _____ _____ _____
HW _____ _____ _____ _____
LW _____ _____ _____ _____
HW _____ _____ _____ _____

Height of tide at any time

Location _____ Time _____ Date _____

Duration of Rise or Fall _____
Time from Nearest Tide _____
Range of Tide _____
Height of Nearest Tide _____
Correction from Table 3 _____
Height of Tide at _____ _____

Depth of water at any time

Charted Depth of Water _____
Height of Tide at _____ _____
Depth of Water at _____ _____

Unlike earlier editions of the Tide Tables, the 1994 edition shows every single sub station on the east coast of the United States as an asterisked ratio. Added and subtracted values are shown for many Canadian and South American sub stations with only a few shown as ratios.

Begin by filling in the given data.

Substation New Bedford Date 3 April

Reference Station Newport

HW time diff. +0 07 Diff. in height of HW *1.05

LW time diff. +0 07 Diff. in height of LW *1.05

	Ref. Sta. Newport	
HW	0112 (= 0212 EDT)	3.6
LW	0728 = 0828	0.3
HW	1346 = 1446	3.2
LW	1947 = 2047	0.4

Table 1 provides standard time. Because it is so easy to forget, it's a good idea to convert standard time to daylight savings time right away. Sub station values are entered directly in DST. Now, apply the time and height differences to obtain the time of high and low waters at New Bedford as well as the heights of the highs and lows. The time difference, +0 07, is read as 0 hours, 7 minutes later than the time at Newport.

	Sub Sta. New Bedford	
HW	0219 (0212 + 0 07)	3.6 x 1.05 = 3.78 = 3.8
LW	0835	0.3 x 1.05 = 0.3
HW	1453	3.2 x 1.05 = 3.4
LW	2054	0.4 x 1.05 = 0.4

The times and heights of tide, above, define high and low waters at New Bedford on 3 April. That data provides everything needed to enter Table 3 to determine the height of tide at New Bedford at 1712. 1712 is the time of interest. That falls between the high water at 1453 and the low water at 2054. Since the preceding event is high water, and the following event is low water, the tide is going out. Whatever the height of tide at 1712, it must be equal to or higher than the low water height of tide, and it must be equal to or lower than the high water height of tide. The duration of the tide

is 2054 - 1453 or 6h 01m and the range is from 0.4 feet above datum to 3.4 feet above datum for a total of 3.0 feet. The nearest tide to 1712 is the high water at 1453 and the time between that event and 1712 is 2h 19m. This data is entered into the worksheet as

Duration of rise or fall	(1453 to 2054) 6h 01m
Time from nearest tide	(1453 to 1712) 2h 19m
Range of tide	(0.4 to +3.4) 3.0 feet
Height of nearest tide	3.4 feet

Since the tide is going out and the nearest tide is high water, the water will be shallower than at high water and the correction will be subtracted from the high water value. If the nearest tide was low water and the tide was going out, the water would be deeper and the correction would be added to the low water height of tide. The same sort of reasoning is applied if the preceding event is low water and the following is high water. The tide is coming in and for all times after the low water until high water the depth will be shallower than at high water but deeper than the low water.

The correction is found from Table 3. Enter the table in the row headed 6 00 in the top portion of the table (the part labeled Duration of Rise or Fall). Remember, we do not interpolate, so enter at the closest value. Go across that row to the entry that is closest to 2h 19m, or 2 24. Go down that column into the lower part of the table until you intersect the row labeled 3.0 (the closest range of tide to 3.0 ft) and read the correction to be 1.0. Since the tide is going out and high water is the nearest tide, the water is shallower and the correction is subtracted from the high water value. High water was 3.4 ft above datum. The water is one foot shallower at 1712, so the height of tide is 2.4 ft above datum at 1712.

Correction from Table 3	+ 1.0
Ht. of tide at 1712	3.4 - 1.0 = +2.4 ft

The charted depth, datum, was given as 8 feet. Since the height of tide at 1712 is +2.4 ft, the depth of water at 1712 is 10.4 ft. The filled out worksheet is on page 7-15.

7-1. (True/False) Volume 2 of the NOAA Tide Tables contains tide data for 198 reference stations and about 6500 subordinate stations.

HEIGHT OF TIDE WORKSHEET

Substation New Bedford Date 3 April

Reference Station Newport

HW time difference 0 07 Diff. in height of HW *1.05

LW time difference 0 07 Diff. in height of LW *1.05

	Ref. Sta. Newport		Sub Sta. New Bedford	
HW	0112 = 0212	3.6	0219	3.6 x 1.05 = 3.8
LW	0828	0.3	0835	0.3
LW	1446	3.2	1453	3.4
HW	2047	0.4	2054	0.4
LW				
HW				

Height of tide at any time

Location New Bedford Time 1712 Date 3 May

Duration of Rise or Fall	6h 01m
Time from Nearest Tide	2h 19m
Range of Tide	3.0
Height of Nearest Tide	3.4
Correction from Table 3	1.0
Height of Tide at 1712	2.4

Depth of water at any time

Charted Depth of Water	8 ft
Height of Tide at 1712	2.4 ft
Depth of Water at 1712	10.4 ft

7-2. (True/False) Tide data for the reference stations is based on an 18.6 year moving average of mean low water or mean lower low water.

7-3. Datum for the east coast of the United States is based on _____.

a. Mean Low Water
b. Mean High Water
c. Mean Lower Low Water
d. Mean Higher High Water

7-4. _____ tides occur when the sun and moon are in _____ _____ and have the greatest tidal ranges.

a. Neap, quadrature
b. Neap, alignment
c. Spring, quadrature
d. Spring, alignment

7-5. ____ tides occur when the sun and moon are in _____ and have the smallest tidal ranges.

a. Neap, quadrature
b. Neap, alignment
c. Spring, quadrature
d. Spring, alignment

7-6. _____ tides occur on the Gulf coast of the United States and have only one high water and one low water in each lunar day.

a. Mixed
b. Compound
c. Diurnal
d. Semidiurnal

7-7. The lunar day is _____ long.

a. 24 hours
b. 24 hours 50 minutes
c. 26 hours
d. 26 hours 30 minutes

7-8. _____ is the difference in depth of water from _____ at any given time.

a. height of tide, datum
b. height of tide, lower low water
c. sea level, height of tide
d. depth of water, datum

7-9. _____ is _____ plus the height of tide at any given time.

a. height of tide, datum
b. height of tide, lower low water
c. sea level, height of tide
d. depth of water, datum

7-10. _____ is the charted _____ at any point.

a. depth, datum
b. datum, depth of water
c. height of tide, depth
d. datum, height of tide

7-11. (True/False) Diurnal tides occur on the east and west coasts of the United States and have two highs and two lows in each lunar day.

7-12. (True/False) Mixed tides are a variation of semidiurnal tides in which the lows are fairly close in height while the highs are far apart.

7-13. If the longitude of a location in the western hemisphere is less than the longitude of the standard (time) meridian of the time zone, the location is ____ of the time meridian and sunrise or sunset is _____ than at the time meridian.

a. west, earlier
b. west, later
c. east, later
d. east, earlier

7-14. If the longitude of a location in the eastern hemisphere is greater than the longitude of the standard (time) meridian of the time zone, the location is ____ of the time meridian and sunrise or sunset is _____ than at the time meridian.

a. west, earlier
b. west, later
c. east, later
d. east, earlier

7-15. _____ at a given location is the difference between adjacent high and low waters at that location.

a. Depth of water
b. Range of tide
c. Height of tide
d. Datum

7-16. (True/False) Duration of rise or fall is the time for the tide to ebb, starting at high water, or flood, starting at low water.

7-17. (True/False) An in-coming tide is ebbing.

7-18. (True/False) An out-going tide is ebbing.

PROBLEMS

7-1. What time is sunrise at Little Harbor at Woods Hole, on 1 April (EST is in effect)? (use tables in Appendix A) _____

7-2. What is the maximum range of tide at Newport, Rhode Island on 6 April? ____

7-3. What is the maximum duration of tide at Newport on 7 April? _____

7-4. What is the height of tide at Tarpaulin Cove at 1506 on 6 Apr. (EDT is in effect)? (Use tables in Appendix A) _____

7-5. What time is sunset at Tarpaulin Cove on 6 April? _____

7-6. What is the depth of water at Little Harbor at 1100 on 2 April if the charted depth is 24 feet? _____

CHAPTER 8
TIDES AND CURRENTS - CURRENTS

8. CHAPTER 8.

8.1. INTRODUCTION. Current, as used in this chapter refers to the movement of water as opposed to “all external influences” as used in Chapter 6, Current Sailing.

8.2. TIDAL CURRENT TABLES.

8.2.1. Description. Current information is contained in Tidal Current Tables, 1994, published in two volumes by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce. Volume I is for the Atlantic Coast of North America, Volume II for the Pacific Coast of North America and Asia.

8.2.2. Tables. The volumes contain five tables and a wealth of other information in tabular, graphic, or narrative form. The tables are very similar in construction and use to those contained in the Tide Tables, also published by NOAA. Table 1 contains reversing tidal current data for 24 reference stations on the Atlantic coast of Canada and the United States, the Gulf coast of the United States, and Puerto Rico. Table 2 contains “current differences and other constants” for more than 1200 subordinate stations. Table 3 provides factors for determining the speed of current at any time. Table 4 is a special purpose table with no equivalent in the tide tables. It allows the determination of the duration of weak currents near the time of slack water. Table 5 provides data for rotary tidal currents which occur offshore and which, as their name implies, are not reversing. Data is provided on the Gulf Stream and wind driven currents, neither of which is of particular interest to the coastal navigator. It also provides current diagrams and explanations for selected bodies of water.

8.2.3. Current Defined. Current is defined in the Glossary to Tidal Current Tables, 1994, as “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 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.”

8.2.4. Diurnal and Semidiurnal Currents and Other Definitions. Just as tides are diurnal or semidiurnal, so are tidal currents. A diurnal tidal current is one with a single flood and a single ebb in a lunar (tidal) day. A semidiurnal tidal current has two

floods and two ebbs in each tidal day. A rotary current is diurnal if it changes direction through all points of the compass once each tidal day.[48] Other definitions of importance, quoted from the Glossary to Tidal Current Table, 1994, are:

Double ebb or double flood	An ebb tidal current where, after the ebb begins, the speed increases to a maximum called *first ebb*; 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. For flood tides the definition is the same except flood is substituted for ebb and ebb for flood. These currents correspond, roughly, to mixed tides
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 period in which it is ebbing. Together they cover, on an average, a period of 12.42 hours for a semidiurnal tidal current or a period of 24.84 hours for a diurnal current.
Ebb current	The movement of a tidal current away from shore or down a tidal river or estuary....The expression *maximum ebb* is also applicable to any ebb current at the time of greatest speed.
Flood current	Same as ebb current except flood is substituted for ebb and movement is toward shore or up the tidal river or estuary.
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. The current in the East River, NY, connecting Long Island Sound and New York Harbor is an example.
Reversing current	A tidal current which flows alternately in approximately opposite directions with a slack water at each reversal of direction. Typical current curves are on page 8-5. Note the similarity to the tide curves on page 7-2
Rotary current	A tidal current that flows continually with the direction of flow changing through all the points of the compass during the tidal period...The speed of the current usually

[48] Tidal Current Tables, 1994 Atlantic Coast of North America, US Dept. of Commerce, NOAA, issued 1993, p. 227

	varies throughout the tidal cycle, passing through the two maxima in approximately opposite directions and the two minima with the direction of the current at approximately 90° from the direction at the time of maximum speed.
Set (of current)	The direction towards which the current flows.
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.

8.2.5. Explanation of Tables. Extracts of Tables 1 and 2 of the 1994 Tidal Current Tables, for Pollock Rip Channel (MA) and subordinate stations on Pollock Rip are provided in Appendix A. Extracts of the 1994 Tables 3 and 4 are also in Appendix A

8.2.5.1. Table 1. Table 1 provides times of slack water and times of maximum flood or ebb plus the current speed when maximum for every day of the year for 24 reference stations. It also identifies the time meridian for each reference station and the direction of set of flood and of ebb. Note that the ebb is 180° from the flood, as would be expected, in some cases (less than half) but in most other cases it is not, ranging from 143° at Boston to 215° at Charleston. Counting those locations where the flood is close to 180° (between 175° and 185°), about half the reference stations show close to a true reversal.

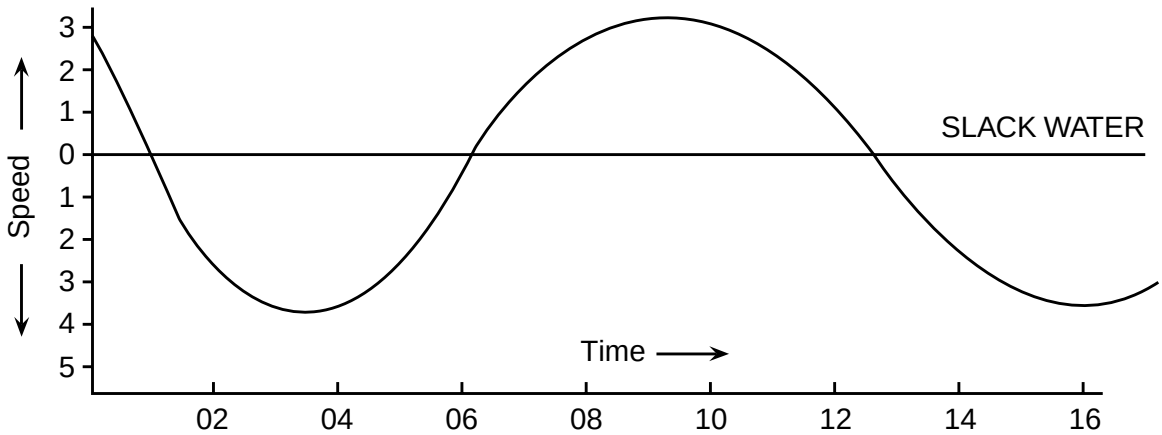
8.2.5.1.1. Slack Water. The columns headed "slack water" contain the predicted times when there is no current; that is, when the current has stopped setting in a given direction and is about to begin to set in the opposite direction. Beginning with the slack water before flood (equivalent to low water) the current increases in speed until the maximum speed of the flood current is reached; it then decreases until the following slack water (or slack before the ebb - the equivalent to high water). The ebb current now begins, increases to the maximum speed, then decreases to the next slack.[49]

8.2.5.1.2. Relation of Tidal Currents to Tides. It is important to understand that the data in Table 1 refers to the horizontal movement of the water and not to the vertical rise and fall of the tide. The relation of current to tide is not constant, but varies from place to place, and the time of slack water does not generally coincide with the time of high or low water, nor does the time of maximum speed of the current usually coincide with the most rapid change in the vertical height of the tide.[50] This seems intuitively incorrect; however, an examination of just one sub station revealed dramatic differences. According to Tidal Current Tables 1994, the slack before the

[49] Tidal Current Tables 1994, NOAA, p. 1

flood occurs at 0758 and 2011 at Tarpaulin Cove (41° 28.3'N, 70° 43.5'W, 1.5M east of), off Vineyard Sound, on 1 January 1994. According to Tide Tables 1994, low water occurs at Tarpaulin Cove (41° 28'N, 70° 46'W) at 0425 and 1657, 1 January 1994. This is due in large part to the fact that current is not measured at the same place where height of tide is measured.

8.2.5.2. Table 2. Differences in Table 2 for slack water times at sub stations are called "minimum before the flood" or "minimum before the ebb" because the current does not drop to zero speed, or true slack water, at various times at various locations.[51] Sub station 641, Hussey Sound, shows the minimum before the flood is 0.1 knots setting 114°. The flood sets 016° and the ebb 197° The set of the minimum is 90° to the set of the flood and ebb ± 10°. The minimum before the ebb is zero which means that instantaneously the incoming current stops moving before it reverses direction and begins to go out.

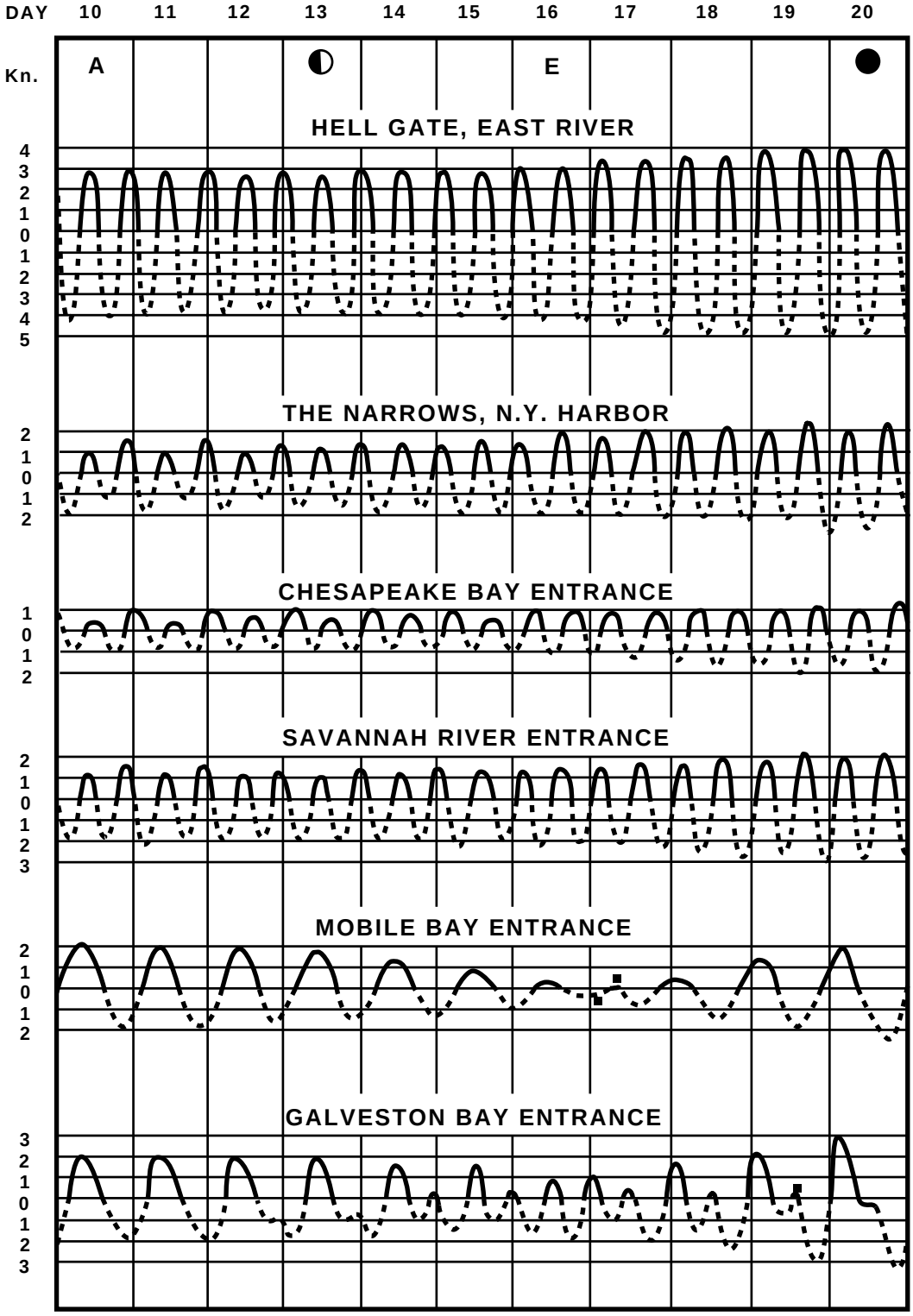


The Cyclical Nature of Currents
Figure 8-1

[50] Tidal Current Tables 1994, NOAA, p. 137
[51] Shufeldt, Fig. 14-10, p. 127

TYPICAL CURRENT CURVES FOR REFERENCE STATIONS

(Flood: Solid line, Ebb: Broken Line.)



TIDAL CURRENT WORKSHEET

Locality: _____ Date: _____

Reference Station: _____

	Min. before Flood	_____
Time Diff.:	Flood	_____
	Min. before Ebb	_____
	Ebb	_____
Speed Ratio:	Flood	_____
	Ebb	_____
	Flood Direction:	_____
	Ebb Direction:	_____

Ref. Sta: _____		Locality: _____		Locality: _____	
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Velocity of Current at any Time; _____

Interval between slack and desired time	_____	_____
Interval between slack and max. current	_____	_____
Max. current:	_____	_____
Factor, Table 3	_____	_____
Velocity	_____	_____
Direction	_____	_____

Duration of Slack

Times of max. current	_____	_____	_____
Max. current	_____	_____	_____
Desired max.	_____	_____	_____
Period - Table 4	_____	_____	_____

Sum of periods	_____	_____
Average period	_____	_____
Times of slack	_____	_____
Duration of period (±___ min.)	_____	_____

8.3. CURRENT SPEED AND DIRECTION.

8.3.1. Tidal Current (Reversing) Worksheet. A worksheet for determining speed and direction of currant is shown on page 8-6. It is a slightly modified version of the worksheet provided in Piloting and Dead Reckoning.[52]

8.3.2. An Example. The procedure to determine the speed of the current at any time is very similar to that followed to find the height of tide at any time. What is the speed of the current 1.4 M SW of Brenton Point, which is on Narraganset Bay, at 1425 on 2 April (refer to the extracts in Appendix A)? Table 2 tells us that Brenton Point tidal currents are on Pollock Rip Channel. The first part of the worksheet is completed using data in Table 2:

TIDAL CURRENT WORKSHEET

Locality: Brenton Point, 1.4 M. SW of Date: 2 April

Reference Station: Pollock Rip Channel

	Min. before Flood	-1 03
Time	Flood	-0 38
Diff.	Min. before Ebb	-1 20
	Ebb	-1 04
Speed	Flood	0.2
Ratio:	Ebb	0.4
	Flood Direction:	347˚
	Ebb Direction:	170˚

The data indicates that all events (slack waters and maximum currents) occur earlier at Brenton Point than in Pollock Rip Channel and the maximum currents are considerably weaker. Data for the reference station is obtained from Table 1, entered into the worksheet, and information for the sub station is calculated:

[52] Shufeldt, Fig. 14-10, p. 127

Ref. Sta: Pollock Rip Chan. Locality: Brenton Point

0133	0	(Min bfr Ebb)	0133 - 1 20 = 0013	0
0414	1.8E	(Ebb)	0414 - 1 04 = 0310	1.8E x 0.4 = 0.72 = 0.7E
0728	0	(Min bfr Flood)	0728 - 1 03 = 0625	0
1059	2.0F	(Flood)	1059 - 0 38 = 1021	2.0F x 0.2 = 0.40 = 0.4F
1418	0		1258	0
1656	1.6E		1552	0.6E
2010	0		1907	0
2335	1.7F		2257	0.3F

All of the information needed to determine the current velocity and direction at any time on 2 April is now in the worksheet. Fill in the remaining section:

Velocity of Current at any Time; Brenton Point - 1425

The desired time is 1425. The events (slack water or maximum current) of interest are those that bracket the desired time, in this case maximum ebb at 1258 and slack water at 1552.

Interval between slack and desired time	1 27	
Interval between slack and max. current	2 54	
Max. current:	0.6 E	
Factor, Table 3	0.6	
Velocity	0.6 x 0.6 = 0.36 = 0.4 E	
Direction	170°	

It doesn't matter if slack water is before or after the time of interest. In this case it was before. The time of interest is always bracketed by a slack and a maximum current, either flooding or ebbing. The maximum current was after the time of interest so the current was speeding up to the ebb (maximum current was ebbing and the time of interest is before the maximum; therefore, the outgoing current has to be speeding up). Table 3 provides factors. Factors are always multipliers, that is, the maximum current which is part of the bracket around the time of interest is multiplied by the factor. The completed worksheet is on page 8-9:

8.3.3. Duration of Slack. Table 4 is used when a navigator or skipper is interested in times during which the current is so weak it's considered negligible. That's defined as a current speed under 0.5 knots. The table works off of the premise that the incoming

current is practically equal to the outgoing so the period on each side of slack water when the current speed is the same is equal. Practically, currents differ in speed as they come in and go out. Assuming a 2.0 knot current (maximum speed), the length of time that the current is moving 0.4 knots or slower is 46 minutes, or 23 minutes before slack and 23 minutes after. If the current were 3.0 knots the interval would be 31 minutes, or 15.5 minutes before and 15.5 after slack. It would seem obvious that for 23 minutes before slack water and for 15.5 minutes after, a total of 38.5 minutes, the current would be 0.4 knots or less if the flooding tide were 2 knots and the ebbing tide were 3 knots. However, precision should never be applied to the imprecise. That is, when we consider that times of slack and maximum currents obtained from these tables are commonly off by 30 minutes and sometimes, though rarely, by as much as an hour, and we use nearest values instead of interpolating for more precise values, it makes little sense to try to refine these numbers to the skewed values of varying currents. Therefore, "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."[53] Applying that to this example would result in 46 minutes (the duration for 2.0 knots) plus 31 minutes (the duration for 3.0 knots), divided by 2, or 38.5, the same total duration as before and the time when the current would be 0.4 knots or less is slightly more than 19 minutes before and after slack water. Use Hell Gate (off Mill Rock), East River, New York, as an example. Tidal Current Tables 1994 shows the following data for Sunday, 24 March 1994:

	1620	3.5F
1928	2216	4.8E

How long is the current 0.4 knots or less?

Duration of Slack

Times of max. current	1620	2216	
Max. current	3.5F	4.8E	
Desired max.	0.4	0.4	
Period - Table 4	23m	18m	

Sum of periods	41m	
Average period	20.5m	
Times of slack	1928	
Duration of period (10m)	1918 - 1938	

[53] Tidal Current Tables 1994, NOAA, p. 199

TIDAL CURRENT WORKSHEET

Locality: Brenton Point, 1.4 M. SW of Date: 2 April

Reference Station: Pollock Rip Channel

	Min. before Flood	-1 03
Time	Flood	-0 38
Diff.	Min. before Ebb	-1 20
	Ebb	-1 04
Speed	Flood	0.2
Ratio:	Ebb	0.4
	Flood Direction:	347˚
	Ebb Direction:	170˚

Ref. Sta:	Pollock Rip Chan.		Locality: Brenton Point	Locality: _____
0133	0	0013	0	
0414	1.8E	0310	0,7E	
0728	0	0625	0	
1059	2.0F	1021	0.4F	
1418	0	1258	0	
1656	1.6E	1552	0.6E	
2010	0	1907	0	
2335	1.7E	2257	0.3F	

Velocity of Current at any Time; Brenton Point - 1425

Interval between slack and desired time	1 27	_____
Interval between slack and max. current	2 54	_____
Max. current:	0.6 E	_____
Factor, Table 3	0.6	_____
Velocity	0.36 = 0.4 E	_____
Direction	170˚	_____

Duration of Slack

Times of max. current	_____	_____	_____
Max. current	_____	_____	_____
Desired max.	_____	_____	_____
Period - Table 4	_____	_____	_____

Sum of periods	_____	_____
Average period	_____	_____
Times of slack	_____	_____
Duration of period (±___ min.)	_____	_____

Note that the time was rounded later on the early side and earlier on the late side. Carrying times to 0.5 minutes implies a far greater precision than is warranted. Rounding up on the low side and down on the high side keeps the times within the established bracket (the effect is the same as merely dropping the .5 and using only the whole number value, which is 20 in this case. This will always be true).

8.3.4. Rotary Currents. Offshore and in some of the wider bay and estuary entrances tidal currents are different from the reversing tidal currents that have been discussed to this point. Offshore the currents never come to a complete stop before changing direction. There is no true slack water. The offshore currents constantly change directions so that in a tidal cycle of about 12 (semidiurnal datum areas) hours the current will have set in every direction. Not surprisingly, the offshore currents are called *rotary* currents Just as with reversing currents, the rotary currents go from a minimum velocity (0 or slack water in reversing currents) to a maximum velocity in about 3 hours, followed by the next minimum in another three hours, and three hours later another maximum. The set of the current at one maximum is almost 180° from the set at the next maximum and the set at one minimum is both about 90° from the maximums and 180° from the next minimum. Table 5 of Tidal Current Tables, 1994, provides data on 44 different rotary currents off of six reference stations. Most of these currents are very light, hardly exceeding a half knot; but at all of the sites currents have been recorded from 1.5 to 3 knots and at Diamond Shoal Light they have been recorded as high as 4 knots. The rotary currents are effected by moon phases and position, and by wind. The data for the rotary current at Gooseberry Neck (in Rhode Island Sound) is reproduced below and in Appendix A. Table 5 is used in conjunction with Table 1. Look at the data for Pollock Rip Channel on April 4. Maximum flood occurs at 0054 and 1331 with speeds of 1.7 knots and 1.9 knots, respectively.

TABLE 5. ROTARY TIDAL CURRENTS

Gooseberry Neck, 2 miles SSE of Buzzards Bay entrance
Lat 41° 27' N, Long 71° 01' W

	Time	Direction (true) Degrees	Velocity Knots
	0	52	0.6
Hours	1	65	0.4
after	2	108	0.2
maximum	3	168	0.3
flood	4	210	0.5
Pollock Rip	5	223	0.5
Channel	6	232	0.5
see page 28	7	249	0.3
	8	274	0.2
	9	321	0.2
	10	16	0.3
	11	38	0.5

Table 5 says that the drift and set of the rotary current off Gooseberry Neck is 0.3 knots, setting 168° true, at 0354 (3 hours after the 0054 max.) and is 0.5 knots, setting 038° at 0031, 5 April (11 hours after the 1331 max.). The speeds in the table will be increased about 15 to 20% when the moon is new, full or in perigee (at its closest point to the earth). They will be increased 30 to 40% if the moon is new or full and in perigee. The speeds will be decreased 15 to 20% if the moon is in quadrature (first or last quarter) or in apogee (at its most distant point from the earth) and 30 to 40% if it is both in quadrature and apogee. Data on the phases and positions of the moon are contained on the inside back cover of Tidal Current Tables 1994. The astronomical data for 1994 on the inside back cover shows the moon to be in quadrature on 3 April, and in line (new) on 11 April. Apogee and perigee are far enough away that the current is probably decreased only about 15%. The maximum current in the rotary current off Gooseberry Neck is 0.6 knots. A 15% decrease is 0.09 knots which would decrease the current to 0.51 (0.5) knots.

8.3.5. Wind Driven Currents. There are wind driven currents which combine with tidal and other currents to increase or decrease the total movement of water that influences the location of a vessel. So many things influence the effect of wind on the movement of water that tables can only provide a rough average.

8.3.5.1. Current Speed. The length of time a wind blows and the fetch influence the speed of a wind driven current. Observations were taken hourly at offshore light ships for two years in most locations, for 5 years at Nantucket Shoals, and for 9 years at Diamond Shoal. This data produced a table that showed wind driven currents for most locations as shown below. Note that 30 mph winds are in the small craft advisory range and 40 and 50 mph winds indicate a gale. These are conditions under which most recreational vessels, including Auxiliary facilities, should not be out.

10 mph	0.2 knots
20 mph	0.3 knots
30 mph	0.4 knots
40 mph	0.5 knots
50 mph	0.6 knots

As stated in Chapter 6, wind driven currents generally do not affect coastal navigation since the wind must act over long fetches for 12 hours or so in order to generate the currents. Nevertheless, a knowledge and understanding of them is prudent for the navigation specialist. Note: Wind driven current is not leeway.

8.3.5.2. Coriolis Effect. Wind driven currents do not move in the direction of the wind. The forces applied by the rotation of the Earth, the Coriolis effect, causes

a wind driven current to set to the right of the direction the wind is blowing towards. Tidal Current Tables provides the amount of deflection for old light ship stations for N, NNE, NE, ENE, E, etc. around the compass (every two points — a point is 11°). The data for Brenton Reef is extracted from the table on page 168 of Tidal Current Tables, 1994:

Average deviation of current to the right of wind direction
[A minus sign (-) indicates that the current sets to the left of the wind]

Wind from	N	NNE	NE	ENE	E	ESE	SE	SSE	S
Brenton Reef	34	25	22	19	25	1	-7	8	27
	SSW	SW	WSW	W	WNW	NW	NNW		
	48	23	41	41	31	21	24		

This table says that if a NE wind is blowing, the wind driven current will set 247° (a NE wind is from 045° blowing towards 225° and the current sets 22° to the right or 247°).

8.4. COMBINING CURRENTS. Combining currents is a simple matter of vector arithmetic done on the maneuvering board as was done in current sailing. One current is drawn from the origin of the maneuvering board in the direction of its set for a distance corresponding to its speed. The next is drawn from the head of the first in the same manner, and so on. The resultant current, drawn from the board's origin to the head of the last current, reflects the combined effect of all the currents acting at one place at one time.

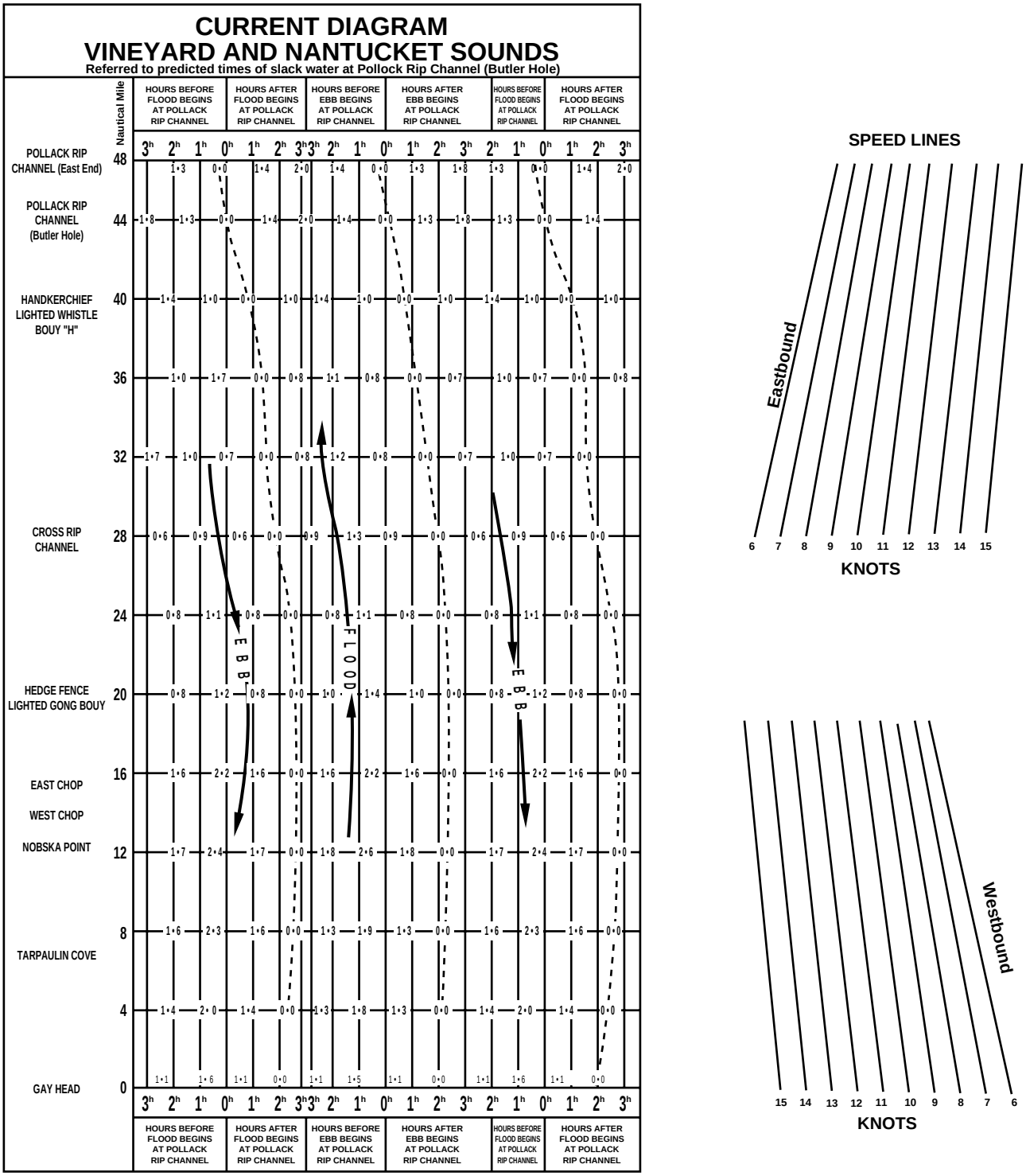
8.5. CURRENT DIAGRAMS.

8.5.1. Purpose of the Diagrams. Current diagrams are graphic tables that show velocities of flood and ebb currents and the times of slack and strength over a considerable stretch of the channel of a tidal waterway. The diagrams are presented in Tidal Current Tables, Atlantic Coast of North America, for five areas: Vineyard and Nantucket Sounds, referred to predicted times of slack water at Pollock Rip Channel (the reference station); East River, New York, referred to Hell Gate; New York Harbor (via Ambrose Channel), referred to The Narrows; Delaware Bay and River, referred to Delaware Bay Entrance; and Chesapeake Bay, referred to Chesapeake Bay Entrance. The diagrams show the velocities and changes of the currents through their flood and ebb cycles. They allow the mariner to determine the most advantageous time to pass through the water to gain the most benefit from a fair current. They also allow determination of the currents to be encountered in the channel at any time. The current diagram for Vineyard and Nantucket Sounds is reproduced in Figure 8-2 and in Appendices A and D.

8.5.2. Use of the Diagrams. Use of the diagrams is much easier than it looks. In Vineyard and Nantucket Sounds, easterly streams are flood currents and westerly are ebb. The speed lines are directly related to the current diagram. Transferring the line corresponding to the speed of the vessel to the current diagram with parallel rulers will show the general direction and speed of current to be encountered by the vessel or the most favorable time for leaving any place on the left margin.

8.5.2.1. An example. A vessel leaves Tarpaulin Cove, eastbound at 9 knots, at 1330 hours, 3 April. Table 1 shows that the flood begins (the slack before the flood) at 0834 and the ebb begins at 1525. The time of departure is about 2 hours before the ebb. Using parallel rulers, transfer the 9 knot eastbound speed line to the diagram at the point where the two hour before the ebb vertical line intersects the Tarpaulin Cove 8 mile horizontal line. For 24 miles, to the 32 mile line, the vessel will experience a fair current averaging about 1.3 knots. Roughly half way between Cross Rip Channel and the Handkerchief Buoy, at about 27 miles from Tarpaulin Cove, the vessel encountered a foul current (the ebb). From there until the vessel exits Pollock Rip Channel, 39 miles from Tarpaulin Cove, the vessel will experience an average 1.1 knot, roughly, foul current. To carry this example further: consider the entire time from Tarpaulin Cove until the vessel encounters slack water. The average fair current for the entire 27 miles is about 1.2 knots. Combining the current with the speed of the vessel gives an average speed over the ground of 10.2 knots, which would take 2h 39m. The last 12 miles would be run at a speed over the ground of about 7.9 knots, taking 1h 31m. The entire run of 39 miles would take 4h 10m for an average of 9.4 knots. At 9 knots the voyage would take 4h 20m. A reminder: too many variables are involved to time events to the nearest minute. The point here is that use of the current diagrams can provide an indication of what will be encountered. The skipper of the vessel in this example could say, with reasonable assurance, "If I leave Tarpaulin Cove at 1000 and run at 9 knots, I'll probably have the current working for me most of the way and I'll probably make it through the channel around ten minutes earlier than I would with no current."

8.5.2.2. Another Example. A second use of the diagrams is to determine the best time to start through, or from a point within the channel to ensure the most favorable current for the trip. Suppose a vessel wants to travel at 10 knots through Pollock Rip Channel from the entrance at the east end to Gay Head at the west end, on 2 April. Table 1 shows that the flood begins at 0728 and 2010 EST and the ebb begins at 1418 EST. A cursory look at the Vineyard and Nantucket Sound current diagram indicates that ebb currents are fair westbound, while flood currents are fair eastbound. Obviously, this vessel wants an ebb current as much of the way as possible. Using parallel rulers, transfer the 10 knot westbound speed line to the diagram into the ebb regions and see where the best currents are obtained. Where the best average current is obtained is a judgment call by the navigator (to recommend) or skipper (to decide).



Current Diagram – Vineyard and Nantucket Sound
Figure 8-2

In Figure 8-3, two lines have been drawn which indicate a fair current all the way. The left line, entering the channel three hours before the flood begins, appears to have the highest average current speed, something over 1.2 knots. The right line, entering the channel two hours after the ebb begins, encounters the highest speed of current but also averages about 1.2 knots or less. The flood begins at 0728 and 2010. The vessel can enter the channel at half past four in the morning and between four and five in the afternoon and have approximately the same results.

8-1. Currents may be classified as _____ and _____.

a. ebb, flood
b. reversing, rotary
c. ocean, coastal
d. tidal, non-tidal

8-2. Tidal currents are caused by the gravitational interaction between the ___, ____, and _____.

a. earth, sun, moon
b. sun, moon, perigee
c. moon, sun, apogee
d. earth, moon, quadrature

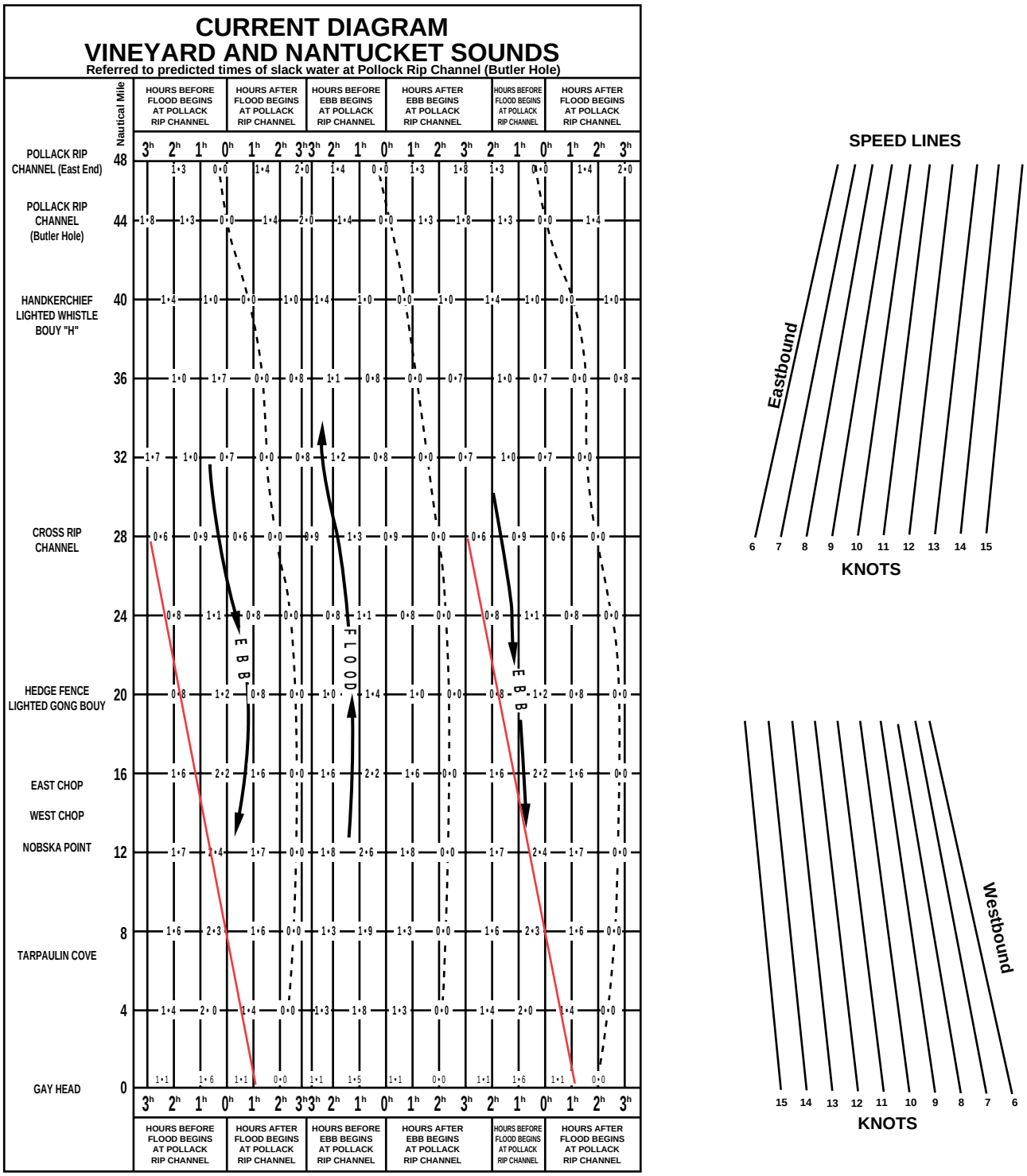
8-3. (True/False) Permanent nontidal currents are part of the gravitational interaction of the seas.

8-4. (True/False) Temporary nontidal currents are caused by meteorological variability, such as wind.

8-5. (True/False) A tidal current with a single flood and a single ebb in a lunar day is diurnal; one with two floods and two ebbs is compound.

8-6. (True/False) A double ebb or double flood current corresponds roughly to a semidiurnal tide.

8-7. (True/False) An ebb current is the movement of water toward shore or down a tidal river.



Finding Most Favorable Current
Figure 8-3

8-8. A hydraulic current is a current in _____ with a difference in _____ _____.

a. the ocean, direction of set around the clock
b. a channel, surface levels at each end
c. a river, direction of outgoing tides from direction of river flow
d. the ocean, temperature of opposing water systems

8-9. A tidal current which flows alternately in approximately opposite directions with _____ at each change of direction is a _____ current.

a. a change of speed, rotating
b. a Coriolis Effect caused offset, wind-driven current
c. slack water, reversing
d. minimum velocity, tidal

8-10. A tidal current that flows continuously with the direction of flow changing _____ during the tidal period is a _____ current.

a. due to Coriolis Effect, rotary
b. back and forth, reversing
c. continuously, rotary
d. approximately 180°, reversing

8-11. True slack water occurs when current speed drops to ____ at the time ____ _____. It is instantaneous.

a. zero, of a reversal in direction
b. a minimum, of the flood
c. a minimum, of the ebb
d. zero, the moon is in apogee

8-12. _____ and _____ is used for the differences from the reference station in Table 2 because the current does not always drop to ____ in some locations.

a. Slack water, flood, datum
b. Minimum before the ebb, minimum before the flood, zero speed
c. Direction of ebb, direction of flood, zero speed
d. Duration of ebb, duration of flood, a minimum

8-13. The set of a rotary current at one maximum is approximately ____ from the set at the next maximum and the set at one minimum is approximately ____ from the set at the maxima and ____ from the set of the next minimum.

a. 90°, 90°, 180°
b. 180°, 90°, 90°
c. 180°, 90°, 180°
d. 90°, 180°, 90°

8-14. Rotary current speeds will be increased about 15% to 20% when the moon is ___, ____, or in _____.

a. one-quarter, three-quarter, perigee
b. on-quarter, three quarter, apogee
c. new, full, perigee
d. new, full, apogee

8-15. Rotary current speeds will be reduced 30% to 40% when the moon is in _____ and in _____.

a. quadrature, perigee
b. alignment, perigee
c. quadrature, apogee
d. alignment, apogee

8-16. (True/False) Wind driven currents move to the right of the wind (direction towards which the wind is blowing) in the Northern Hemisphere because of the effect of the rotation of the Earth.

8-17. (True/False) Leeway is the most important effect of wind driven current to the navigator.

8-18. (True/False) The Coriolis Effect is the name given to gyroscopic precession caused by the combination of the rotation of the earth and the gravitational pull of the sun and moon.

8-19. (True/False) Currents acting in the same place at the same time are combined through vector arithmetic to obtain a resultant current.

8-20. (True/False) Current diagrams are mathematical tables that show velocities of flood and ebb currents and the times of slack and strength over a considerable stretch of the channel of a tidal waterway.

PROBLEMS

8-1. What is the set and drift of the current 1.4M SW of Brenton Point (on Pollock Rip Channel) at 1015, 3 April? _____

8-2. What is the maximum current at Tarpaulin Cove (on Pollock Rip Channel) on 6 April? _____

8-3. What is the time period during which the current will be 0.3 kts or less 1M southeast of West Island (on Pollock Rip Channel) during the morning of 1 April (EST is in effect)? _____

8-4. What is the speed and set of the current 2M SSE of the Buzzards Bay Entrance at Gooseberry Neck at the time of the last slack water in Pollock Rip Channel on 2 April? _____

8-5. What is the speed and direction of current from a Nor' Easter (wind is NE at 50 mph and has been blowing in excess of 12 hours) at the old Brenton Reef Lightship station (uses "most" stations data)? _____

8-6. A trawler type yacht traveling westbound through Pollock Rip Channel at 7 knots departs Cross Rip Channel at 0710 on 6 April (Daylight Savings Time is in effect). What is the yacht's average speed over the ground from Cross Rip Channel to Gays Head? _____

8-7. What is the best time for the yacht to leave Cross Rip Channel? _____

CHAPTER 9
ELECTRONIC (RADIO) NAVIGATION

9. Chapter 9.

9.1. RADIO DIRECTION FINDING.

9.1.1. General. Radio direction finding (RDF) equipment is very expensive considering its inherent inaccuracy and difficulty to use. It is seldom found on Auxiliary facilities and recreational vessels anymore and this course will spend little time on it. Shufeldt's Piloting & Dead Reckoning devotes a chapter to RDF. Dutton's Navigation and Piloting provides a lot more information and is recommended reading for those Auxiliarists who still have and use RDF. Bowditch's American Practical Navigator, Vol. 1, and Chapman's Piloting, subtitled Seamanship and Small Boat Handling, and the USCG Auxiliary's Advanced Coastal Navigation (public education course) text, second edition, also contain good descriptions of RDF.

9.1.2. The Null Signal. RDF bearings are obtained through use of a loop antenna which can be rotated to determine signal strength at various bearings. The signal is strongest when the loop is in line with the signal and weakest when perpendicular to the signal. The latter is called the *null* signal and is the one used to determine the bearing to the transmitter because it gives the sharpest definition of signal strength and, therefore, the most accurate relative bearing.

9.1.3. Characteristics of RDF.

9.1.3.1. Great Circle. Radio waves follow a great circle. RDF LOPs, then, cannot be plotted on a Mercator chart if the range from the transmitter is more than 50 miles. In the northern hemisphere, the great circle path will always be north of the rhumb line; in the southern hemisphere, it will always be south. For bearings relatively close to a north-south line, the separation between the great circle path and the rhumb line is small. For east - west bearings it is large, more so in the higher latitudes than near the equator. Conversion tables are necessary. One is found in Bowditch, Vol. 2., in Dutton's, and in Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) publication RAPUB 117.

9.1.3.2. RDF Deviation. A vessel imposes deviation on a radio receiver just as it does on a compass, with a very important difference. The compass deviation is the result of the vessel's magnetic field interacting with the earth's and changes with the heading of the vessel. The radio wave deviation is the result of the vessel's electrical fields and changes with the relative direction of the radio signal.

9.1.3.3. Relative Bearings. RDF bearings are relative; therefore, knowing the vessel's precise heading at the instant of the LOP is very important.

9.1.3.3.1. RDF LOP. To determine a radio LOP the navigator must correct the relative bearing of the vessel's radio receiver to the transmitter antenna by the radio deviation (same rule applies as in compass deviation: the bearing is being corrected so east deviation must be added and, in setting up the radio deviation card, if the bearing read from the RDF is less than the charted bearing, deviation is east) and must correct the vessel's heading by applying compass deviation and variation to obtain the true heading. The corrected relative bearing to the transmitter is added to the true heading to determine the true LOP.

9.1.3.3.2. Direct and Reciprocal Bearings. Unless the RDF has a vertical sensing antenna the indicated bearing to the transmitter can be direct or the reciprocal. The direct bearing will draw aft as the vessel proceeds, the reciprocal will draw forward.

9.1.3.4. RDF Accuracy. Radio bearings have an accuracy no better than $\pm 2°$. A polarization, called *night effect*, occurring during morning or evening nautical twilight (half an hour before sunrise or after sunset) further reduces the accuracy of the radio bearing.

9.1.3.5. RDF Position. "Radio bearings are plotted and labeled in the same manner as visual bearings. RDF bearings are, however, usually much less precise and accurate; a position found with one or more radio bearings must be identified as an "RDF fix," or as an estimated position (EP)."[54] [55]

9.2. LORAN

9.2.1. General. With the dramatic decrease in price, LORAN (LOng RAnge Navigation) has become the electronic navigation system of choice for Auxiliarists and for the general boating public. Global Positioning System (GPS) is also increasingly popular and common and has experienced even more dramatic drops in price. Though LORAN was scheduled to be replaced by GPS by the year 2000, indications are that it will be with us until around 2015.

9.2.2. Description. LORAN-C, which is the mode in use, is a very accurate, repeatable, electronic navigation system employing lines of position based on time differences in receiving signals from paired stations. The LORAN system is made up of chains consisting of a master station (M) and two to four secondary stations (W, X, Y, Z) several hundred to a thousand miles apart, transmitting precisely timed pulsed

[54] Dutton's, para 3207, p. 448

[55] Some publications use the term RDF Fix without mention of EP associated with it. This course calls a RDF Fix an EP.

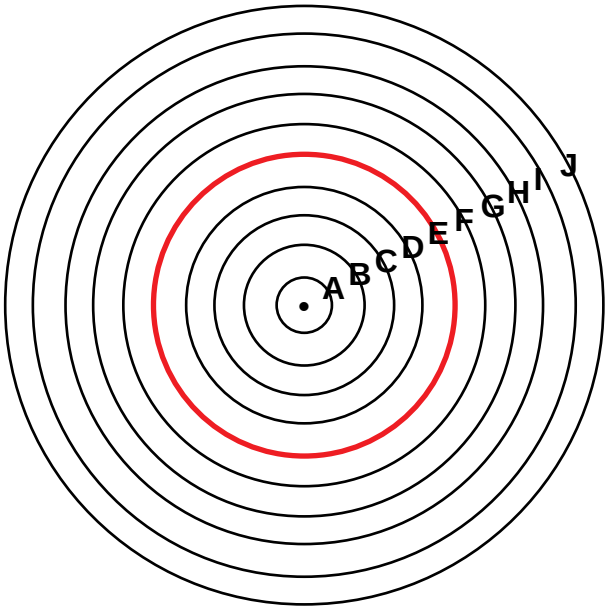
signals, all on the same HF frequency, 100 khz. Figures 9-1 and 9-2 are of the manned station at Dana, IN. The Dana facility is both the master station for the 8970 Great Lakes Chain and the Z station for the 9960 Northeast US Chain. The signals are timed by an "atomic" clock, one using cesium time and frequency standards.[56] The basics of LORAN are quite simple. If two signals are sent simultaneously from two transmitters the distance of the receiver from each transmitter can be determined by the time required for each signal to reach the receiver (circles of position from each transmitter). In modern LORAN-C, the signals are not sent simultaneously, but with an incredibly small built in delay which can be measured by the receiver's computer and converted

LORAN Station, Dana, IN (Inside)
Figure 9-1[57]

LORAN Station, Dana, IN (Outside)
Figure 9-2[58]

to show the time difference without the delay. That is, the receiver will show a time difference of 0 for all points equidistant from both stations. For the purpose of this discussion, ignore the built in delay, which is there solely to prevent the otherwise simultaneous receipt of the signals from interfering with each other. The LOPs are defined by the time difference (TD) between the receipt of signals from each station. Identical time differences between receipt of the two signals will plot as a *hyperbolic* LOP. The master station forms a pair with each secondary station. LOPs from two pairs constitute a fix. Omnidirectional radio waves, such as those produced by a LORAN station, radiate away from the transmitter station in all directions, similar to the circular ripples obtained if a stone is dropped in smooth water. This omnidirectional ripple effect is shown in Figure 9-3. A receiver would receive the signal some time after its transmission, somewhere on a circle of position, based on that time around the transmitter. If a second transmitter were located so that their signals overlap, the receiver would pick up its signal, on a circle of position around the second transmitter. When the difference in time between the reception of the two signals is compared, the receiver can be anywhere on a hyperbolic curve reflecting that same time difference.

[56] Dutton's, p. 455
[57] Photo: USCG
[58] Photo: USCG



Omnidirectional Radiation of a Signal
Figure 9-3[59]

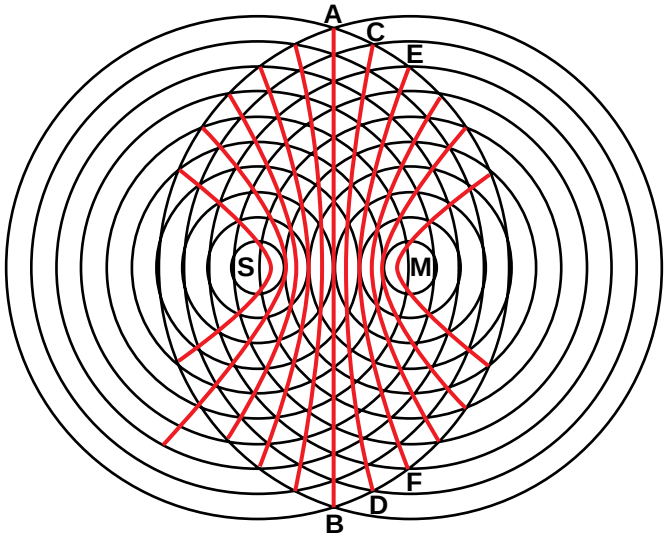
9.2.3. Time Differences.

9.2.3.1. Transmitters Equidistant From the Receiver. A very simple explanation of time differences and hyperbolic curves is contained in The Loran-C Users Guide by Bonnie Dahl, published by Richardsons' Marine Publishing, Evanston, Illinois. Ms. Dahl uses concentric circles about the transmitter, each at a 100 mile greater radius than the one preceding. She assumes, for the sake of illustration, that the signal takes 1 second to travel 100 miles. If the receiver is 400 miles from the transmitter, it is anywhere on the fourth circle and it took 4 seconds for the signal to reach it. If the receiver was also 400 miles from the second transmitter it would receive the signal at the exact same instant as the first transmitter. If the receiver were 500 miles from each transmitter it would still receive the signal at the same instant; the same is true of 600 miles, 700 miles and so on. That being the case, the receiver could be anywhere on line AB in Figure 9-4, which represents a time difference in signal reception of zero (both signals received at the same time).

9.2.3.2. Transmitters Different Distances From the Receiver. If the receiver is 400 miles from station A and 500 miles from station B, it will pick up the signal from B one second after the signal from A. The same is true for 500 from A and 600 from B, etc. A second curve, CD, represents the time difference of one second between reception of the two signals (note that if the receiver is closer to B, the curve of one second time difference would be on the other side). Curve EF represents a two-

[59] The Loran-C Users Guide, Bonnie Dahl, Richardson's Marine Publishing, Evanston, IL, 1991. Fig. 2-2, p. 27

second time difference between receipt of the signals, B's signal being received after A's. The curves of equal time difference are hyperbolic. LORAN sets determine the time differences and define a LOP for each pair of stations as shown in Figure 9-5. Actually, signals are not transmitted simultaneously, as stated in paragraph 9.2.2. The secondaries follow the masters. The receivers are programmed to apply the location time difference to the fixed time difference and handle the complete set of events as simultaneous transmissions.

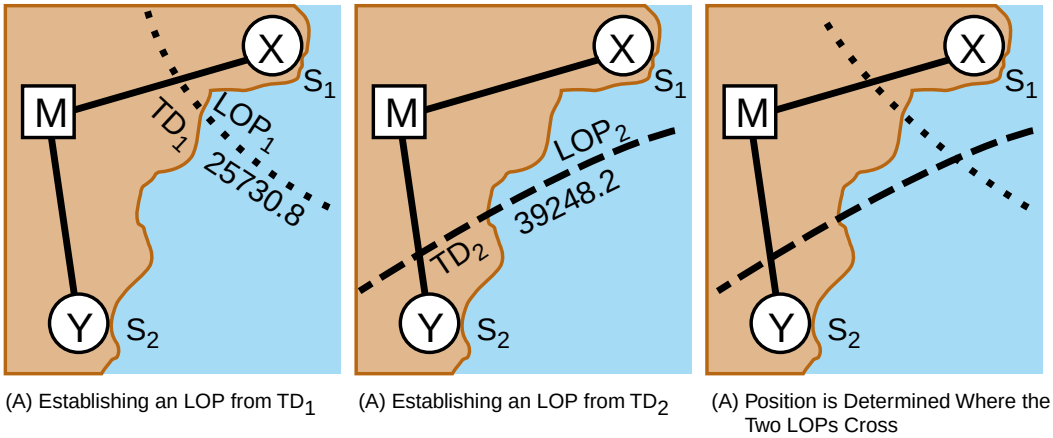


Reception of Signals From Two Stations
Figure 9-4[60]

9.2.4. Time Differences vs. Geographic Coordinates. LORAN is based on determining time differences, and that's what LORAN sets do. Most LORANs will give positions in geographic coordinates (Latitude and Longitude), but that's a manufacturer's add-on. Time Difference LOPs from different manufacturers' sets will be quite close. Geographical coordinates from those sets may be quite different. Where accuracy and precision is required, such as SAR cases, TDs should be used whenever possible to run to a specified location. Radionavigation Bulletin Number 26, Spring/ Summer Issue 1993, published by the USCG Radionavigation Division (G-NRN) of USCG Headquarters addresses this point in an article titled "Loran Latitude Longitude Readouts - The Lat/Long your receiver gives you may not be as accurate as you think". The article points out that the latitude/longitude conversions are made within the receiver by mathematical algorithms using Additional Secondary Phase Factor (ASF) information stored in the receivers computer memory. It says that while many manufacturers go to great pains to make the ASFs as accurate as possible, others are so inaccurate that the internal ASF corrections resulted in greater latitude and longitude

[60] The Loran-C Users Guide, Fig. 2.3, p. 28

errors than if no corrections had been applied at all. The article states, "It is possible for two Loran receivers located next to each other to register exactly the same TDs, but slightly different positions in latitude and longitude terms."



Establishing a Fix From LORAN Lines of Position
Figure 9-5[61]

9.2.5. Group Repetition Interval. Chains are identified by a Group Repetition Interval (GRI), the time required for each station in the chain, beginning with the master and followed by the secondaries in turn, to transmit its eight (nine for the master station) pulses. The Northeast United States Chain has a GRI of 99600 µsec and is identified as the 9960 chain. The GRI measures the time from the first pulse of the master station to the first pulse of the master station on the next cycle as shown in Figure 9-6.[62]

9.2.6. Pulses and the Receiver. The cesium clock precisely times the interval between pulses of each station, the time between pulse groups within one cycle; that is the time between the master and the W secondary, between the W secondary and the X secondary, etc., as well as the GRI. Each master transmits nine pulses, each secondary eight pulses. The receiver recognizes the number of pulses and accepts a TD LOP if a master pulse group and a secondary pulse group from the same chain is present. It will not accept a TD LOP from the time difference between two secondaries. It also recognizes the presence of a second set of time differences from another chain and can discriminate between the two to display only the TDs for the proper, dominant system for the location of the receiver.

9.2.7. Position Accuracy. LORAN-C is precise, providing position accuracy as close as 50 feet (15 meters) with maximum error of about 1700 feet (520m) or around a third of a mile, when around 1000 miles from the master station. At 1000 miles, accuracy is often as close as 500 feet (150m).

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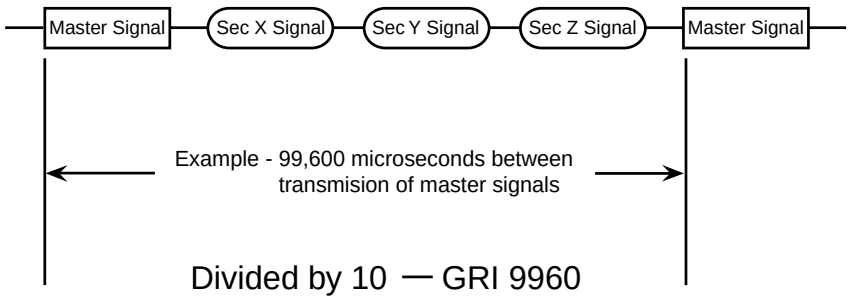
[61] The Loran-C Users Guide, Fig. 2.4, p. 29
[62] The Loran-C Users Guide, Fig. 2.12, p. 41

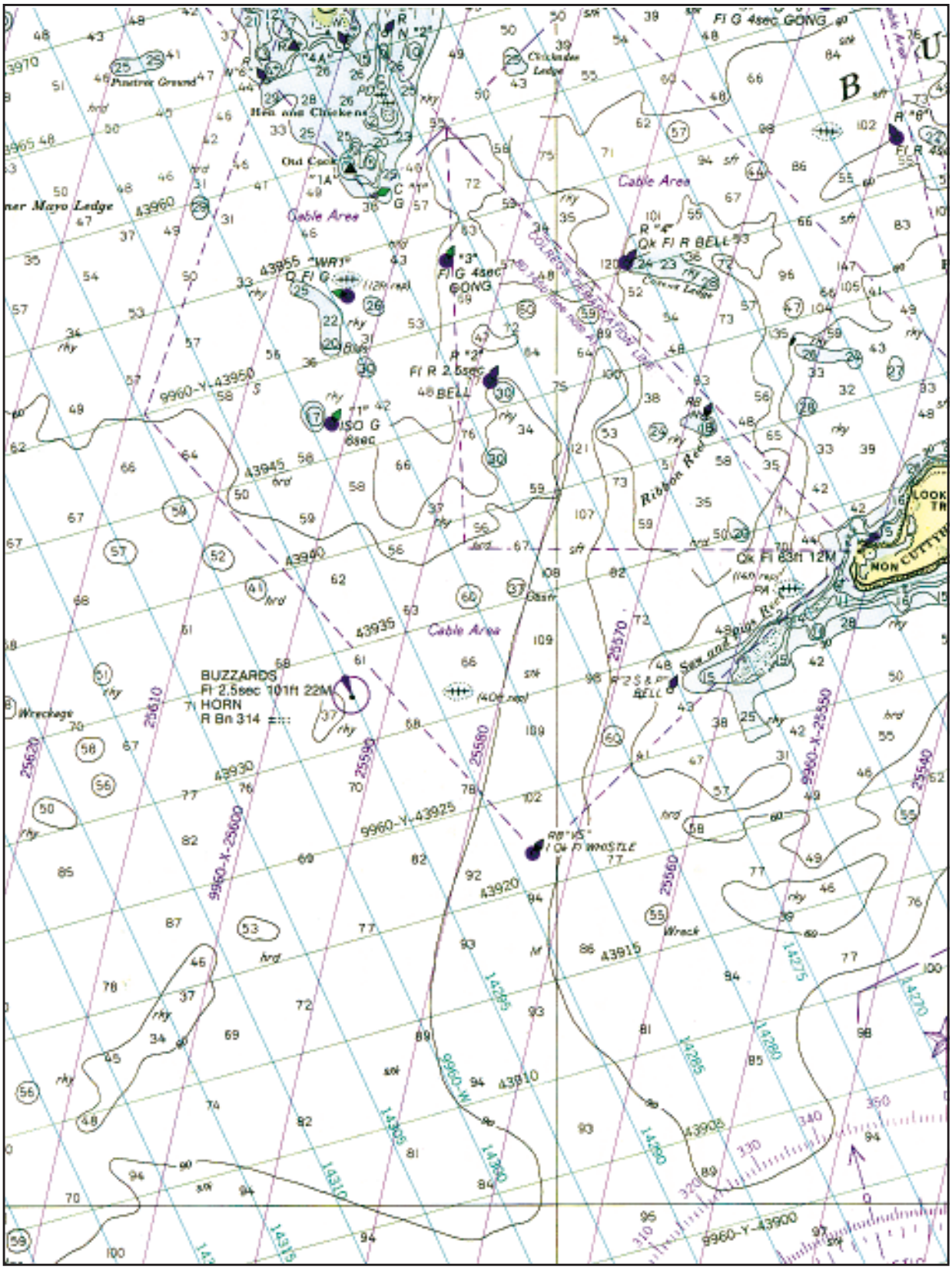


Pulse groups for the 9960 Northeast North America Chain
Figure 9-6

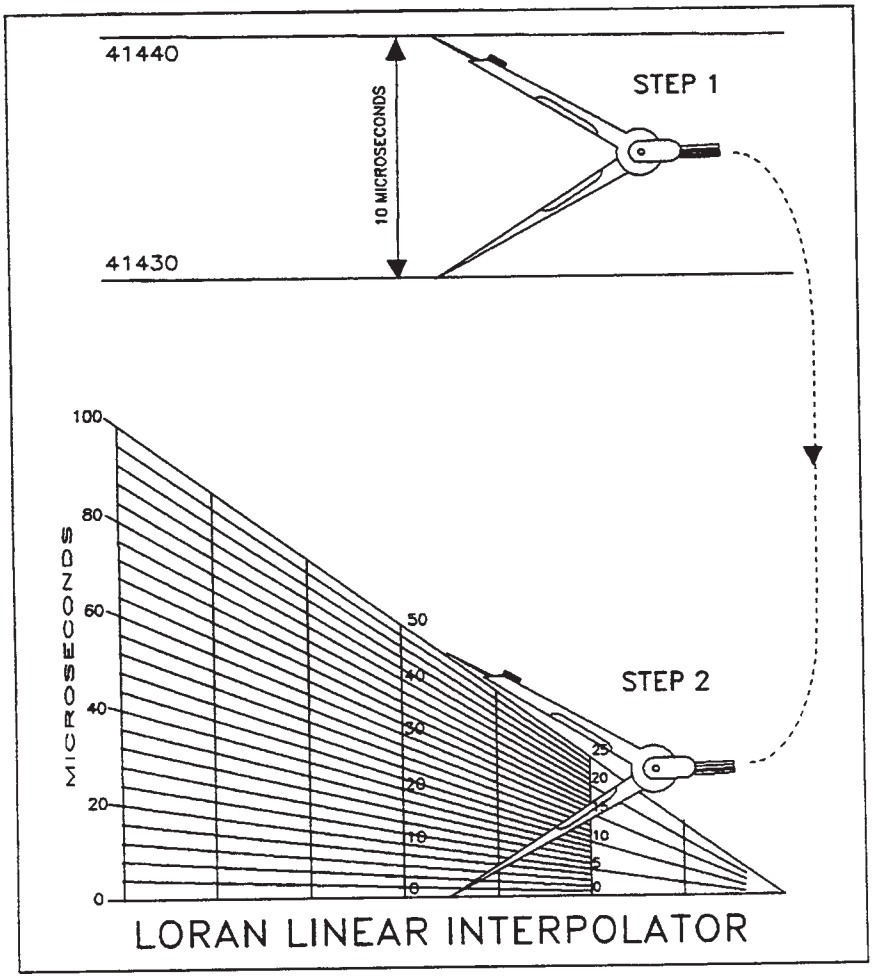
9.2.8. Repeatability. A very important characteristic of LORAN is its repeatability; that is, the precision with which a vessel can return to a specific point marked by TDs read off of its LORAN Receiver. Modern, inexpensive receivers can repeatedly bring a vessel back to anywhere between 50 feet and 300 feet (15 - 90m) from a previously determined location.

9.2.9. Charts and LORAN Overlays. NOAA charts in scales of 1:80,000 and smaller are usually overprinted with LORAN TD curves for each pair of stations in the chain covering the area. The curves are 5 or 10 μsec apart. Larger scale charts generally cover areas with a lot of land. LORAN overprints are not prepared for these areas because of the local distortions caused by the land. LORAN can still be used in these areas and will provide the repeatability that makes LORAN so attractive to recreational boaters. Page 9-8 is a reproduction of a segment of a chart (1210 Tr) showing the LORAN overprint. On the chart, the 9960-W curves are green, the 9960-X curves are magenta, and the 9960-Y curves are dark gray.

9.2.9.1. Linear Interpolator. Figure 9-7 and 9-8 show how to use a LORAN Linear Interpolator which is imprinted on every chart that contains a LORAN overprint. This diagram is easy to understand but complex to explain. The two figures show how to find a target or position, given in time differences, using the interpolator. The interpolator can also be used to determine the hyperbolic coordinates (position as defined by time differences) of a target or a fix, for example. On the chart segment on page 9-8, find the Ribbon Reef buoy, located NW of the monument on the western tip of Cuttyhunk Island. What is its location? As with visual LOPs, its desirable for LORAN LOPs to be as close to 90° from each other as possible. By examination, that would be the 9960-W and the 9960-Y curves. Both sets of curves are 5 μsec apart. The interpolator's horizontal line is marked "0" and the outer sloped line is marked "100," "50," and "25." The 100 and 50 are the same as 10 and 5 when


Fl G 4sec GONG
Pinetree Ground
Hen and Chickens
Chickenbone Ledge
Out Cock
Cable Area
Mayo Ledge
Fl G 4sec GONG
Fl R 2.5sec BELL
ISO G 6sec
Qk Fl R BELL
Ribbon Reef
Qk Fl 8ft 12M
NON CUTTING
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Wreckage
Wreck
Qk Fl WHISTLE
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25550

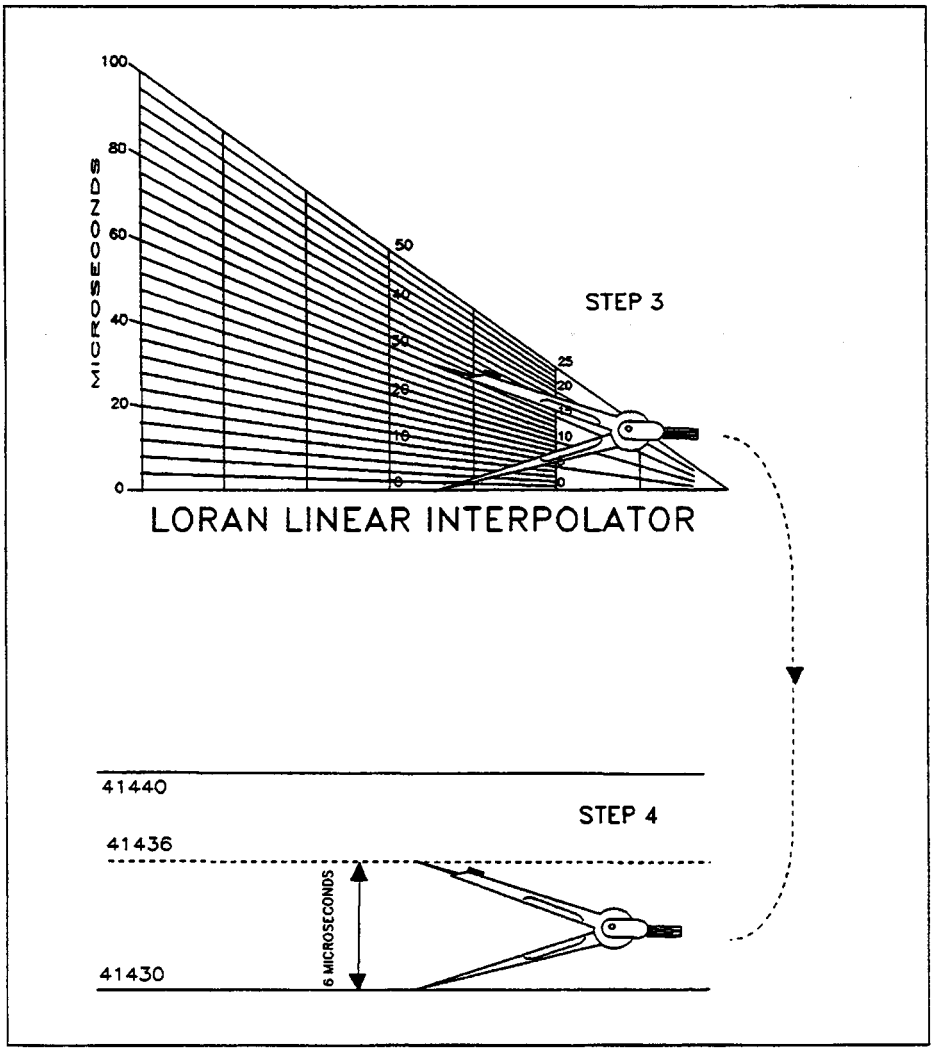
Step	Action
1.	Using a set of dividers, measure the distance between lines 41430.0 and 41440.0. The distance is equal to 10 microseconds.
2.	Place the dividers on the interpolator exactly where one point rests on the top line and the other point on the bottom line.



LORAN Linear Interpolator
Figure 9-7[63]

[63] Navigating and Piloting BM3, US Coast Guard Institute Pamphlet No. D30915 (07/92), Fig. 3-5, p. 3-12

Step	Action
3.	Without moving the bottom point, bring the top point straight down to a position six divisions from the bottom point.
4.	Now go back to the chart. Place the bottom point on the 41430 line; the top point indicates 41436.0. Draw a line parallel to the printed lines through this point. You have now plotted the 41436.0 LOP.



LORAN Linear Interpolator
Figure 9-8[64]

[64] Pam No. D30915, Fig. 3-6, p. 3-13

dealing with curves such as those shown on the chart segment. In this case, the outer line represents 5 μsec and each internal line is 0.2 μsec apart. Start with the W curves. Draw a faint line through the buoy as close to perpendicular to the W curves as possible. Set dividers to the exact distance between the curves and find the place on the interpolator where the points hit the two outer lines (while perpendicular to the horizontal line) and mark them. Draw a faint line across the interpolator through both marks. Set the dividers on the buoy and the lowest valued W curve (in this case, 14265, which means that the time difference between receipt of the signal from the master and the W secondary stations is 14265.0 μsec everywhere on the line). Transfer the dividers to the line on the interpolator and read 14265.9 μsec. Do the same for the Y curves and read 43941.7 μsec.

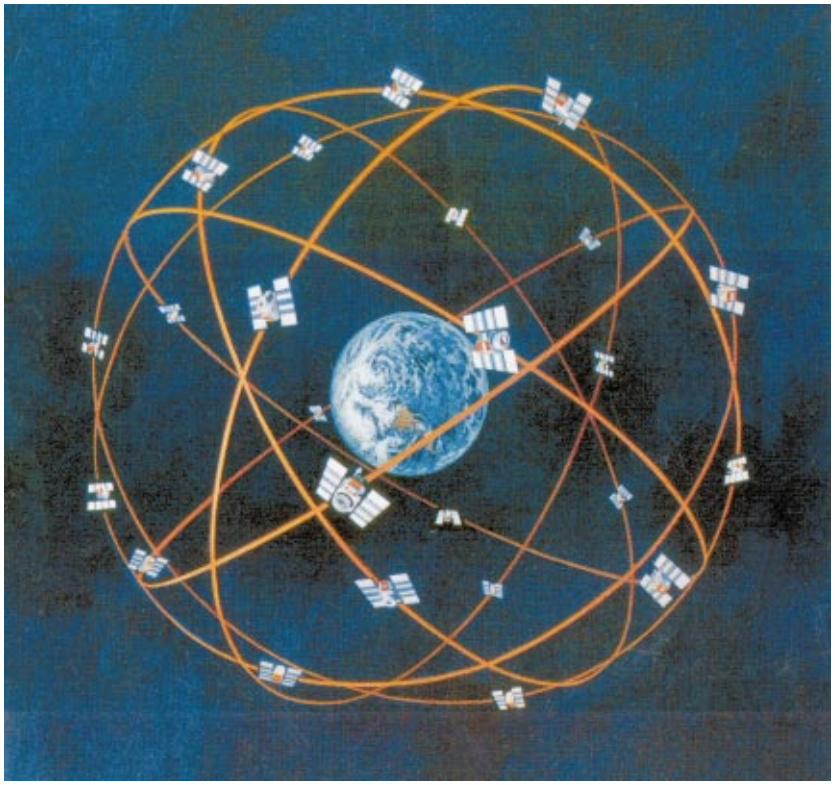
9.2.9.2. LORAN Plotter. Another interpolation device is the LORAN-C Plotter, shown in Figure 9-9. The plotter has series of 1-10 graduations scattered around its outer edge. To use it, simply find a scale slightly larger than the space between the TD curves and lay the plotter so that the first and fifth or tenth tic marks intersect the TD curves and the edge passes through the object. Read the TD position directly off the plotter, making a mental interpolation of the distance from the closest tic mark. If trying to find an object at a set of TD coordinates, the same thing is done except that a mark is made on the chart at the desired TD and a faint line is drawn on the chart as close as possible to parallel to the TD curves. As close as possible is used because the TD curves are just that, they are curves and are never actually parallel. Do the same for the other set of TD curves. Where the two lines intersect is the location of the object.

LORAN-C Plotter
Figure 9-9

9.2.10. The Future of LORAN. With the advent of GPS, there is concern about the continued use of LORAN. Many publications and books on the subject indicate that LORAN will phase out around 2000. Issue 26 of the Radionavigation Bulletin says that LORAN-C is expected to be around until at least 2015. LORAN-C remains the designated federally-provided radionavigation for civil marine use in US coastal waters. The Federal Aviation Administration has designated it as a supplemental navigation system for use in the National Airspace System. The Coast Guard is turning overseas stations over to foreign governments but is actively upgrading US coverage and improving the system.

9.3. GLOBAL POSITIONING SYSTEM.

9.3.1. Principals of Operation. GPS is a second-generation SHF satellite navigation system which will use twenty-one satellites, with three spares, orbiting at 10,898 miles above the earth, in six different circular orbital paths, to provide continuous accessibility of satellite signals, worldwide. GPS consists of three segments: the USAF operated space and control segments, and the user segment.

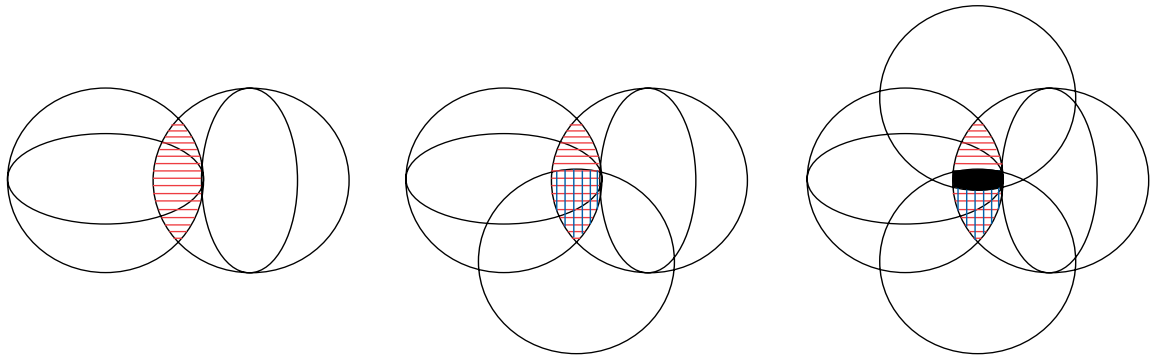


The Global Positioning System
Figure 9-10[65]

[65] GPS World, Vol. 6, No. 6, June 1995, Published by Advanstar Communications, Rockwell Aerospace advertisement, p. 70, Courtesy of Boeing North American, Inc.

9.3.1.1. Space Segment. The space segment satellites are spaced so that at least six will be in line-of-sight of any viewer anywhere in the world.

Essentially, GPS works through satellite ranging, which resembles triangulation in practice; that is, the receiver receives simultaneous signals from three or more satellites. Actually, GPS uses four satellite signals, which increases the precision of the GPS fix. Each satellite radiates a digitally encoded signal as an expanding sphere, with the satellite at the center. The signal contains a discrete code, identifying the satellite, and a message precisely describing the satellite's orbit and the GPS time the signal originated. The receiver compares the GPS time of transmission with the GPS time of reception of the signals from each satellite and computes the spherical radii of the signals, the intersection of the four spheres is the location of the receiver, as shown in Figure 9-11 (which shows the decreasing common area as the number of satellites ranging on the target increase). Oversimplified, the position of the receiver is a fix at the intersection of three or more circles of position.



GPS Receiver Determines Position by Satellite Ranging
Figure 9-11[66]

[66] Courtesy of USCG

9.3.1.2. Control Segment. A master control station in Colorado Springs computes extremely accurate orbits for each of the operating satellites. These computations are based on information from five monitor stations, located throughout the world, which collect information from all of the satellites in view at any given time and send it to the master station. The master station formats the data received from the monitor stations into the discrete messages referred to in paragraph 9.3.1.1. and sends them to the satellites by means of the three ground antennas, which also transmit and receive satellite control and monitoring signals.

9.3.1.3. User Segment. The ground sea, and airborne receivers, processors, and antennas that provide the users precise position, speed, and time.

9.3.2. Selective Availability. GPS is being developed by the military but will be made available to civil navigational needs. Military accuracy provided by coded signals (for security reasons) will provide position information within approximately 25 feet horizontally and 33 feet vertically. Speed accuracy will be to 0.1 knot and time accuracy to a fraction of a micro-second. Uncoded signals are used in civilian applications with a degradation of accuracy to about 300[67] feet. The civilian uncoded signal can be turned off or be deliberately degraded by the military services when necessary in the interests of national security. This practice is called *selective availability* (SA). There are two types of GPS receivers, the PPS (Precise Positioning System) for the military and "approved" civilians, and SPS (Standard Positioning System) for the rest of the population. PPS can sense and correct for SA. SPS receivers, which are available to the boating public, are manufactured to be accurate to 50 feet (15 meters). However, they are accurate to 100 meters (324 feet) 95% of the time and 300 meters (about 1000 feet) 5% of the time because of SA. The biggest problem is that users don't know when SA is in effect, or the amount of distortion, so it's impossible to determine the accuracy of GPS at any given time.

9.3.3. Differential GPS. Differential GPS (DGPS) can provide accuracy down to about 15 feet by placing a special receiver directly over a precisely surveyed known location, using US Geodetic Survey benchmarks. The receiver is precisely located to an accuracy of 0.5 cm. This receiver compares where the satellite signals say it is to where it knows it is and computes corrections to the received data. The corrections are then transmitted to the user's receiver. Special HF receivers are required by the user as well as special radio beacon receivers which add substantially to the costs. Figure 9-12 is a very simple view of how DGPS works.

9.3.3.1. Accuracy of DGPS. Figure 9-14[68] shows a scatter plot of 1701 GPS fixes (without DGPS) for a receiver at the center of a 100 meter (radius) circle.

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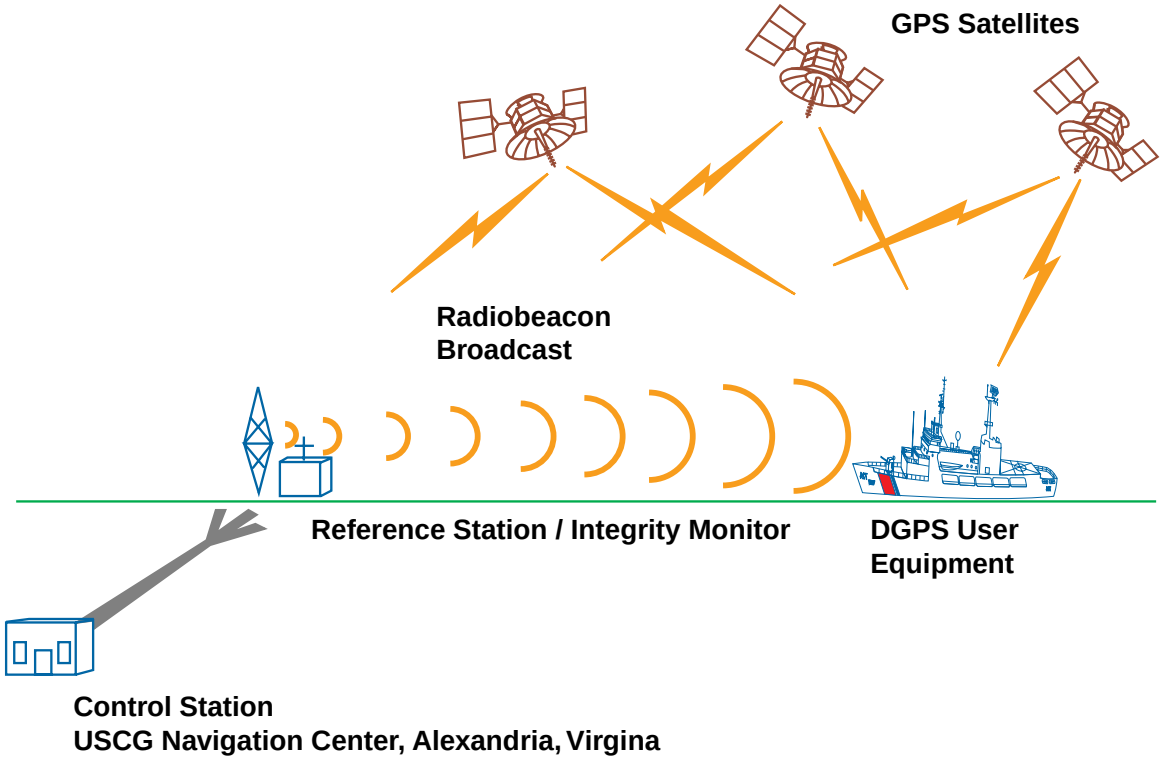
[67] Radionavigation Bulletin Number 27, Fall/Winter Issue 1993, HQ US Coast Guard (G-NRN), Washington, DC

[68] Courtesy of USCG Navigation Center



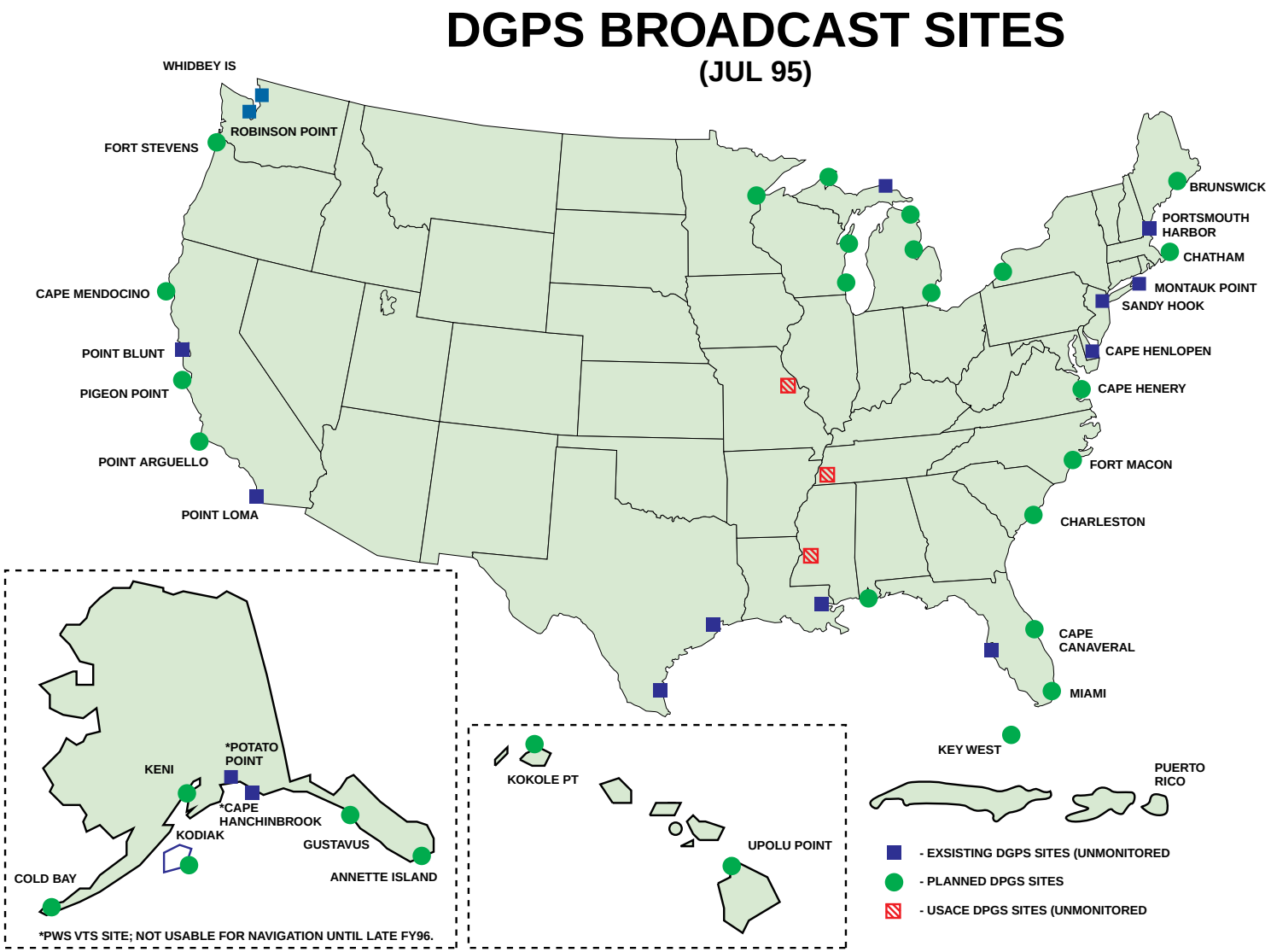
Simplified Perspective of Differential GPS
Figure 9-12[69]

10.1 % of the fixes are within 10 meters of the actual location and another 88.2% are within 100 meters. Figure 9-15[70] shows a scatter plot of 3488 DGPS fixes for a receiver at the center of the 100 meter circle (the small circles shown in the two figures are 10 meters in radius). 100% of the fixes are within 10 meters and more than 90% appear to be within 5 meters.

9.3.3.2. Control of DGPS. GPS is a Department of Defense system operated by the US Air Force. DGPS is a Coast Guard system, operated by the Coast Guard. The control station at the USCG Navigation Center, Alexandria, VA, has real time control over all of the DGPS stations in service. If a station goes down, or is degraded, the Navigation Center can intervene immediately to correct the problem. Each station has an Integrity Monitor which verifies the signal received by the main DGPS receiver and confirms that the computed correction to be transmitted is accurate. It is actually a second receiver whose signal reception and computed correction must agree within prescribed very close tolerances.

9.3.4. Current Status of GPS. GPS has achieved Initial Operational Capability (IOC). DGPS is still experimental. As of June 1995, 16 of the 47 DGPS stations were

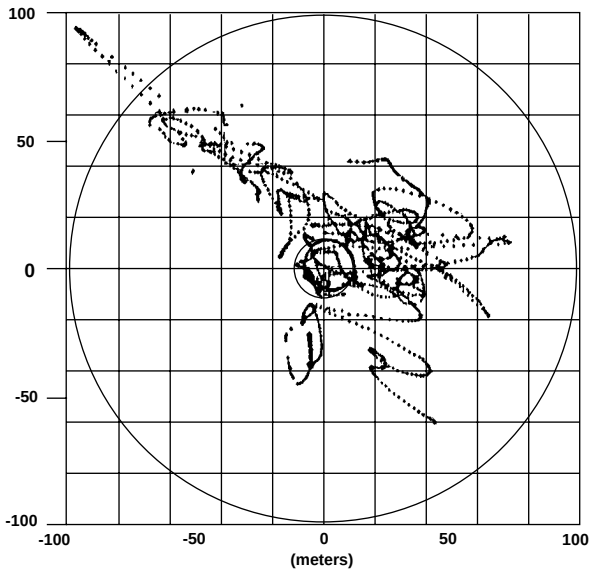
[69] Courtesy of USCG Navigation Center
[70] Courtesy of USCG Navigation Center



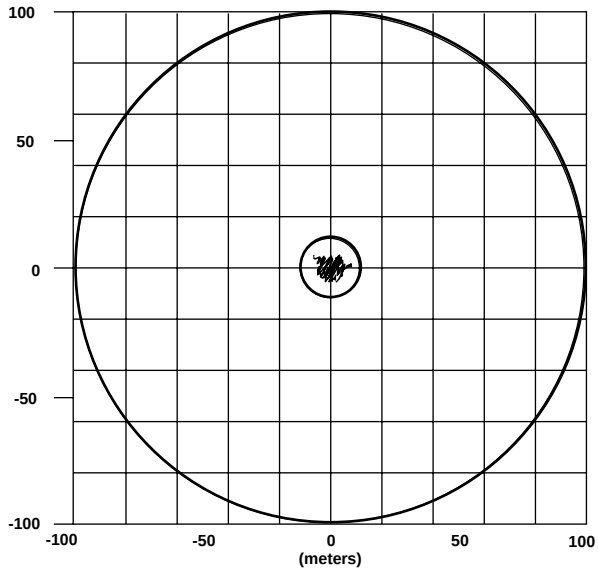
Actual and Proposed DGPS Sites
Figure 9-13[71]

[71] Courtesy of USCG Navigation Center

in service. As of June 1998, 55 stations were in service. GPS is being used in both aircraft and surface vessels, and the price of receivers is now affordable for many, but the system is subject to shutdown without notice. Most receivers being sold today are DGPS ready and can be converted by addition of the special receiver and beacon. It is the wave of the future and will be seen on more and more small vessels over time. Location of existing and proposed sites are shown in Figure 9-13 on page 9-16.



GPS Fixes Without DGPS Correction
Figure 9-14



GPS Fixes With DGPS Corrections
Figure 9-15

9-1. The null is obtained when the RDF loop antenna is _____ to the signal and is used in radio direction finding because it is more sharply defined than the maximum strength signal.

a. tuned
b. on the reciprocal bearing
c. perpendicular
d. parallel

9-2. RDF _____ is caused by the electrical fields of the vessel.

a. variation
b. deviation
c. distortion
d. reciprocity

9-3. RDF bearings are _____.

a. direct
b. relative
c. reciprocal
d. reversible

9-4. (True/False) RDF variation must be applied to the RDF bearing to the transmitter before adding the relative bearing to the true heading of the vessel to obtain the true bearing.

9-5. (True/False) RDF Bearings are less accurate at night than in the daytime. This is particularly true during morning and evening nautical twilight (the half hour before sunrise and the half hour after sunset).

9-6. (True/False) Being less precise, fixes obtained with RDF must be labeled RDF Fix or EP.

9-7. (True/False) LORAN stations transmit on a frequency of 100 khz.

9-8. (True/False) A LORAN LOP is a catenary curve reflecting every location where the time difference between receipt of the signal from the master station and a secondary station is the same.

9-9. LORAN sets provide accurate determination of ___. Two sets side-by-side will provide very similar indications.

a. latitude and longitude
b. geographic coordinates
c. time differences
d. polar coordinates

9-10. _____ provided by side-by-side sets may be different because of the difference in care used in handling additional secondary phase factor information within the sets of different manufacturers.

a. Latitude and longitude
b. polar coordinates
c. time differences
d. hyperbolic coordinates

9-11. LORAN chains are identified by the _____, the time required for all stations in the chain to transmit their signals.

a. group repetition interval
b. group repeatability index
c. linear interpolator
d. hyperbolic interactivity coefficient

9-12. If a chain is identified as 7980 (the Southeast United States Chain), it takes _____ for the entire chain to transmit.

a. 79,800 msec (microseconds)
b. 79,800 millionths of a second
c. Both of the above
d. Neither of the above

9-13. LORAN provides an accuracy as close as _____, depending on distance from the stations and other factors.

a. 15 feet
b. 50 feet
c. 520 feet
d. 1700 feet

9-14. LORAN overprints are provided on charts of scales _____.

a. 1:80000 or smaller
b. 1:80000 or larger
c. 1:150000 or smaller
d. 1:150000 or larger

9-15. _____ is the characteristic of LORAN that permits a vessel to return to a location previously entered into the LORAN set.

a. Reciprocity
b. Reportability
c. Responsiveness
d. Repeatability

9-16. (True/False) LORAN-C is the designated, federally provided radionavigation for civil marine use in US coastal waters.

9-17. (True False) Global Positioning System consists of three segments, the Air Force operated space segment, the Coast Guard operated control segment, and the user segment.

9-18. (True/False) Global Positioning System will use 21 operational satellites plus 4 spares orbiting at 10,898 miles above the earth to provide continuous coverage worldwide.

9-19. (True/False) GPS will eventually provide an accuracy of 15 feet horizontally and 33 feet vertically for military users.

9-20. (True/False) GPS will be accurate to 50 meters for civilian users.

9-21. (True/False) As a military system, GPS can be turned off or deliberately degraded at any time in the interest of National Security.

9-22. Differential GPS can provide accuracy's to _____.

a. 15 feet
b. 15 meters
c. 10 meters
d. 100 meters

9-23. DGPS requires _____, precisely surveyed in using US Geodetic Survey bench marks so it can correct data received from the satellites. The corrections are transmitted to shipboard receivers.

a. a transmitter
b. a receiver
c. an antenna
d. an integrity monitor

9-24. The integrity monitor

a. checks security clearances of operators
b. verifies the signal received and the computed correction
c. sounds and flashes an alarm if the receiver is turned off
d. sounds and flashes an alarm if another station goes down or is degraded

PROBLEMS

9-1. What is found at 9960-X-25593.4 and 9960-Y-43932.5? _____

9-2. What is the location of Chickadee Ledge, in TDs? _____

9-3. What is the location by TDs of buoy "6" in the Hen and Chickens area? _____

9-4. What is the best set of Time Difference curves to use to locate "1" ISO, north of Buzzards Light? _____

CHAPTER 10
RADAR PILOTING AND RELATIVE MOTION

10. Chapter 10.

10.1. RADAR DESCRIPTION.

10.1.1. Introduction. RADAR (RAdio Detection And Ranging) is following the trend of most electronic equipment by significant decreases in price over the last few years. Sets with sophisticated features are now available for $1500 and up. Its use on Auxiliary facilities and recreational boats is increasing all the time. It's no longer unusual to see a radar antennas on 25 footers.

10.1.2. Piloting and Collision Avoidance. Radar is both a piloting device and a collision avoidance device. Its use is required by law on some ships as a function of their size. Radar is such a powerful and important tool in collision avoidance, as well as navigation, that this chapter includes information on relative motion and its application to collision avoidance. It is also prudent that we review the Navigation Rules as they apply to radar, or better — as radar is used to comply with them.

10.1.3. Navigation Rules. Part B — Steering and Sailing Rules of the Navigation Rules (commonly called COLREGS or Collision Regulations) is made up of Rules 4 through 19. Rules 5, 6, 7, and 19 deal either specifically or implicitly with the use of radar. Rule 4 merely says that the rules in this subsection apply in <u>all</u> conditions of visibility.

- Rule 5 (both International and Inland): "Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of risk of collision."

"Available means appropriate..." includes radar.

- Rule 6 (both): "Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions.

In determining a safe speed the following factors shall be among those taken into account:

(b) Additionally, by vessels with operational radar:

(i) the characteristics, efficiency and limitations of the radar equipment:

(ii) any constraints imposed by the radar range scale in use;

(iii) the effect on radar detection of the sea state, weather, and other sources of interference;

(iv) the possibility that small vessels, ice and other floating objects may not be detected by radar at an adequate range;

(v) the number, location, and movement of vessels detected by radar; and

(vi) the more exact assessment of the visibility that may be possible when radar is used to determine the range of vessels or other objects in the vicinity."

- Rule 7 (both): "(a) Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is doubt such risk shall be deemed to exist.

(b) 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."

(c) Assumptions shall not be made on the basis of scanty information, especially scanty radar information....."

These rules combine to make it clear that any vessel, regardless of size, that has a working radar must use it when visibility is restricted. The rules say "every vessel" and no exceptions are made. Rule 19 goes on to address conduct of vessels in restricted visibility and specifies actions for vessels that detect another vessel solely by radar:

- Rule 19 (both): "(d) A vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided:

(i) an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken; and

(ii) an alteration of course toward a vessel abeam or abaft the beam."

Sub paragraph 19(d)(i) is the source of the convention that course alterations will be to starboard.

10.2. THE RADAR SET.

10.2.1. Transmitter and Receiver in One Unit. The radar set is both a transmitter and a receiver in one unit. It transmits a signal which is reflected back to the set by objects in the path of the signal. The reflected signal is called an *echo*. The quality of the echo is a function of pulse width, beam width, and power of the radar, and radar cross-section of the target.

10.2.2. Components of the Set. Radar sets have five basic components. The transmitter is an oscillator that produces electro-magnetic energy of super-high frequency (3-30 Ghz). The modulator contains circuitry that turns the transmitter on and off, which causes the energy to be sent out as pulses 1 μsec or less in length. From 500 to 3000 pulses are transmitted each second by most surface-search radars, depending on the range scale selected.[72] The antenna usually transmits and receives. It is highly directional and rotates about 15 - 25 rpm. The receiver amplifies the incoming reflected signal (the echo). The indicator displays the information that the radar provides on a cathode ray tube (CRT) called a *scope*. (The screen of a television set is a CRT). The scope on navigation radars is called a *Plan Position Indicator* or PPI scope.

10.2.3. Plan Position Indicator.

10.2.3.1. Radar Bearings. The center of the PPI scope represents the vessel and 000° on the scope is dead ahead. Radar bearings, then, are relative bearings. (Some more sophisticated radars can be coupled with gyro or fluxgate compasses, LORAN, electronic map displays, or GPS to provide true bearings. This course will treat the theory and practice of radar with relative bearings). An object is "painted" by the radar beam as the antenna rotates and an image, or *blip*, appears on the scope at the relative bearing and precise distance out. A *bearing curser*, a faint line of light, electrically imposed on the PPI, can be rotated to the blip so that its relative bearing can be read on the outer scale of the scope.

10.2.3.2. Radar Distances. Most radars have range rings that can be displayed or suppressed at the operator's option. Most small boat radars also have range scales from as close as $\frac{1}{8}$ mile to 16 miles, doubling as $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, 16 miles. Sometimes a *range strobe*, a spot of light that can be moved in or out, or a *variable range ring*, that can be manually positioned over the object, are provided for more accurate range determinations.

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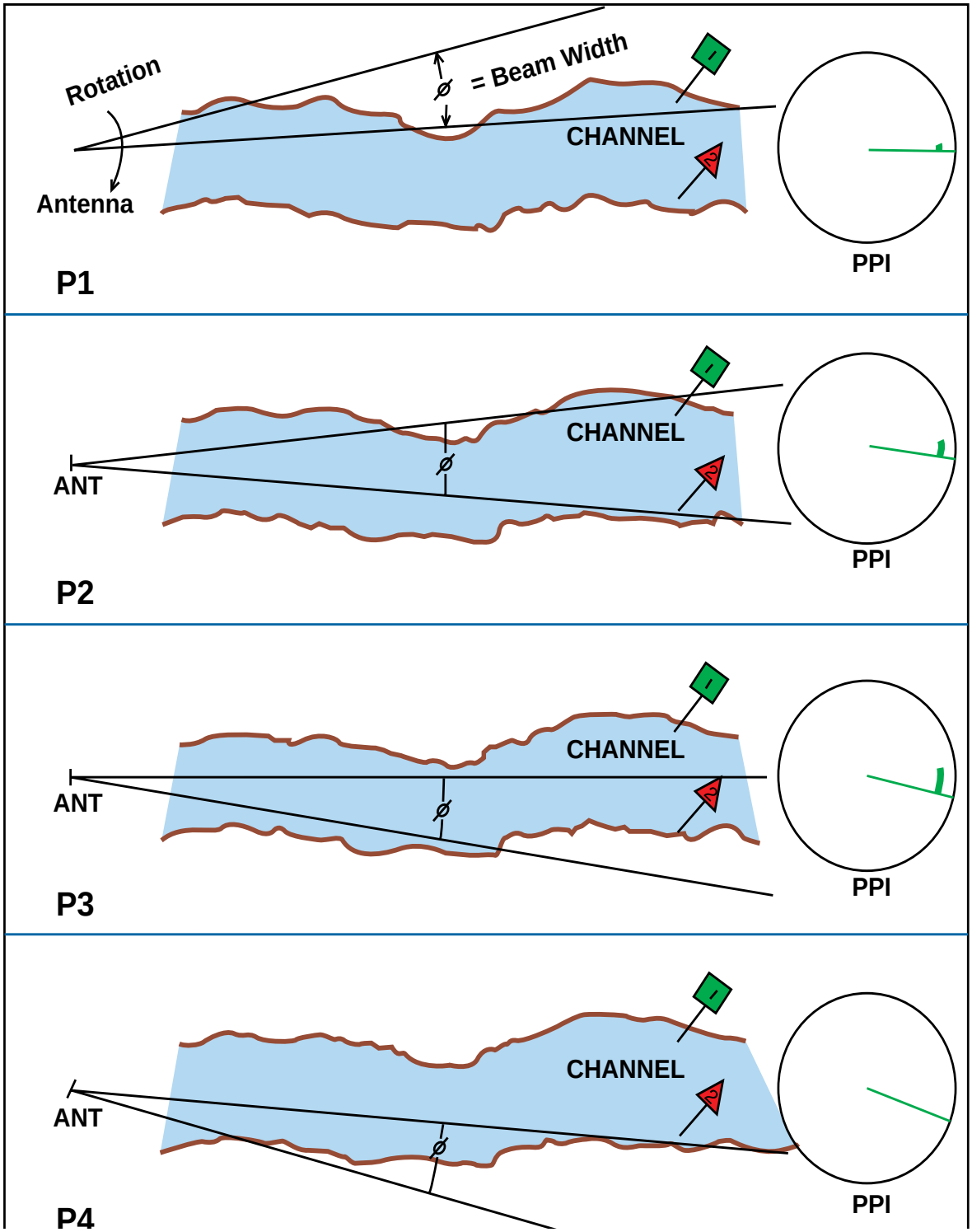
[72] Dutton's, p. 223

10.3. BEAM WIDTH AND PULSE WIDTH.

10.3.1. Design Limitations. Radar, while a form of high-technology piloting, is subject to two serious limitations or ambiguities based on separate, but interrelated functions. The first, beam width (BW), is determined by the antenna design. The second, pulse width (PW), is determined by the length of time the transmitter is turned on by the modulator.

10.3.1.1. Beam Width. Beam width is a major factor in the accuracy of radar bearings. Beam width is measured horizontally and vertically. The vertical beam allows the painting of targets from close to the vessel all the way out to the radar horizon. It also compensates for the pitch and roll of the vessel, allowing the radar beam to continue to scan the target despite the gyrations of the platform (the vessel). Obviously, the greater the vertical beam width, the greater the ability of the radar to hold the target. The horizontal beam sweeps across, or paints the target. This causes the target blip to appear for the whole length of time it takes the beam to cross it. It also causes the object to appear wider than it is. Bearings are read to the center of the blip. In the case of two targets close together, the leading edge of the rotating beam may be on one target while the trailing edge is on the other. This will cause the two objects to appear as one bigger object on the scope. With a narrower beam width the two objects may be closer together and still appear as two objects. The horizontal beam of some radars is as narrow as one degree. Beam width does affect cost of the set. Good accuracy for small boat navigation and collision avoidance can probably be obtained with beam widths of around 4°. Beam width of the AN/SPS 69 radar on USCG 41 foot UTBs is 2.2°. Vertical beam width is 30°. These sets cost around $5000. Good sets with 4° beam widths can be obtained for under $2000.

10.3.1.2. Bearing Discrimination. Beam width determines the ability of the radar to discriminate between two objects at the same distance (range) from the radar set, but on slightly different bearings (say 2° apart). Consider two entrance buoys marking a narrow channel. Figure 10-1 illustrates this bearing (azimuthal) ambiguity. The antenna radiates a beam of radar energy; like the beam of a spotlight it “spreads” into a beam of energy, but radio energy rather than light energy. The antenna rotates and picks up the green marker first as shown at P_1 and results in the beginning of reflected radar energy. As the antenna rotation continues, the beam picks up the red marker while still painting the green, as shown at P_2. Radar energy continues to be reflected, but now from both buoys. At P_3 the antenna has rotated further to the right and only the red buoy is still in the beam, still reflecting radar energy as a continuous echo (return) from the time the green buoy was first “caught” in the beam. Finally, at P_4 the antenna has rotated far enough that neither buoy is painted and there is no radar energy reflected to the receiver. One pulse of reflected radar energy has been received even though two objects exist. This results in one long blip



Beam Width (Bearing) Ambiguity[73]
Figure 10-1

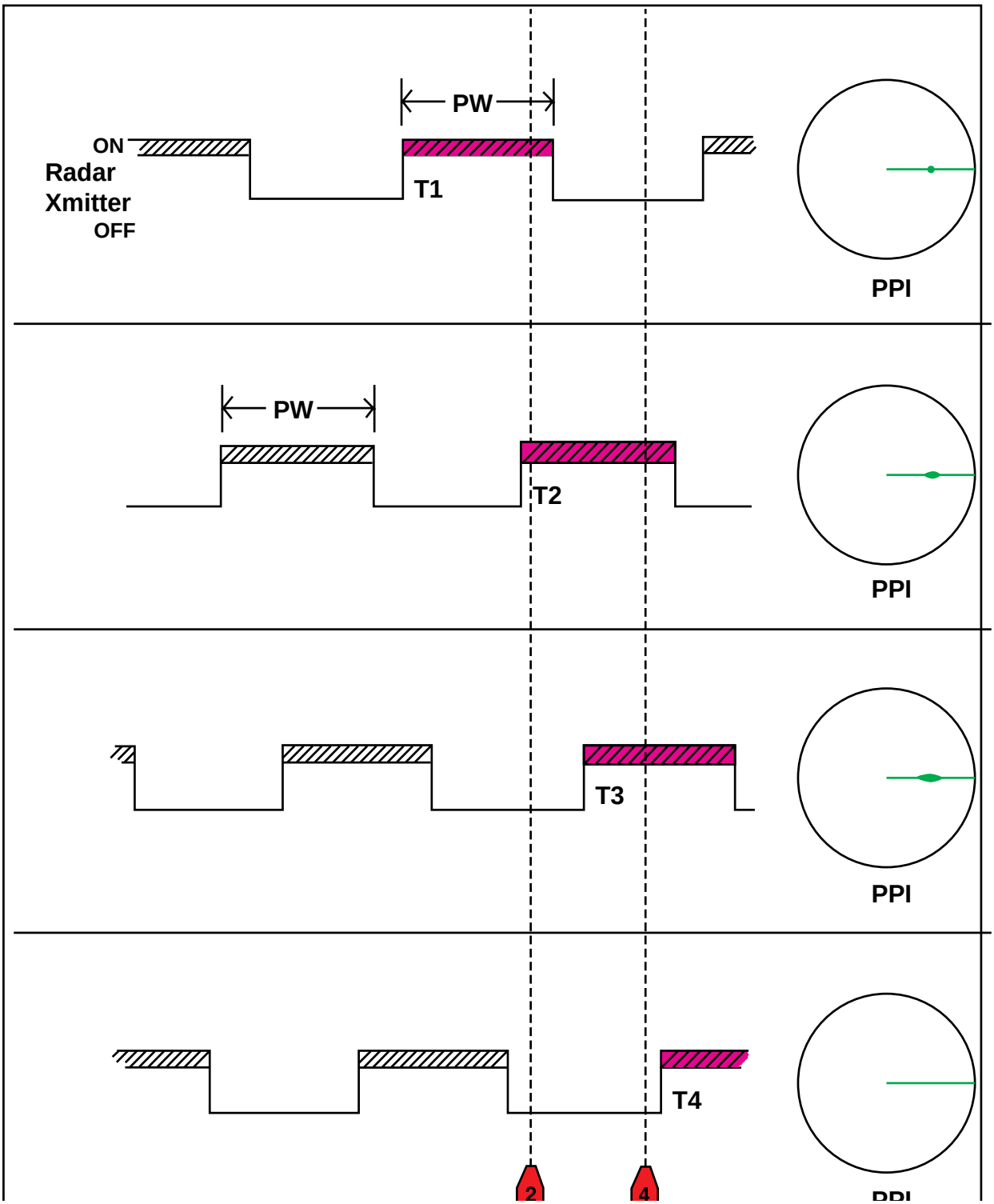
[73] Description provided by David H. Thomas, II (Col, USAF, Ret), PDCP XVI, 5CGD (SR)

and there is no radar energy reflected to the receiver. One pulse of reflected radar energy has been received even though two objects exist. This results in one long blip in the shape of an extended arc. By convention in radar plotting, the channel entrance lies in the center of the long blip.[74] However, because the objects are not differentiated, an untrained operator may not identify the single blip as representing the two buoys marking the channel entrance. It follows, then, that the narrower the horizontal beam width the greater the bearing resolution.

10.3.1.3. Pulse Width. Radar transmits a radio pulse that travels at the speed of light (186,000 statute miles, 161,633 nautical miles, or 300,000,000 meters per second). The radar determines ranges by measuring how long it takes for the echo from the painted object to be received after the pulse is transmitted. The receiver is controlled by timing circuits in the modulator to disconnect it until after the pulse is transmitted. A pulse 1 μsec wide reflected back from a target is received for 1 μsec. In 1 μsec (one one-millionth of a second) the pulse travels 300 meters. The depth of the blip is half the pulse width (the distance traveled by the pulse in 1 μsec) or 150 meters. This is the shortest distance that two objects on the same bearing can be separated and still show up as two objects. If the pulse width were 0.1 μsec, the distance required for separate blips would be only 15 meters. Just as a narrower beam width gives a better resolution in bearing, a shorter pulse width gives a greater resolution in range, and the radar is more accurate. The 41 foot UTB's radar has a variable pulse width of 0.25 - 0.8 μsec, depending on range scale used (0.125 - 1.5 M, 0.8 μsec with 2250 pulses transmitted per second (pulse repetition rate or PRR); 3 - 6 M, 0.25 μsec at 1500 pulses/second; and for the 12, 24, and 48 M ranges; 0.5 μsec at 750 pulses/second). This radar transmits with 4 kw of power at a frequency of 9.410 Ghz.

10.3.1.4. Range Discrimination. Transmitted pulse width provides the second ambiguity. It determines the ability of the radar to discriminate between two closely spaced (say, 100 yards apart) objects lying on the same bearing. Figure 10-2 illustrates the range ambiguity. The top line shows the radar set's on and off times as several pulses. Shown at the bottom are two buoys marking a channel's edge. At time one (T_1) the leading edge of the pulse of transmitted radar energy is just reaching the first (nearest) buoy; this will result in the beginning of a reflected energy pulse to the receiver. At time T_2 the transmitted pulse continues and now paints both buoys, resulting in a reflected pulse representing both. At time T_3 the transmitted pulse has passed the first buoy while still reflecting from the second. Thus, one pulse of reflected energy is received at the receiver, resulting in one return, or blip, extended in range, for two separate targets. At T_4 the pulse has cleared both buoys and no energy is reflected to the receiver. In radar plotting, the first buoy lies at the edge of the blip closest to the center of the PPI scope and the second lies at the far edge of the blip.[75] Once again, an untrained operator may identify the blip as a single target rather

[74] Thomas, ibid.
[75] Thomas, ibid.



Pulse Width (Range) Ambiguity[76]
Figure 10-2

[76] Thomas, ibid.

than the two it represents. As with beam width, it follows that the shorter the pulse width the greater the range resolution.

10.3.2. Antenna. Radar sets using the rotating bar-like antenna seen on some vessels generally will provide narrower horizontal beam widths, approaching 2°. Because of wind resistance, the drive components require more power to rotate, and the antenna costs more than the circular radome types, which generally have 4° or greater beam widths.

10.4. THE RADAR IN NAVIGATION.

10.4.1. Line of Sight. Because radar is line of sight, its range is limited by the curvature of the earth, although refraction will allow radar to detect objects just over the horizon. Distance, in nautical miles, at which the eye can see to the horizon is $1.17\sqrt{h}$, where h is the height of the eye in feet. The distance at which radar can see the "horizon" is $1.22\sqrt{h}$[77],where h is the height of the radar antenna. Horizon is in " " for the radar because refraction allows the radar waves to bend somewhat and pick up targets beyond the visual horizon. The higher the antenna and the taller the object, the further the object can be seen. The line-of-sight characteristic causes some problems. A low-lying area behind higher ground will not be painted by the radar and can make the higher ground look like a point of land or a peninsula. Objects near shore can look like a part of the land behind them. The picture on the scope is not necessarily the same as the picture on the chart. Radar operators require training and experience to get the most out of their sets, to be able to interpret them correctly.

10.4.2. Radar Visibility. Radar navigation is usually pretty accurate. Radar bearings are not as precise as visual bearings (the beam width phenomena) but the ranges are quite accurate. Radar can be used to navigate when objects shown on charts are painted and show up on the scope. The radar is a piloting device because the navigation is by reference to visible charted objects, though they may be visible only to the radar. This is, of course, why radar use is written into the Navigation Rules and why the radar must be used, if it is aboard and working, during periods of limited or restricted visibility. It can see when the human operators cannot. This is not true in all cases. During heavy seas and high winds, blowing spray may reflect the radar waves and show on the scope as sea return. This can obscure actual targets beyond the clutter. Close in, the radar shows sea return and clutter which shows up as bright light around the center of the scope.

10.4.3. Radar Fixes. Radar fixes are of several types (in order of preference - accuracy) :

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[77] Dutton's, p. 229

10.4.3.1. A radar range can be combined with a visual bearing (most accurate).

10.4.3.2. Two or more radar ranges can be plotted as circles of position.

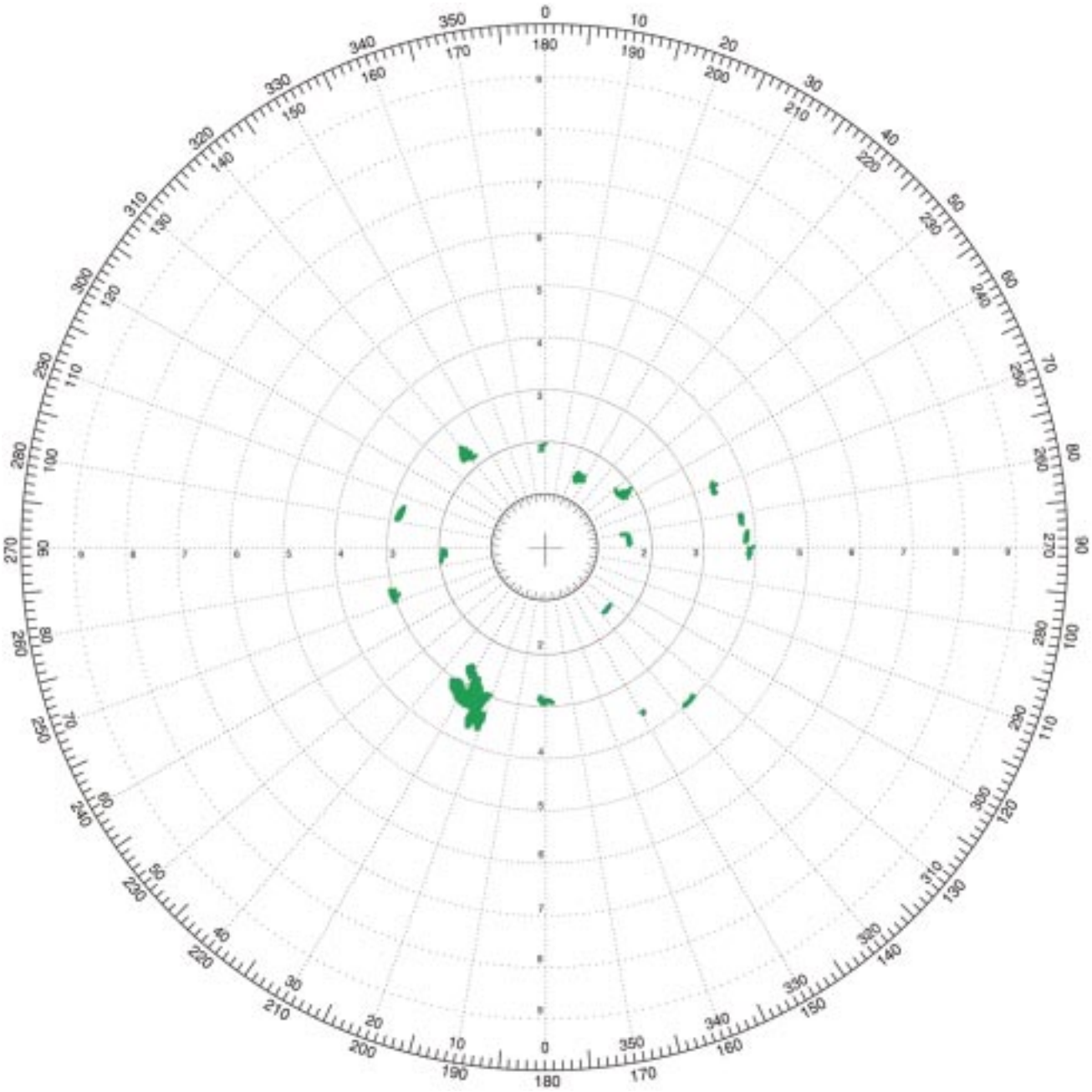
10.4.3.3. A radar bearing and range on the same object constitute a fix.

10.4.3.4. Two or more radar bearings to separate objects that show on the scope can be plotted to obtain a fix (least accurate).

10.4.4. Use of Maneuvering Board in Plotting Radar Information. Remember when using radar bearings, that they are relative and must be converted to true before plotting. Radar plotting is done on both charts and maneuvering boards. It is important to remember that the maneuvering board is not a replication of the PPI scope. The maneuvering board is a tool to help make the radar information meaningful. The scope shows relative bearings; they are converted to true before plotting. Figure 10-4 on page 10-11 pictures the target area of Figure 10-3 (page 10-10) as seen on the PPI scope. The scope is set to a range of 10 miles and range rings are shown every 1 mile. The vessel mounting the radar is at TDs 9960-W-14277.6 and 9960-Y-43942.0 heading 255° true. The vessel's heading information is important. Since the radar bearings are relative, the operator needs to know relative to what. Notice how the target area looks different from the chart. The monument and light on Cuttyhunk Island are on the same bearing but are close enough together that they appear as one blip. The area immediately behind the monument, as seen from the vessel, is water but it doesn't show on the radar scope because of the high ground in front of it. The whole perspective has changed also, because 000° on the PPI scope is actually 255°. Objects to the left of the vessel's position as seen on the chart are to the right of it on the scope. Objects north and east appear east and south and even west of south. Keep in mind, too, that the PPI scope representation of the target area changes constantly as the vessel moves. Figure 10-5 shows the same view with the radar scale set to half the range. Two things should be apparent: first, use the shortest range scale that will embrace the area of interest. The shorter the range scale, the greater the detail. Objects of poor reflection that probably would not show up at the longer range might at the shorter range. Second, interpreting the scope and identifying the objects is not easy. It obviously requires training and practice. Figure 10-6 shows the same situation plotted on a maneuvering board. This view brings things back into a chart like perspective.

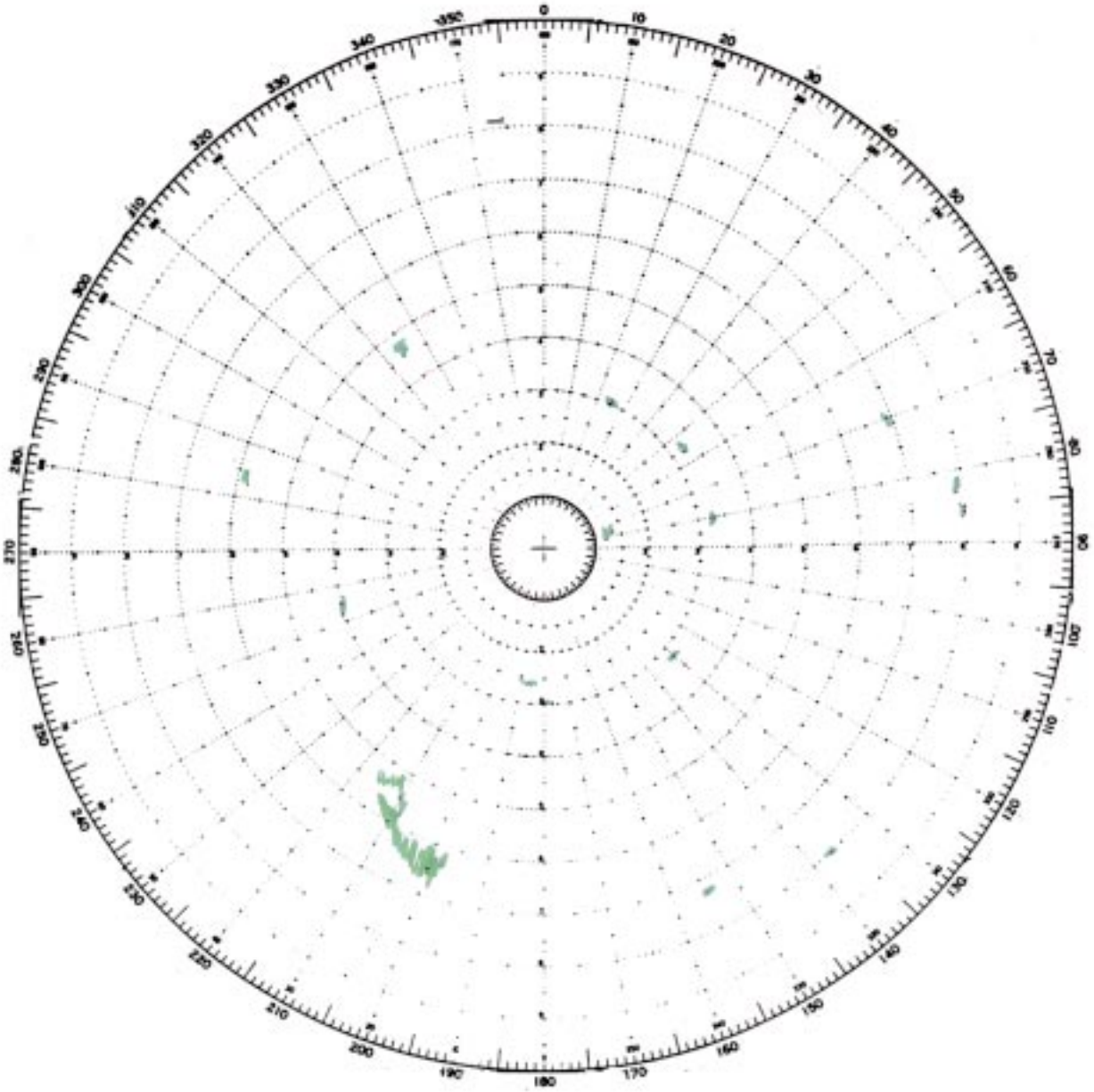
10.4.5. Radar Fixes Plotted on the Chart. Figure 10-7 shows a radar fix for the vessel at 1000 hours as circles of position from Buzzards Light and the monument on Cuttyhunk Island. The range to each object as shown by the radar is plotted as an arc of that radius with the center at the object. Where the arcs intersect is the fix. The same limitations apply as with any other circles of position; that is, they intersect in

Radar Target Area
Figure 10-3



Plan Position Indicator Presentation - 10 Mile Range
Figure 10-4

shown in Figure 10-8. This is exactly the same thing as a fix from a circle of position and a line of position except that the same object is used. The most accurate radar fix is one obtained with a visual bearing (LOP) and a radar range (COP). This is shown in Figure 10-9. A fix from two radar ranges is the next most accurate (Figure 10-7). The fix obtained with two radar bearings is the least accurate.



Position Plan Indicator Presentation - 5 Mile Range
Figure 10-5

This goes back to the beam width and the fact that the beam paints the target as it moves across it, distorting its size and requiring the radar operator to estimate the center of the blip. Note that the fixes in Figures 10-7 and 10-8 are indicated by dots in a circle while that in Figure 10-9 is indicated by a dot in a triangle. The triangle issometimes used for all electronic fixes; it is properly used only for multi-media fixes, that is, two different methods as a visual LOP with a Radar LOP or COP

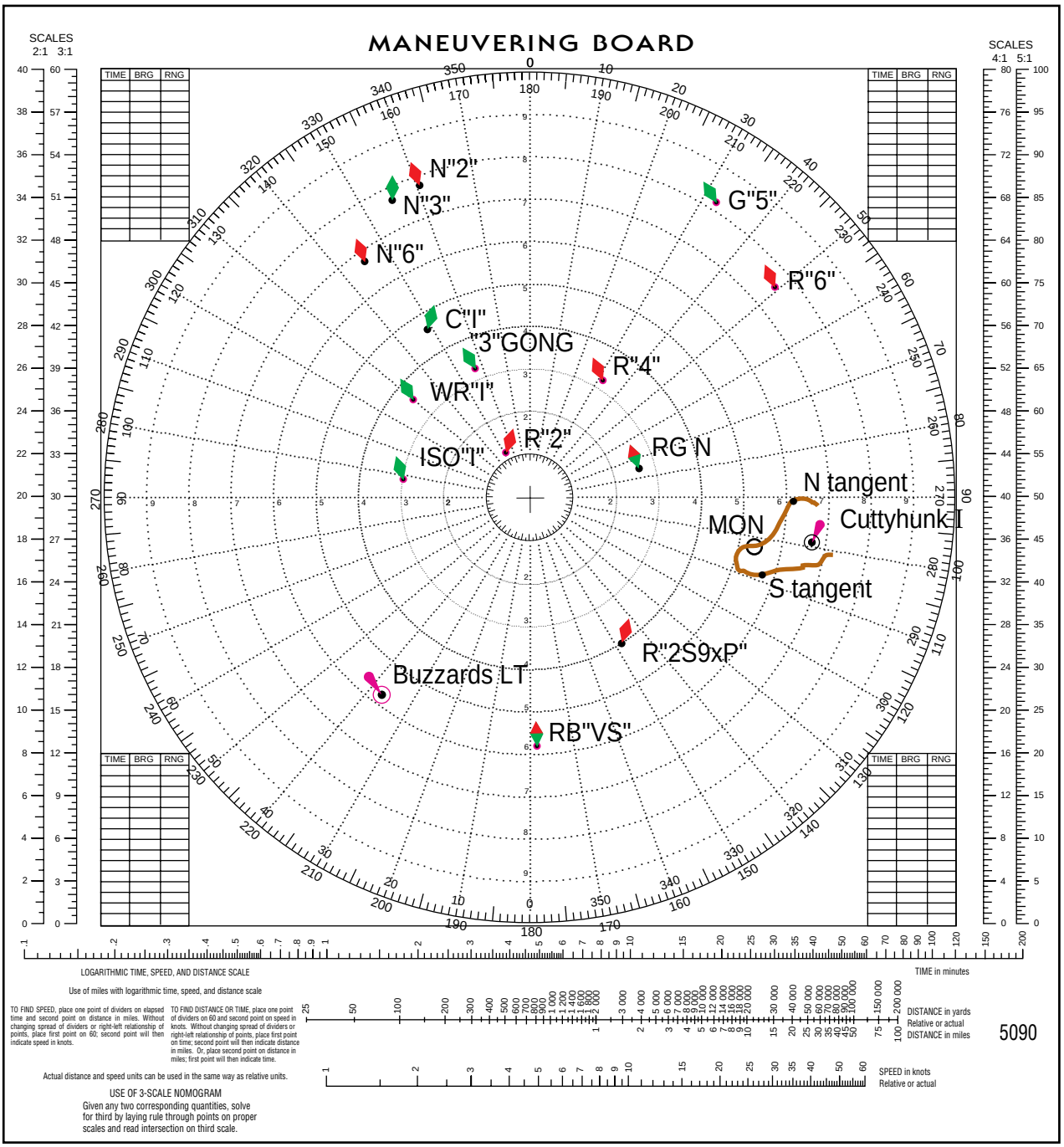


Figure 10-5 Situation Plotted on a Maneuver Board
Figure 10-6

Fix From Radar Ranges - Circles of Position
Figure 10-7

Fix From Radar Bearing and Range to the Same Object
Figure 10-8

Fix From Visual Bearing and Radar Range (Δ Indicates Fix is Based on Two Media)
Figure 10-9

10.4.6. Advantages and Disadvantages of Radar in Navigation.

10.4.6.1. Advantages. Radar has several advantages in piloting:

- It can be used at night and during periods of low visibility, when most other methods are limited, or not available at all.
- Navigation by radar is often more accurate than other methods of piloting during periods of reduced visibility.
- Fixes may be available at greater distances from land than in most methods of piloting.
- A fix can be obtained from a single object, since both bearing and range are provided. (This is less desirable than a fix by range to two or more objects.)
- Fixes can be obtained rapidly. With the PPI a continuous position is available.
- It may be used to assist in the prevention of collision during periods of low visibility.
- It can be used to locate and track heavy storms."[78]

[78] Dutton's, Article 1608, p. 229

10.4.6.2. Disadvantages. Radar also has disadvantages:

- It is subject to electrical and mechanical failure.
- There are both minimum and maximum range limitations.
- Interpretation of the information presented on the scope is not always easy, even after considerable training.
- Charts do not always give information necessary for identification of radar echoes.
- In some applications, it is less accurate than visual piloting; i.e., a radar bearing is less precise than a visual bearing. (Distance measurements, however, can be quite precise and accurate.)
- Buoys, small boats, etc., may not be detected, especially if a high sea is running, or if they are near shore or other objects.
- It requires transmission of signals from the vessel; this can be a. problem on small craft with limited primary power sources."[79]

10.5. COLLISION AVOIDANCE AND RELATIVE MOTION.

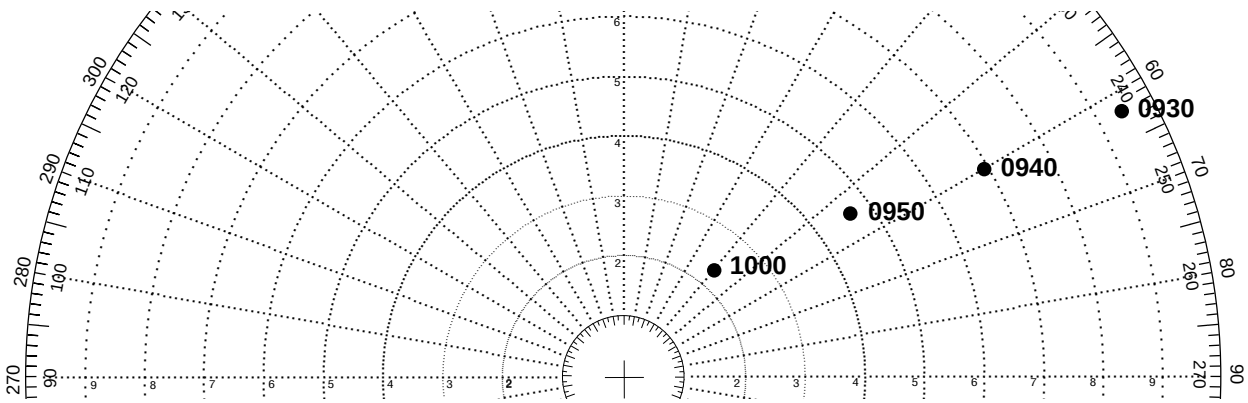
10.5.1. Relative Motion Explained. As stated earlier, one of the principal uses of radar is in collision avoidance. The purpose of navigation is to get a vessel safely from one place to another. The getting from one place to another is *motion.* The operator of a vessel is concerned with the motion (movement) of his vessel over the ground, through the water, and in relation to objects which he or she uses in piloting. He is also concerned with the movement of his vessel in relation to other moving objects, primarily other vessels. The movement of one vessel in relation to other objects, both stationary and moving, is *relative motion.* This course will concern itself with the more elemental aspects of relative motion. Both Dutton's and Chapman's, cited earlier in this workbook, have detailed discussions of relative motion, including motion relative to more than one target, turns by the observing vessel or by the target(s), and various situations such as meeting, crossing, and overtaking. This course will treat closest point of approach (CPA), determination of true course and speed of a target, and the appearance of stationary targets on the radar.

10.5.2. Relative Motion Line and Closest Point of Approach. For the purposes of illustration, let's assume a vessel is traveling 075° at 12 knots. Over a period of 30 minutes the radar operator tracks a series of blips on his PPI scope, as shown in Figure 10-10, that appears to be a vessel that will cross the track of his vessel. At 0930 the radar shows the target to bear 062° relative at 9.5 M. At 0940 the target bears 060° at 7.0 M. At 0950 it bears 055° at 4.6 M, and at 1000 it bears 040° at 2.2 M.

[79] Dutton's, Article 1609, p. 229

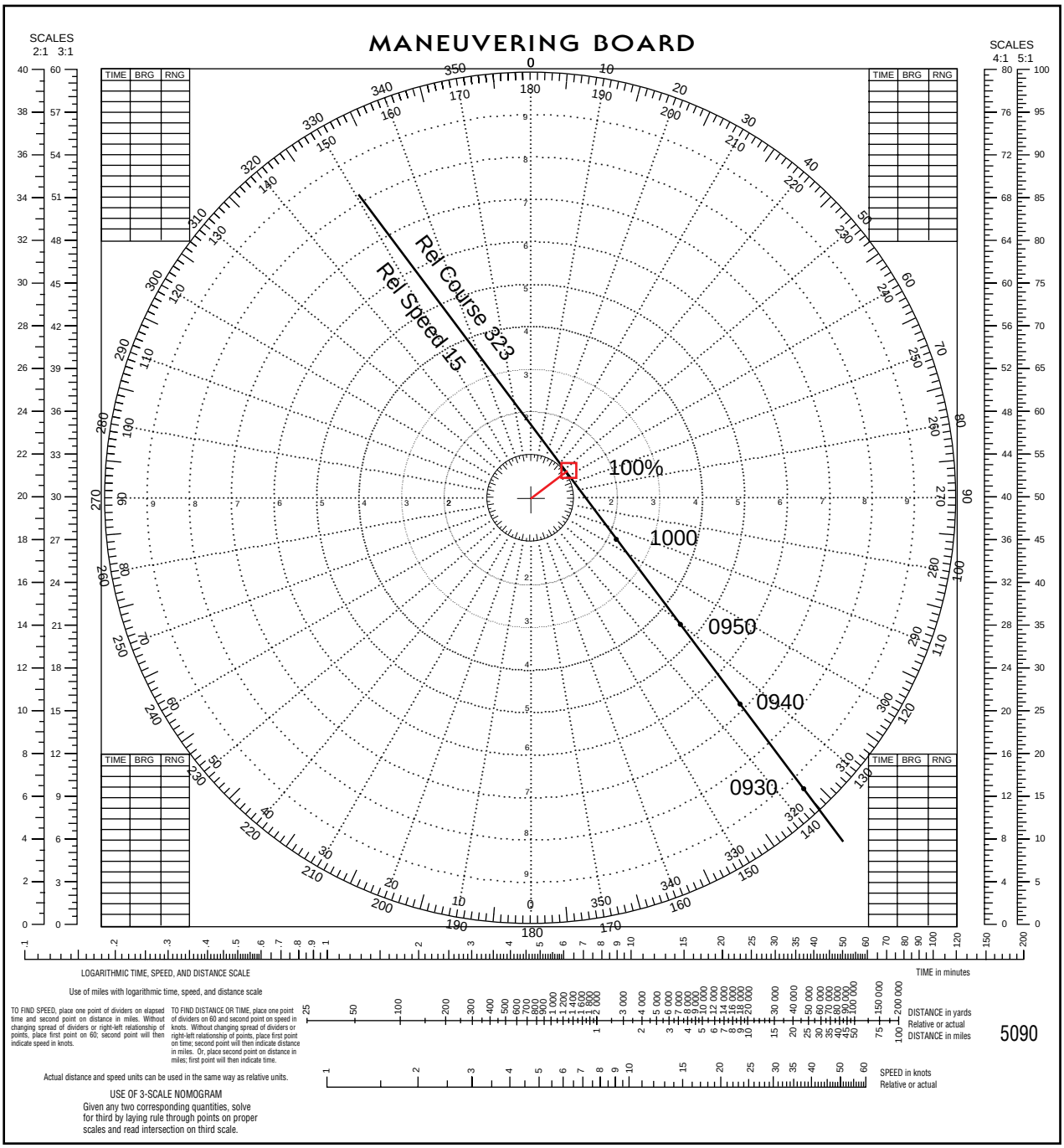
10-10, that appears to be a vessel that will cross the track of his vessel. At 0930 the radar shows the target to bear 062° relative at 9.5 M. At 0940 the target bears 060° at 7.0 M. At 0950 it bears 055° at 4.6 M, and at 1000 it bears 040° at 2.2 M.

The bearings are changing which implies the vessels are not on collision courses; nevertheless, the range is decreasing rapidly. The radar operator prepares a plot on a maneuvering board (Figure 10-11) to determine the closest point of approach (CPA) and when it will occur. The relative bearings are converted from 062°, 060°, 055°,



Moving Target Display on the PPI Scope
Figure 10-10

and 040° to 137°, 135°, 130°, and 115°, respectively. These are plotted on the maneuvering board at a distance from the origin corresponding to their range and labeled with the time of the radar observation. The plotted points are fitted as closely as possible to a straight line. This is the relative motion line representing the speed and course of the target vessel relative to (as it appears from) the observing vessel. The closest point of approach is on the perpendicular from the origin to the relative motion line. The relative course is determined with parallel rulers set along the relative motion line and moved to the origin. Pay attention to the direction in which the target is moving. It is crossing from lower right to upper left, so the relative course is read as 323°. The relative speed is determined by measuring the distance between the 0930 sighting and the 1000 sighting and calculating the speed as $60(7.5)/30 = 15$ kts, where 7.5 is the distance measured on the maneuvering board that was traveled in 30 minutes. The perpendicular from the origin to the relative motion line intersects the line 1.1 miles from the observing vessel (origin) on a true bearing of 053° (the relative bearings were all converted to true; then this is true).

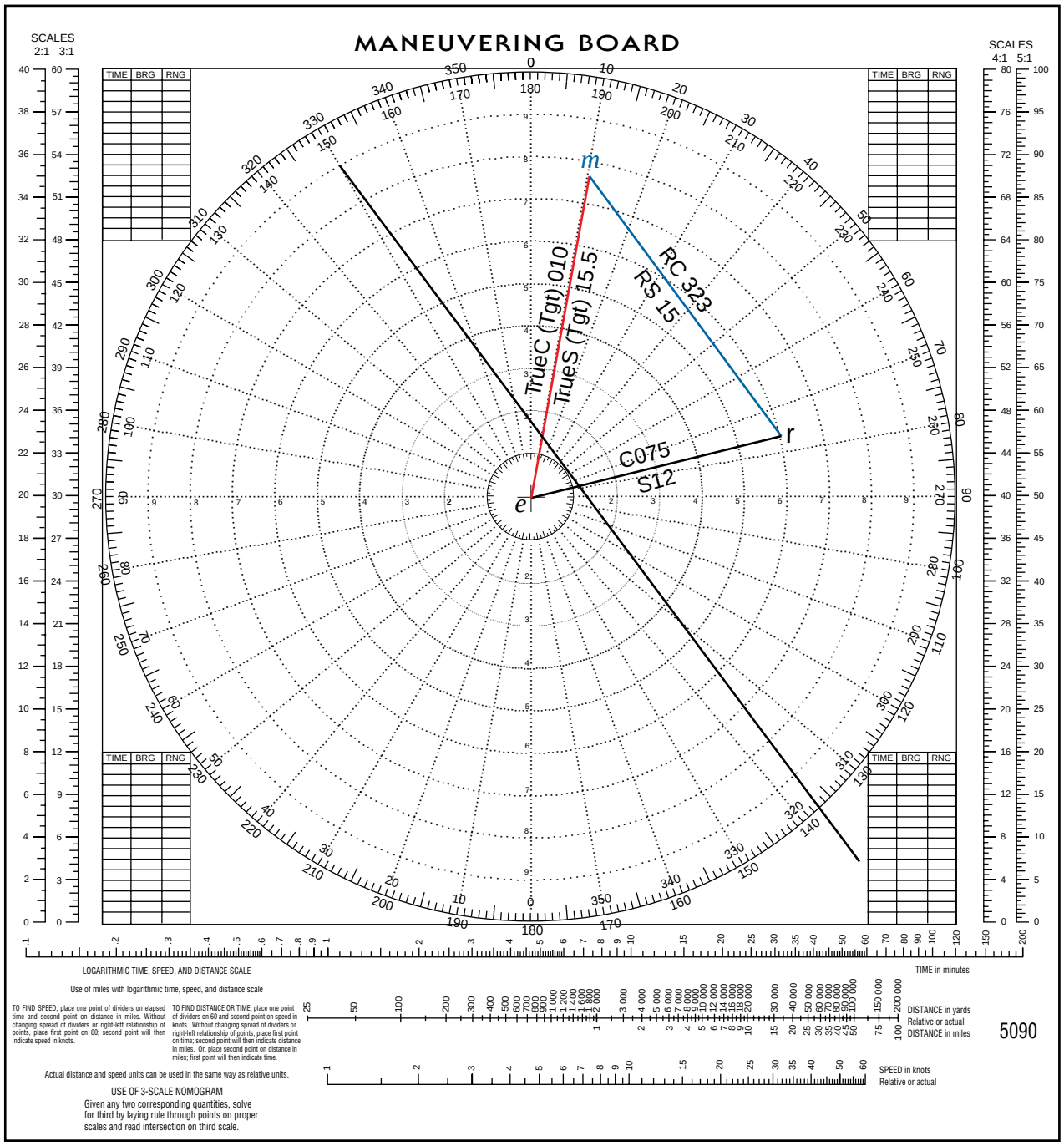


Relative Course, Relative Speed, and Closest Point of Approach
Figure 10-11

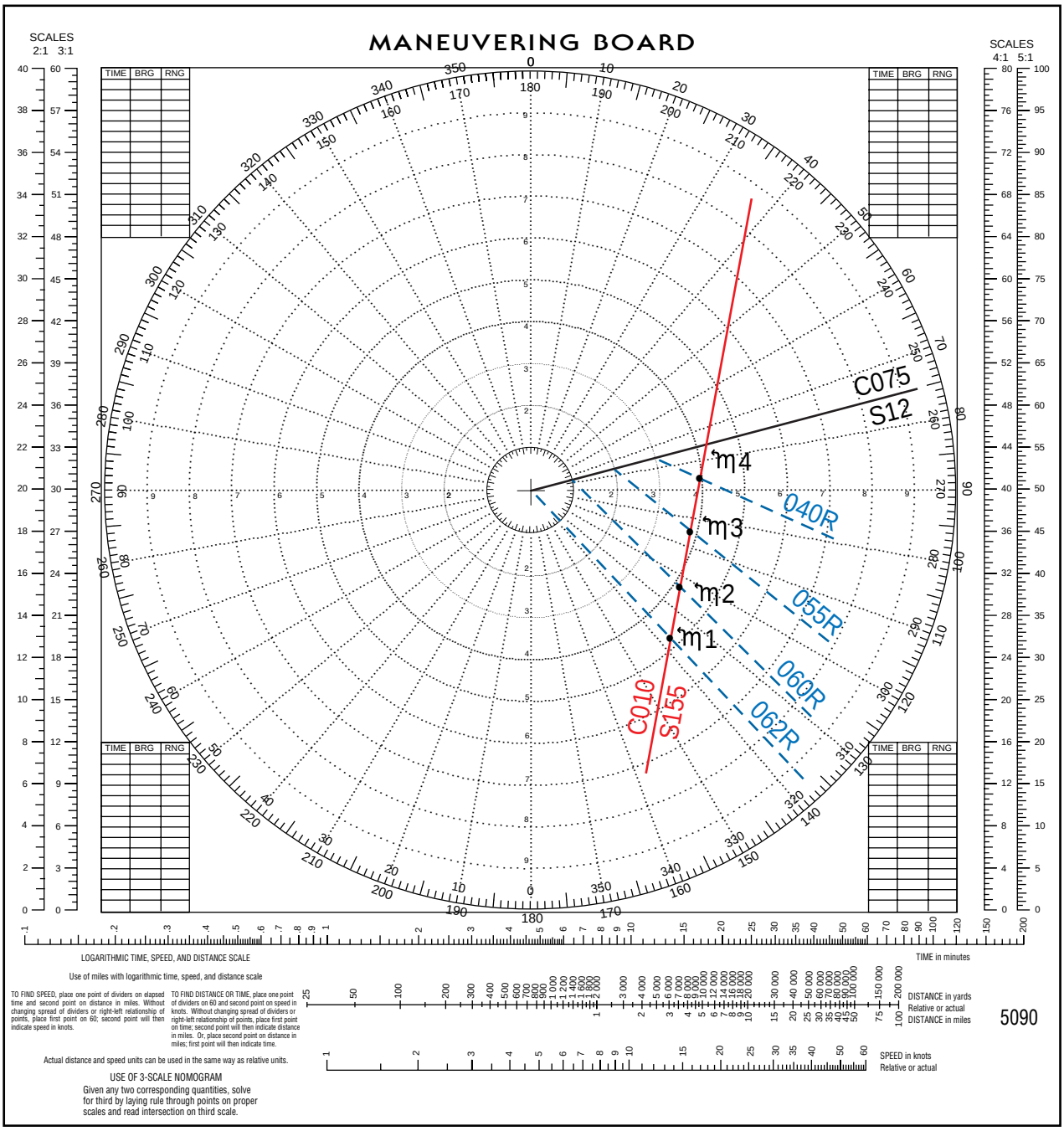
The distance from the 0930 sighting to this point, marked with a square, is divided by the relative speed, 15 kts to determine the time required to get there, 38 minutes. The time of CPA, then, is 1008 (0930 + 38).

10.5.3. True Course and Speed of Target (erm Diagram). The true course and speed of the target is also found on the maneuvering board, using an erm diagram, usually continuing with the board on which the CPA plot was done, as shown in Figure 10-12. It is a vector arithmetic problem as was done in the Current Sailing chapter. Starting at the origin, the observing vessel's course and speed is laid out. The vessel is traveling 075° at 12 knots. Because the speed is 12 knots, the 2:1 scale is used. Draw a vector on the 075° radial from the origin to the 6 ring (12 on the 2:1 scale). Label the origin end (tail) of the vector e and the head r. Using parallel rulers, move the relative motion line plotted in the CPA determination to the head of the observing vessel's vector (point r) and lay out the relative motion vector towards 323° and mark the head at a point equal to 15 knots on the 2:1 scale. Mark this point (the head of the relative motion vector) m. Connect e and m. The direction from e to m is the true course of the target vessel and its length, as read from the 2:1 scale is the true speed. The true course of the target is 010° and its true speed is 15.5 kts. Figure 10-13 is a "bird's eye view" or true plot of this situation. m_1, m_2, m_3, and m_4 are the positions of the target at 0930, 0940, 0950, and 1000, respectively. It is clear that the target is on course 010° at a speed of 15.5 kts.

10.5.4. Relative Motion of a Stationary Target. Suppose a vessel is traveling 255° at 9 kts. At 0950 it observes a target bearing 338° relative at a range of 3.5 miles. At 1000 the target bears 322° relative at a range of 2.25 miles. At 1010 it's 278° relative at 1.4 miles and at 1020, 226° relative at 1.9 miles. The bearings convert to 233°, 217°, 173°, and 121°, respectively. This plots on the maneuvering board as shown in Figure 10-14. The plot indicates a target moving well clear on a relative course of 075° at a relative speed of 9 kts. Figure 10-14 used the 5:1 scale as a 0.5:1 for the relative motion plot and the 1:1 scale for the erm diagram. Note that the transfer of the relative motion line to the erm diagram brings point m right back to the origin, which makes the em vector 0 in magnitude. Whenever this occurs, the radar has detected a stationary object. Some small boat radars can sense this and indicate that the target is stationary. Note that the target area, as presented on the PPI scope changes as the observing vessel moves through the area.

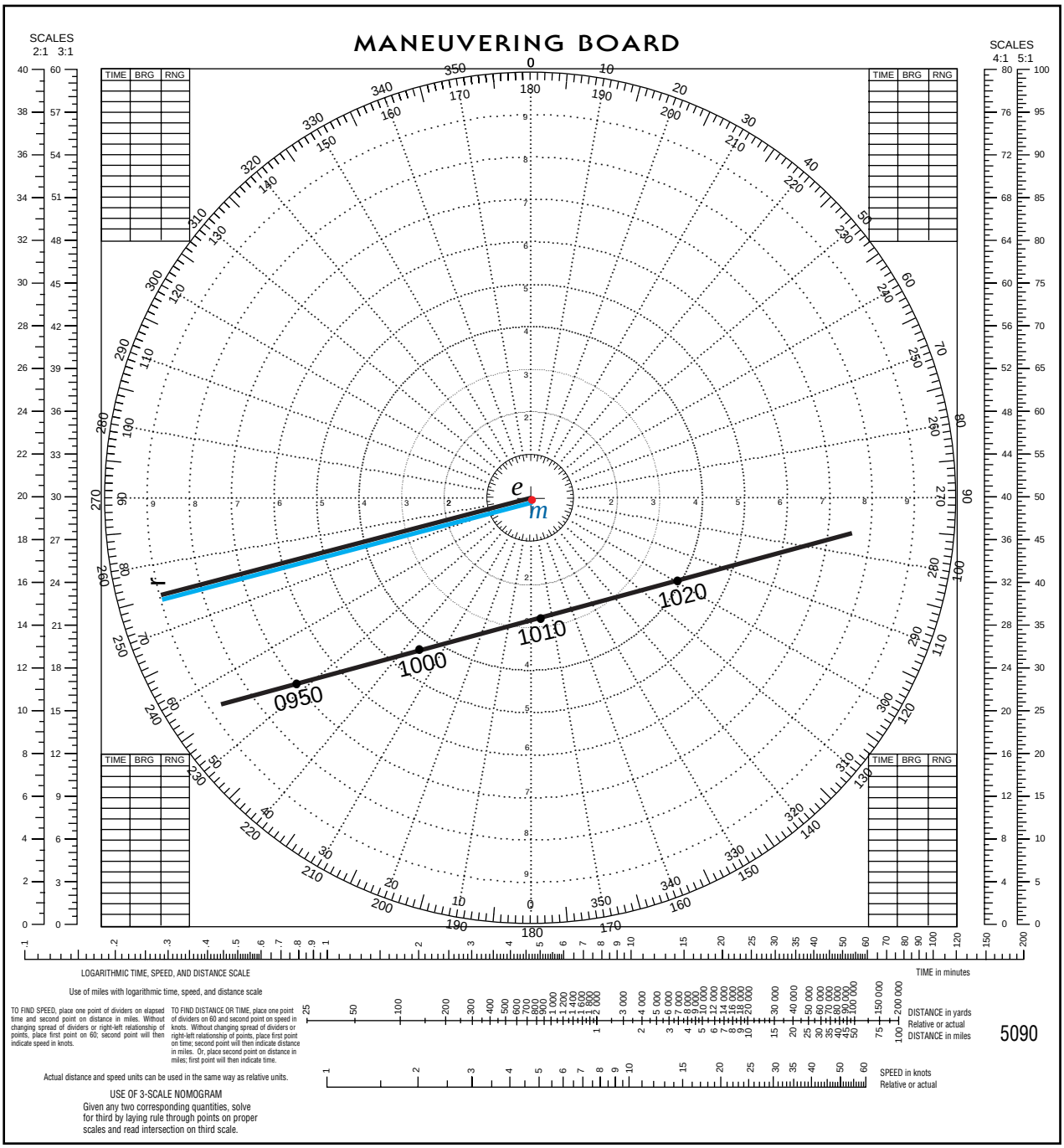


True Course and Speed of Target
Figure 10-12



3-1

Bird's Eye View of Situation in Figure 10-11
Figure 10-13



Presentation of a Stationary Target
Figure 10-14

10-1. Radar is both a _____ and a _____ device.

a. receiving, transmitting
b. piloting, collision avoidance
c. circular antenna, rotating bar antenna
d. relative motion, true course and speed

10-2. _____ radar must be used when in _____.

a. Surface search, the vicinity of other vessels
b. Working, poor or restricted visibility
c. Pulse generation, motion
d. Narrow beam, harbor or other congested areas

10-3. Altering course to avoid collision should be to _____ when a vessel is detected by radar alone, is forward of the beam, is not being overtaken, and the possibility of collision exists.

a. starboard
b. port
c. seaward
d. the shore side

10-4. A radar set is both _____ and _____.

a. an observer, a plotter
b. a beam sweep device, a pulse generator
c. a bearing indicator, and a distance ranger
d. a transmitter, a receiver

10-5. Radar sets have five basic components, the _____, _____, _____, _____, and _____.

10-6. The _____ is the radar information display. It is a cathode ray tube called a _____, or ____scope.

10-7. (True/False) The transmitter sends out pulses which are reflected back to the receiver. The reflected signal is called a blip.

10-8. (True/False) An echo on the PPI scope represents an object painted by the beam projected by the rotating antenna.

10-9. (True/False) A range strobe, a movable spot of light, or a fixed range ring, both of which can be manually positioned, is used to provide more accurate ranges.

10-10. Radar bearings are _____.

a. Repeatable
b. Reciprocal
c. Relative
d. Direct

10-11. The _____ the _____, the greater the resolution in bearing.

a. narrower, horizontal beam width
b. shorter, pulse width
c. longer, pulse width
d. wider, vertical beam width

10-12. The _____ the _____ the greater the resolution in range.

a. narrower, horizontal beam width
b. shorter, pulse width
c. longer, pulse width
d. wider, vertical beam width

10-13. The _____ the _____ the better able the radar on a rolling, pitching vessel is to hold the target in the beam.

a. narrower, horizontal beam width
b. shorter, pulse width
c. longer, pulse width
d. wider, vertical beam width

10-14. Radar requires _____ and _____ to operate it properly.

a. electric power, a rotatable antenna
b. a bearing curser, a range strobe
c. a range strobe, variable range rings
d. training, experience

10-15. The distance to the radar horizon in nautical miles is ____ times the square root of the height of the antenna, in feet. The distance to the eye's horizon is ____ times the square root of the height of the eye, in feet.

a. 1.17, 1.22
b. 1,71, 1.22
c. 1.22, 1.17
d. 1.22, 1.71

10-16. Radar can see farther than the eye because of the _____ of radio waves.

a. reflection
b. refraction
c. distortion
d. propagation

10-17. Blowing spray can obscure targets. It is known as _____.

a. spindrift
b. sea return
c. clutter
d. sea scatter

10-18. (True/False) The bright lighted area at the center of the PPI scope is close-in sea return and sea scatter.

10-19. (True/False) Radar ranges are quite accurate; radar bearings are less accurate than visual eyeballing.

10-20. (True/False) Radar fixes can be obtained with radar ranges to two or more targets, with a radar range and a visual bearing, with a radar range and a radar bearing to the same target, and with radar bearings to two or more targets.

10-21. (True/False) Fixes obtained with two radar ranges are most accurate; those obtained with two radar bearings are least accurate.

10-22. (True/False) Relative bearings are converted to radar bearings before plotting on a maneuver board.

10-23. (True/False) The target area, as presented on the PPI scope, changes as the observing vessel moves through the area.

10-24. _____ range scales provide greater detail.

a. Long
b. Short
c. PPI scope
d. Down

10-25. Radar can be used at _____ and during _____, when most other methods are limited.

a. sea, night maneuvers
b. night, high speed maneuvers
c. sea, restricted visibility
d. night, restricted visibility

10-26. Fixes may be available _____ from land using radar.

a. at night
b. by transmitting
c. at a greater distance
d. by radio

10-27. Radar is subject to _____ and _____ failure.

a. electrical, operator
b. operator, mechanical
c. electrical, mechanical
d. transmitter, receiver

10-28. Interpretation of _____ is not always easy.

a. information on the PPI scope
b. range data
c. bearing data
d. the maneuvering board representation of the PPI scope information

10-29. The movement of a vessel in relation to another or to stationary objects is _____.

a. relative course and speed.
b. true course and speed
c. bird's eye view
d. relative motion

10-30. (True/False) The relative motion plot is used to find the closest point of approach (CPA) of the target.

10-31. (True False) The relative motion plot is also used to find the true course and speed of the target through use of an erm diagram, which is a graphical solution of an arithmetic problem.

PROBLEMS

At 1305 you detect a moving target bearing 322° relative at 9.0 miles. Eight minutes later it bears 324° at 6.5 miles. Continued observation yields the following:

1305	322°R9.0 M
1313	324°R6.5 M
1320	327°R4.4 M
1325	331°R3.0 M

You are on course 280° at 9 knots.

10-1. What is the closest point of approach of the target? _____

10-2. When does this occur? _____

10-3. What is the relative course of the target? _____

10-4. What is the relative speed of the target? _____

10-5. What is the true course of the target? _____

10-6. What is the true speed of the target? _____

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CHAPTER 11
CONSIDERATIONS AND CONCLUSIONS

11. Chapter 11.

11.1. CALCULATORS. Chapter 17 of Piloting & Dead Reckoning treats the use of the scientific calculator in piloting. This will not be covered as part of the Navigation Specialty Course, but it is information that will prove useful to the practicing navigation specialist. Mathematical solutions to most situations that are solved graphically in this course are provided. A knowledge of trigonometry and geometry is not essential for coastal piloting, just as one does not need to know electronics to use radar or LORAN. All three provide a depth of knowledge that is particularly beneficial to the individual who is going to teach navigation. If the teacher understands how or why something works or behaves the way it does, he or she is far more effective in passing knowledge on to students. Almost anybody can pass information. The teacher must be able to provide explanation and clarification. He or she must be able to answer questions correctly.

11.2. COMPUTERS. The use of computers aboard boats is becoming more common and several software companies provide coastal and celestial navigation programs. Some computers are able to interface directly with electronic navigation equipment, taking data from the navigation device, processing it, and displaying solutions or providing steering commands on the navigation device's display. In some cases the navigation equipment and the computer, separately or together, can interface with devices like an autopilot, actually changing course or altitude (for airplanes).

11.3. DANGERS OF SOPHISTICATION. The sophistication of navigational equipment is growing at a phenomenal rate and the boat owner is limited only by his or her desire and what he or she is willing to spend. There is an obvious inherent problem in all of this. What happens when the electrical system fails? It's easy to rely on available equipment, which has demonstrated high reliability, to the exclusion of knowledge or understanding of basic navigation. The owner or operator who would venture far to sea without the knowledge and equipment to employ celestial navigation is asking for trouble. So is the owner or operator who ventures far from home, even though remaining in coastal waters, who does not know basic piloting or does not have the tools to use it when necessary.

11.4. PUBLICATIONS. There are many navigation publications of use to the Navigation Specialist and to the practicing navigator. This text could not have been written without the three texts cited in the Foreword. In addition, Bonnie Dahl's The LORAN-C Users Guide, published by Richardson's Marine Publishing, Evanston,

IL, was particularly helpful in understanding the basics of LORAN. Chapman's Piloting, Seamanship, and Small Boat Handling, provides much information of value to the navigator. This book is cited primarily because it does contain good information and is much more widely used by boaters, including Auxiliarists, than Dutton's or Bowditch. Those volumes are more likely to be in the libraries and aboard the boats of serious navigators and teachers of navigation. The NOAA Tide and Tidal Current Tables and the USCG Light Lists belong in those same libraries and aboard boats that cruise in tidal waters and at night.

11.5. THE PRUDENT NAVIGATOR. A final observation. The prudent navigator and the prudent operator know the idiosyncrasies of their vessel. They know its fuel consumption at different power settings and they know how it handles in various sea conditions and under various loads. They know the limitations of their vessel and of themselves. They do not operate "outside of their envelope;" that is, they don't go out in 8 foot seas when they know their vessel is unsafe with more than 4 foot seas. They don't try to run 200 miles at 20 knots when the fuel consumption at that speed will only allow them to go 150 miles. They do know their fuel consumption at various power settings and plan their voyages to allow a fuel reserve and to allow for refueling as necessary. A good rule of thumb is a third out, a third back, and a third in reserve.

11.6. REFLECTIONS. Chapter 12 of the USCG Auxiliary text (2d Edition) for the Advanced Coastal Navigation public education course is aptly titled, "Reflections." The chapter lists and discusses ten principles (of navigation). The principles are listed here. Chapter 12 of ACN is recommended reading.

Principle 1. Professional navigation is as much an attitude of mind as an art or science.

Principle 2. Practice is essential and can also be fun.

Principle 3. Do not rely on any one technique for determining the vessel's position.

Principle 4. Be alert to anomalies.

Principle 5. Emphasize routine in times of stress.

Principle 6. Slow down or stop the vessel if necessary and circumstances permit.

Principle 7. Preplan as much as possible.

Principle 8. Be open to data or information at variance with your understanding of the situation.

Principle 9. Know and operate within your limits.

Principle 10. Maintain a DR plot.

Principle 10 is one which we can not stress enough. It is here that the proliferation of electronic aids to navigation is most noticeable. Many boaters consider DR plots obsolete because "...all I have to do is turn on this little ole LORAN. Why should I worry about dead reckoning; I'll never have to do it." This is a dangerous mind set, one which we must try to dispel. As stated in Chapter 3, dead reckoning is the basis for all other navigation and it should be evident to the navigation specialist that a rudimentary knowledge of piloting, at least, is necessary for boaters who venture away from home, who operate in areas of quickly changing weather conditions, or who operate in periods of restricted visibility, including at night.

11.7. VOYAGE PLANNING. Voyage planning includes a lot more than just drawing DR plots on a chart. The skipper must consider fuel capacity and range, and the state of repair of the vessel, machinery, and electronics. He or she must also ensure that necessary supplies and equipment to include food, clothing, spare parts, water, oil and transmission fluids, etc., are on board. Depending on the length of the voyage and size of vessel, the current light lists, tide and tidal current tables, navigation rules, and maybe a coastal pilot should be on board. Charts covering the areas to be traversed or operated in should be on board and posted up to date (we recommend that all boaters, but particularly those that cruise some distance from home, subscribe to the local Notices to Mariners published by the various Coast Guard District Headquarters. They can be subscribed to at no charge.). Consideration of fuel capacity and range, concern for proper supplies and equipment, and condition of the vessel and its components are properly elements of seamanship so are not discussed here. Chapter 11 of the ACN course provides good information on this subject. (We note that neither Dutton's, Bowditch, nor Shufeldt, cover these items and Chapman covers it in a section which could be called seamanship but not navigation). A reminder: navigation is simply knowing where you are, where you want to go, and how to get from one to the other.

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CHAPTER 12
AIDS TO NAVIGATION

12. Chapter 12.

12.1. INTRODUCTION. An aid to navigation (ATON) is "a device or structure external to a craft, designed to assist in determination of position, to define a safe course, or to warn of dangers or obstructions. If the information is transmitted by light waves, the device is a visual aid to navigation; if by sound waves, an audible aid to navigation; if by radio waves, a radio aid to navigation. Any aid to navigation using electronic equipment, whether or not radio waves are involved, may be called an electronic aid to navigation."[80] Aids to navigation should not be confused with navigational aids which are the tools used in navigating, such as dividers, parallel rulers, sextants, circular slide rules, calculators, computers, LORAN sets, and the like. This chapter will treat buoys, day marks, lights, and other devices which aid coastal navigation.

12.2. BUOYS AND MARKERS. Buoys are floating aids to navigation, anchored in position, whose shape, color, and numbers generally convey a message to the navigator. Day marks are fixed aids whose shape, color, and numbers convey a message. Both are known as *markers*, for example: a mid-channel buoy and a fairway marker are the same thing. Markers are generally organized into four systems of interest to Auxiliarists: the lateral system, the intracoastal waterway system, the western rivers system, and the uniform state waterway marking system. There are markers that fall outside these systems; they are special purpose, and are of little interest to Auxiliarists and other coastal navigators.

12.2.1. The Lateral System of Buoyage.

12.2.1.1. The Buoys. The buoys and markers in use in, and off the coasts of the United States conform to the International Association of Lighthouse Authorities (IALA) system with a few exceptions where some black buoys and the black bands on preferred channel buoys have not yet been changed to green. The system includes:

1. Green left-hand channel markers.

2. Green lights on lighted left-hand channel markers.

3. Red right-hand channel markers.

[80] Bowditch, p. 7120

4. Red lights on lighted right-hand channel markers.

5. Red and green horizontally banded preferred channel markers.

6. Red and white vertically striped safe water or fairway markers (formerly called mid channel markers).

12.2.1.2. The System. Lateral means "side." The lateral system is a convention which tells the mariner on which side to leave a buoy to ensure the buoy is between the vessel and the danger it protects against (in channels, the buoys protect against the danger of grounding in shallow water). The lateral system is designed to provide safe passage when returning from the sea. The rule is to leave red buoys to starboard when returning to harbor. Obviously, then, green buoys are left to port. All channels do not lead in from the sea; a convention has been established that considers in-from-the-sea to be a clockwise flow down the east coast (red buoys left to starboard when heading south), up the west coast of Florida (red to starboard when heading north), across the Gulf coast (red to starboard when heading west), and up the west coast of the United States (red to starboard when heading north). In-from-the-sea on the Great Lakes is generally northerly and westerly except Lake Michigan, where it's southerly (leading toward the port of Chicago).

12.2.1.3. Color, Shape, and Number Significance. Color, shape, and numbering of buoys and day marks help to identify the side of the channel being marked in the lateral system.

12.2.1.3.1. Color. Green buoys, day marks, and lights mark the left side of the channel coming in from the sea or clockwise around the United States when not connected to the sea. (Some of the green buoys are still black and some of the lights are still white, but they are being changed rapidly). They should be left to port when inbound and to starboard when outbound. Red buoys, daymarks, and lights mark the right side of the channel and should be left to starboard when inbound, to port when outbound. (Some of the red lights may still be white; they, also, are being changed rapidly).

12.2.1.3.2. Shape. Left side of the channel markers are cylindrical (rectangular in a straight on view) and square. Floating markers (buoys) , called "cans," are cylindrical; stationary markers (day marks) are square. Right side of the channel markers are truncated cones (buoys, called "nuns") and triangular (day marks). Unlighted fairway markers are spherical. Lighted buoys are the exception to the rule. Their shape has no significance. Markers for either side of the channel and fairway markers that display lights have a framework sort of structure that supports the light, it's power source, and any enabling mechanism, plus any bells, whistles, or gongs the

buoy may contain. Preferred channel markers take the shape appropriate to the top band color. Preferred channel markers are located at the junction of two channels; i.e., where the traveled channel splits into two channels as with a "Y" intersection. The preferred (deepest, widest, most used, or whatever the reason) is indicated by the color of the top band. If it is green, the marker is left on the port side and the preferred channel is to the right. If it is red, the marker is left on the starboard side and the channel is the left branch. (If a marker at a junction is solid colored, there is only one channel, the other fork can be considered unnavigable). See page 12-5.

Lighted Buoy Marking
Right Side of Channel
Figure 12-1[81]

Nun Buoy with Radar
Reflective Structure
Figure 12-2[82]

12.2.1.3.3. Numbering. The green cans and square day marks, marking the left side of the channel when inbound or traveling clockwise around the United States from the North East to the North West, are odd numbered. The red nuns and triangular day marks, marking the right side of the channel, are even numbered. Lighted buoys are odd numbered if green, even numbered if red.

12.2.1.3.4. Systems Illustrated. Pages 12-5 through 12-8[83] show the Lateral System, a visual guide to the workings of buoyage, a fictitious chart of the visual guide, and the Western Rivers and Uniform State Waterway Marking systems

12.2.2. Western Rivers System. This system pertains to the Mississippi River and its tributaries. Its buoys and marks are shown on page 12-8. It is essentially the same as the Lateral System, except the buoys and markers are unnumbered and it has no safe water (fairway) markers. Green cans and square day marks identify the left side of the channel when bound upstream, red nuns and triangular day marks

[81] Photo courtesy of W. C. Hogan, BC-TAN
[82] Ibid
[83] Plates 1 thru 4, US Aids to Navigation System from Light List, US Coast Guard COMDTPUB P16502 series

identify the right side. In place of numbers, the day marks and beacons support mile boards which indicate the distance upstream of the marker. The system also contains day marks which indicate passing and crossing zones and where the deepest part of the channel migrates from one side of the river to the other.[84]

Can Buoy with Radar
Reflective Structure
Figure 12-3[85]

Lighted Left Side
of Channel Day Mark
Figure 12-4[86]

Lighted Marker with Solar Panels,
Mechanism
Figure 12-5[87]

Silhouetted Day Mark
Identified by Shape
Figure 12-6[88]

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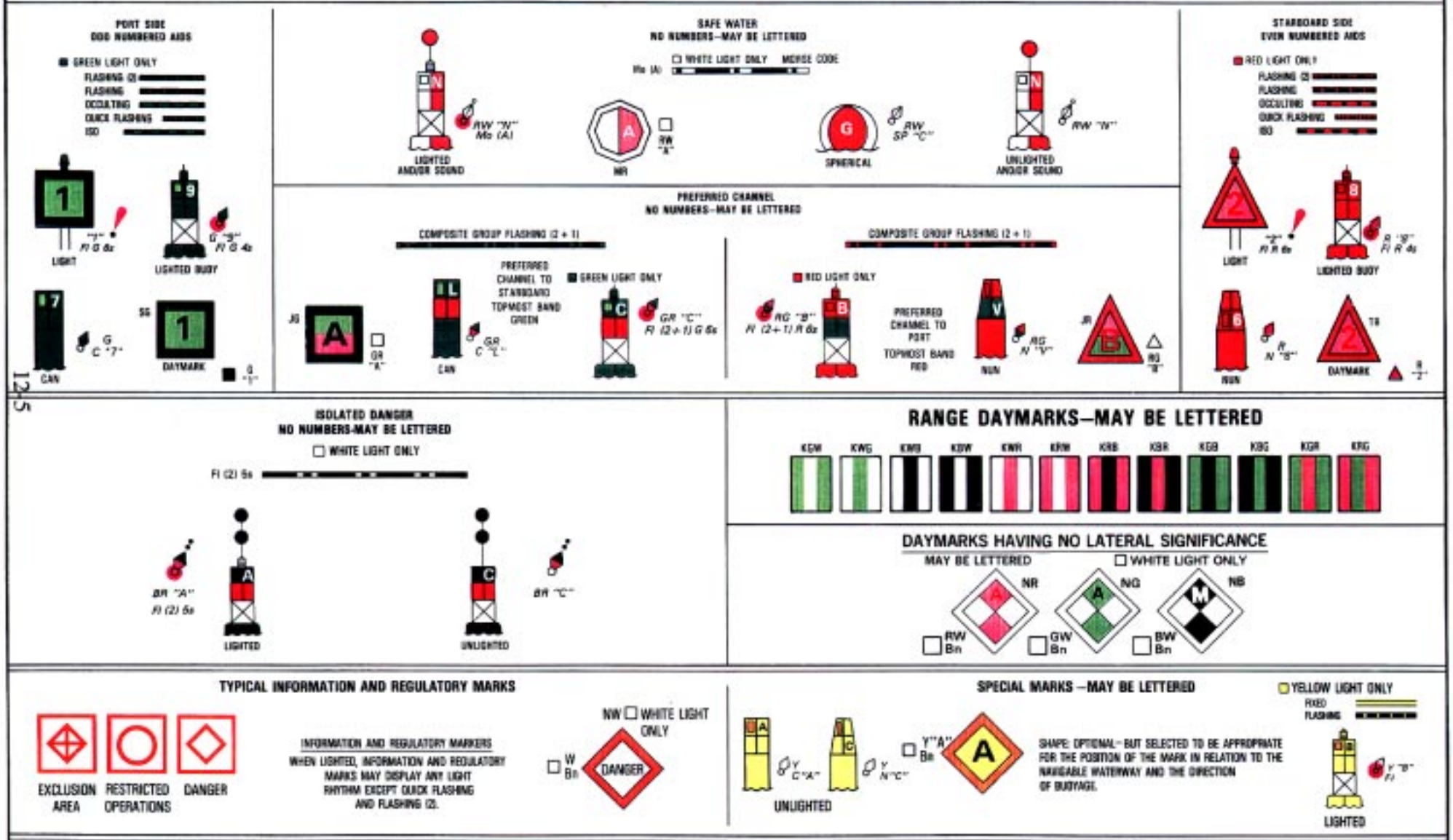
84 Shufeldt, p. 34
85 Photo courtesy of W. C. Hogan, BC-TAN
86 Ibid
87 Ibid
88 Ibid

U.S. AIDS TO NAVIGATION SYSTEM

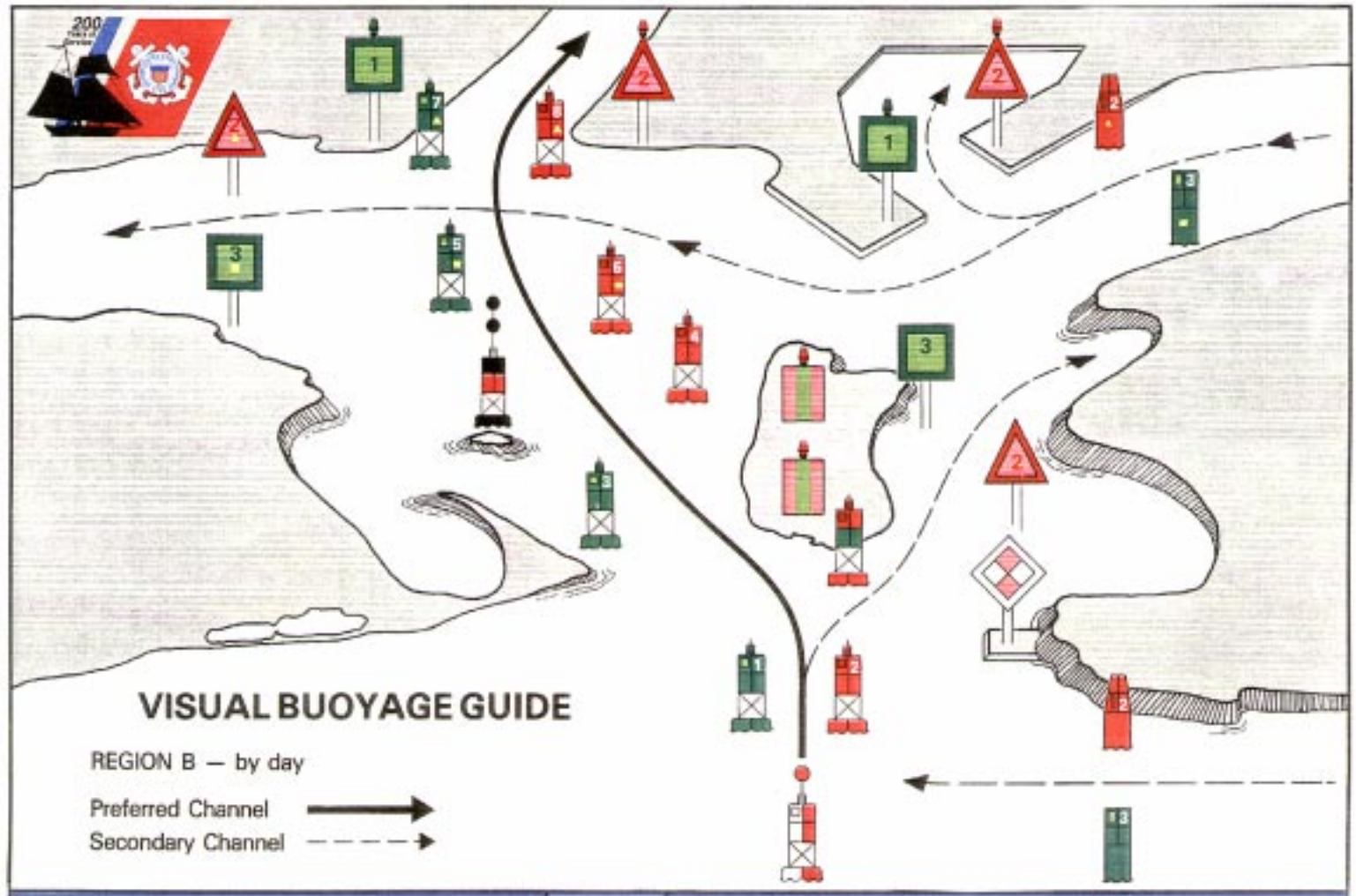
on navigable waters except Western Rivers

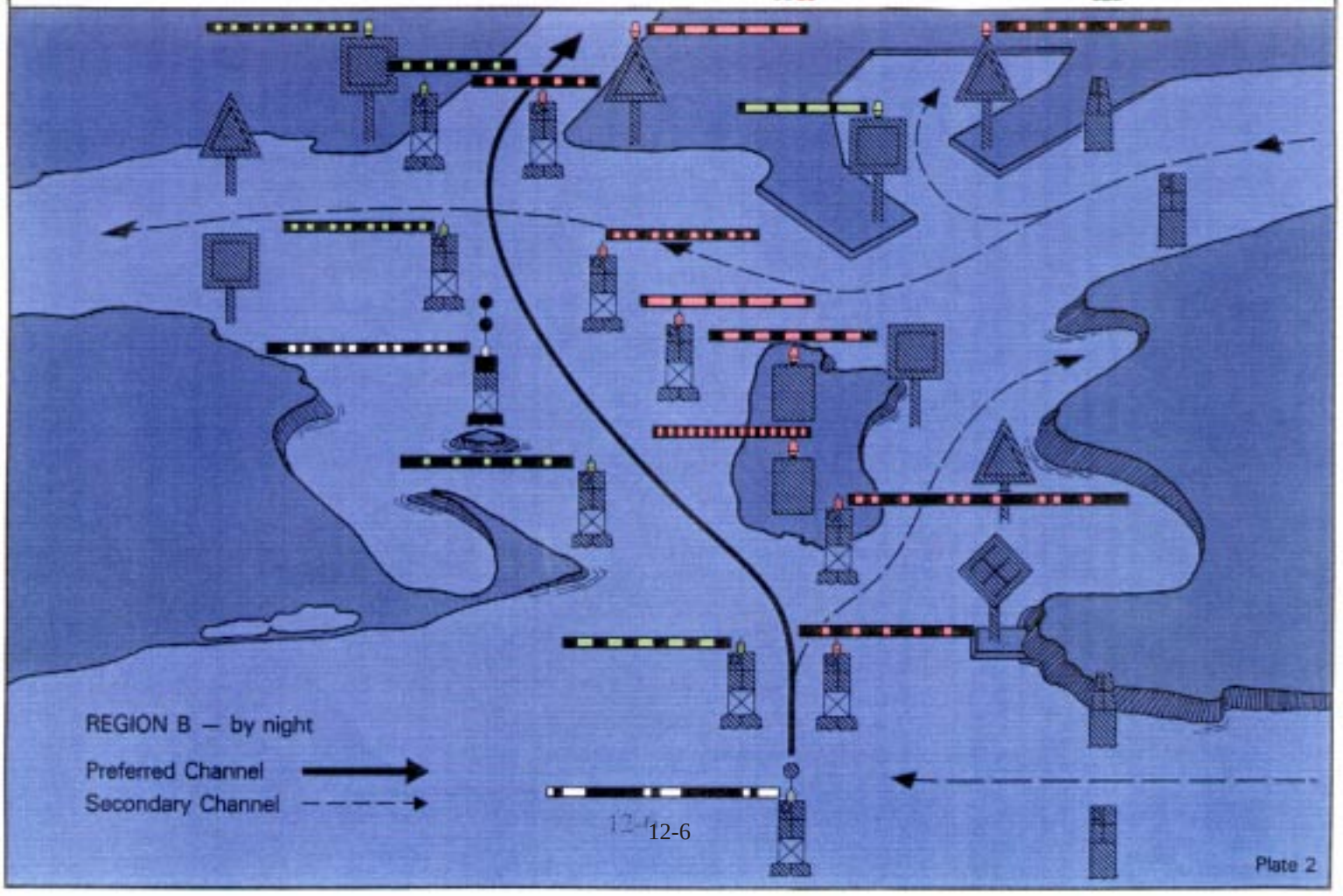
LATERAL SYSTEM AS SEEN ENTERING FROM SEAWARD



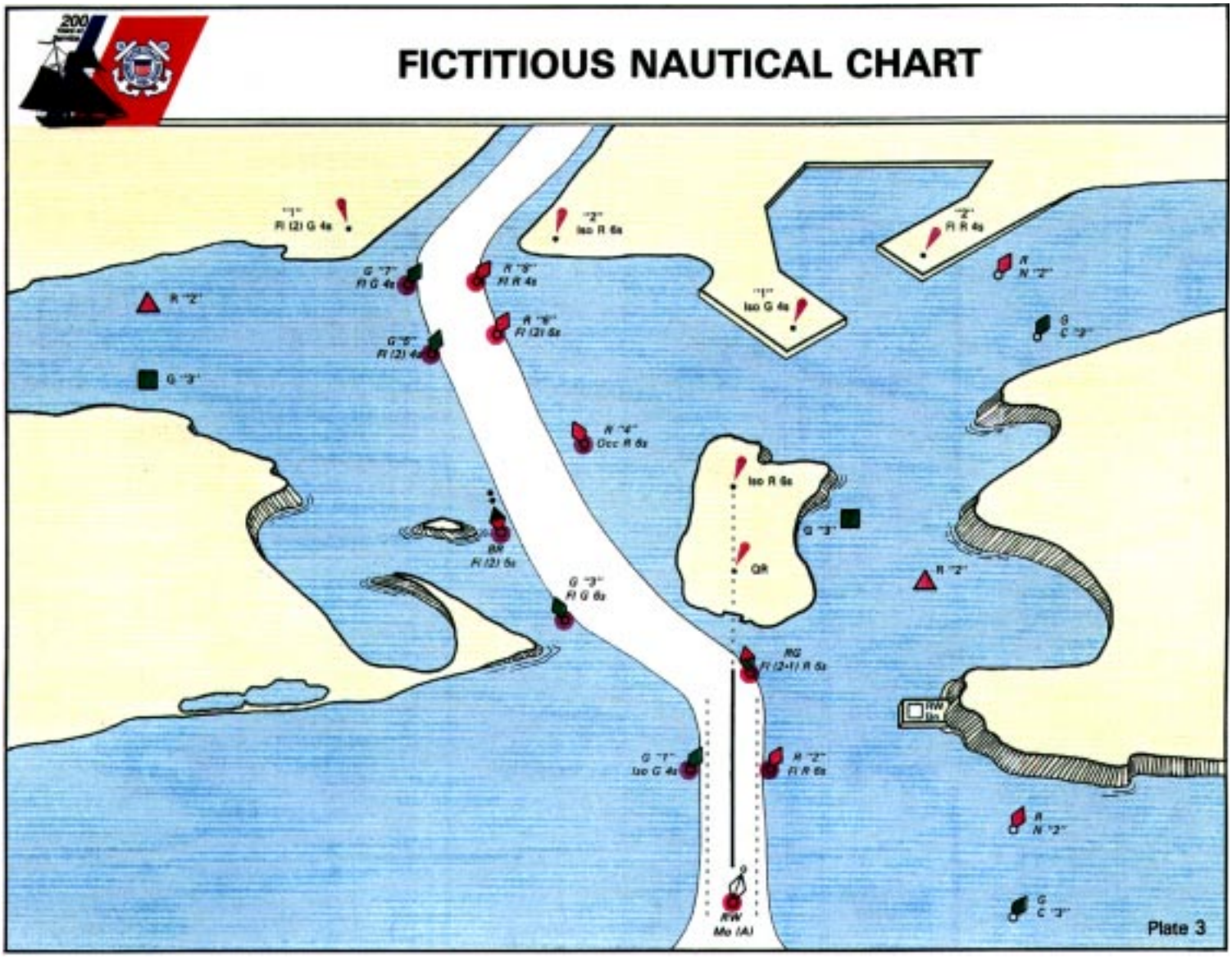
Aids to navigation marking the Intracoastal Waterway (ICW) display unique yellow symbols to distinguish them from aids marking other waters. Yellow triangles △ indicate aids should be passed by keeping them on the starboard (right) hand of the vessel. Yellow squares □ indicate aids should be passed by keeping them on the port (left) hand of the vessel. A yellow horizontal band ▭ provides no lateral information, but simply identifies aids as marking the ICW.

Plate 1


VISUAL BUOYAGE GUIDE
REGION B — by day
Preferred Channel
Secondary Channel

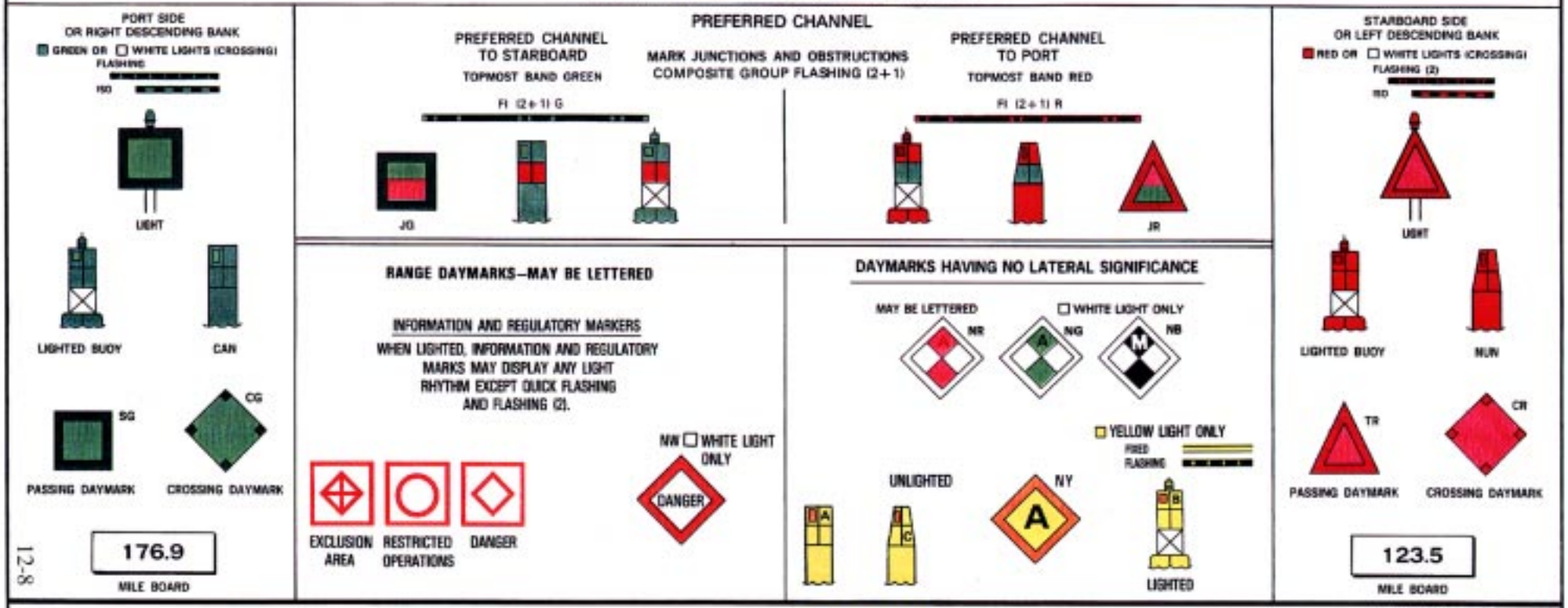

REGION B — by night
Preferred Channel
Secondary Channel
Plate 2

FICTITIOUS NAUTICAL CHART



U.S. AIDS TO NAVIGATION SYSTEM
on the Western River System

AS SEEN ENTERING FROM SEAWARD



UNIFORM STATE WATERWAY MARKING SYSTEM

STATE WATERS AND DESIGNATED STATE WATERS FOR PRIVATE AIDS TO NAVIGATION

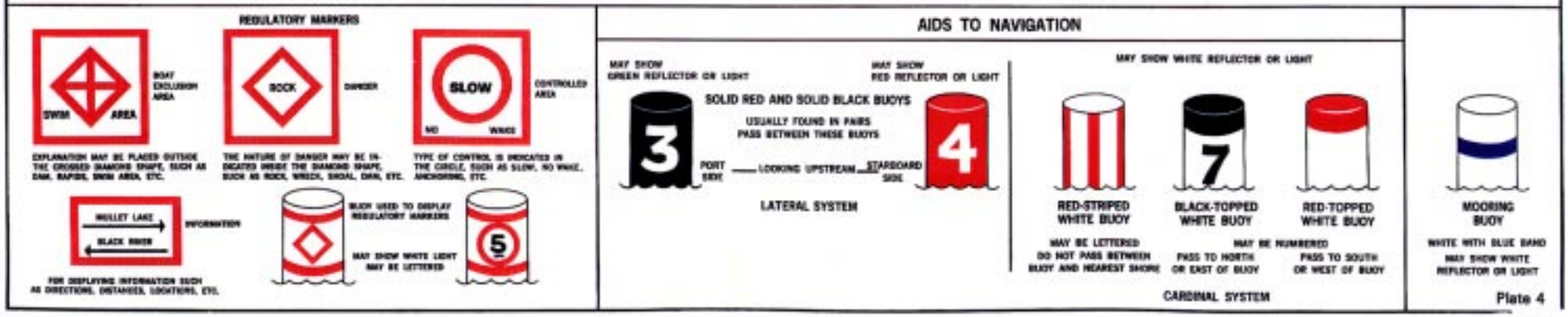


Plate 4

12.2.3. Uniform State Waterway Marking System. This is an optional system used by some states on some waterways. Its buoys and marks are also shown on page 12-8. All lateral (channel marking) buoys are can shaped. Red and white vertically striped buoys have a very important difference from red and white vertically striped buoys in the Lateral System. The Lateral System buoys mark safe water; the buoy may be left on either side. The Uniform State System buoys say just the opposite; i.e., do not pass between me and the near shore.

12.2.4. Intracoastal Waterway (ICW) System. The intracoastal waterway generally provides safe passage for vessels traveling north and south on the east coast of the United States and, to some extent, east and west along the Gulf coast. Vessels can travel most of the way from New York to Florida without having to go "outside" (into the Atlantic Ocean). The system follows the clockwise rule of the lateral system and use the shape, color, and numbering convention of the Lateral System, except that all buoys and day marks have yellow identifiers. Day marks are bordered with a yellow band. Buoys show a yellow square on the left side of the south bound channel and a yellow triangle on the right side. The ICW markers are shown in the Visual Buoyage Guide on page 12-6. Notice buoys 5, 6, 7, and 8 in the left hand preferred channel where it is crossed by the ICW. The buoys are all colored in accordance with the Lateral System, but each also has a yellow triangle or square. Buoys 7 and 8, both have a yellow triangle, indicating the right side of the ICW channel, even though buoy 7 is green, marking the left side of the inbound-from-the-sea channel. Buoy 6 has a yellow square marking the left side of the ICW even though it's colored red to mark the right side of the Lateral System channel.

12.3. LIGHT CHARACTERISTICS. Lights on aids to navigation are either fixed, flashing, or occulting. A fixed light is on continuously. A flashing light is off, with flashes of light. An occulting light is on, with flashes of darkness. An isophase light has periods of darkness and periods of light that are equal in length. The Light List, US Coast Guard COMDTPUB P16502 series, gives the color, and the light pattern of every lighted Aid to Navigation in the country. Charts provide the same information. The different flashing or occulting patterns of the various aids help in their identification at night.

12.3.1. Occulting. The period of occulting lights begins at the instant of darkness and ends at the instant of darkness when the next period begins. For single occulting lights the period includes the flash of darkness and the longer lighted period. For other occulting patterns, the period begins with the flash of darkness immediately after one pattern occurs, and continues through all of the periods of light and darkness in the pattern. The diagrams on page 12-10[89] show the different occulting patterns and their periods.

[89] Chart No. 1, United States of America Nautical Chart Symbols Abbreviations and Terms, 9th Edition, Jan 1990, US Dept. of Commerce, NOAA, NOS, DMA Stock No. WOBZC1

Light Characters

Light Characters on Light Buoys → Q

	Abbreviation		Class of light	Illustration Period shown	
	International	National			
10.1	F	F	*Fixed*		F
	Occulting (total duration of light longer than total duration of darkness)				
10.2	Oc	Oc; Occ	*Single-occulting*		Oc; Occ
	Oc(2) Example	Oc (2); Gp Occ	*Group-occulting*		Oc (2); Gp Occ
	Oc(2+3) Example	Oc(2+3)	*Composite group-occulting*		Oc(2+3)
	Isophase (duration of light and darkness equal)				
10.3	Iso	Iso; E Int	*Isophase*		Iso; E Int
	Flashing (total duration of light shorter than total duration of darkness)				
10.4	Fl	Fl	*Single-flashing*		Fl
	Fl(3) Example	Fl (2); Gp Fl	*Group-flashing*		Fl (2); Gp Fl
	Fl(2+1) Example	Fl (2+1)	*Composite group-flashing*		Fl (2+1)
10.5	LFl	L Fl	*Long-flashing (flash 2s or longer)*		L Fl
	Quick (repetition rate of 50 to 79 – usually either 50 or 60 – flashes per minute)				
10.6	Q	Q; Qk Fl	*Continuous quick*		Q; Qk Fl
	Q(3) Example	Q(3)	*Group quick*		
	IQ	IQ; Int Qk Fl; I Qk Fl	*Interrupted quick*		IQ; Int Qk Fl; I Qk Fl

	Abbreviation		Class of light	Illustration Period shown	
	International	National			
10.7	*Very quick (repetition rate of 80 to 159 – usually either 100 or 120 – flashes per min)*				
	VQ	VQ; V Qk Fl	*Continuous very quick*		VQ; V Qk Fl
	VQ(3) Example	VQ (3)	*Group very quick*		
	IVQ	IVQ	*Interrupted very quick*		
10.8	*Ultra quick (repetition rate of 160 or more – usually 240 to 300 – flashes per min)*				
	UQ	UQ	*Continuous ultra quick*		
	IUQ	IUQ	*Interrupted ultra quick*		
10.9	Mo (A) Example	Mo (A)	*Morse Code*		
10.10	FFI	F Fl	*Fixed and flashing*		F Fl ;
10.11	Al.WR	Al; Alt	*Alternating*	R W R W R W	Al; Alt

Colors of Lights

11.1	W		W		*White (only on sector-and alternating lights)*
11.2	R		R		*Red*
11.3	G		G		*Green*
11.4	Bu		Bu; Bl		*Blue*
11.5	Vl		Vl		*Violet*
11.6	Y		Y		*Yellow*
11.7	Y	Or	Y	Or	*Orange*
11.8	Y	Am	Y	Am	*Amber*

Colors of lights shown on standard charts

on multicolored charts

on multicolored charts at sector lights

12.3.2. Flashing. Flashing lights are sub-divided into flashing, quick flashing (50 - 79 flashes per minute), very quick flashing (80 - 159 flashes per minute), and ultra quick flashing (160 or more flashes per minute). In the United States quick flashing lights usually flash 60 times per minute. In all cases, quick and faster flashing lights mean danger. The various speeds and patterns of flashing and faster lights, and their periods, are shown on pages 12-10 and 12-11.[90]

12.3.3. Isophase. The pattern and period of isophase lights is shown on page 12-10.

12.3.4. Chart Number 1. Chart No. 1 is the legend for all US charts. It provides all of the symbols, abbreviations, and terms used on charts. Section P provides complete coverage of the treatment of lights and lighted aids to navigation as shown on the charts. Section Q deals with buoys. The prudent navigator, and especially the Auxiliary Navigation Specialist will have Chart No. 1 available and will become familiar with it.

12.4. INFORMATION BUOYS. In all the buoyage systems in use in the United States there are white buoys with orange markings on them. These inform the boater of danger and exclusionary areas, defined by an orange diamond with the hazard spelled out (danger area) in black letters and by an orange diamond and cross (exclusionary area) with the reason for exclusion spelled out in black letters. Regulatory information, such as speed limits, no wake zones, and the like, are defined by an orange circle with the type of information spelled out in black letters. These are shown on pages 12-5 and 12-8.

[90] Ibid

ANNEX I

NAVIGATION SPECIALTY COURSE
PART B

FOREWORD: This part of the Navigation Specialty Course is designed to complete your qualification to be a Navigation Specialist. You will be expected to be able to navigate a vessel, using dead reckoning and piloting, with confidence and skill. You will also be expected to have sufficient knowledge and understanding to teach Navigation, Advanced Coastal Navigation, and Piloting in member training and public education settings (if you are a qualified instructor). NAV A provided you with theory and practice in plotting, using maneuver boards. NAV B will provide you with extensive practical chart work.

This course provides you training in one of the most basic and most important skills of the mariner, the ability to determine where you are and how to get to where you want to go. This is important to the Auxiliarist who participates in Search and Rescue or other activities in support of the Coast Guard. It is important to you if you cruise. A secondary objective is to make the designation as an Auxiliary Operational Member (AUXOP) something to be extremely proud of by making this specialty course a challenge, obtainable only through interest, dedication, and work.

This Annex is based upon a continuous cruise. Each section of the Annex represents a leg of the cruise. The successful solution of many problems or answers to questions will depend upon your ability to correctly answer earlier questions or to solve earlier problems. The questions are multiple-choice and we have tried to provide plausible answers among the choices; that is, if you make the common errors there will be choices to match the errors. This has been done deliberately because success on an actual cruise requires you to continuously navigate, updating your position as you go, using your progress as bench marks. Plausible answers will illustrate the dangers of the common errors to you. At some point in each leg a fix, or a known position, or a solid reference will be provided to give you a new starting point. Each leg of the cruise (section of the Annex) will begin with a new situation. No question or problem will carry over to the next leg. The examination will also contain plausible incorrect answers among the choices, but no question will depend upon correct answers to previous questions.

The most important single facet of coastal navigation, which is what this course is really about, is dead reckoning. It is the basis upon which all else is done, including celestial navigation. Dead reckoning is the key to success in that more advanced

arena as well. Because of that, the cruise exercise will contain many dead reckoning position determinations. Generally, your ability to plot a dead reckoning position is measured by the accuracy of the geographic coordinates of your plot. You will obtain considerable practice in determining these positions. Your ability to plot latitude and longitude rapidly can be very valuable, particularly if you are standing into danger at a time of low visibility. When you are comfortable with chart work you will find that you can do this rapidly, accurately, and with confidence.

Experience has indicated that successful completion of this part of the specialty course is dependent upon doing the cruise exercise. Everything you need to do this is in this text. The pertinent part of the latest edition (1994) of the various tables have been extracted from the NOAA publications and are included in the workbook.

Welcome to the world of the Auxiliary navigator. Good luck on the exercise and on the examination.

DEPARTMENT OF TRAINING
Advanced Studies Division
Navigation Branch

I-1. The Cruise Exercise (Section I, The First Leg of the Cruise)

I-1.1. Introduction. This paragraph pertains to every section of this Annex and to every leg of the cruise. This exercise includes at least one of each type of problem or question included in the AUXNAV B examination. The major difference between the exercise and the examination is that some questions in the exercise are interdependent while all questions in the examination are independent. There is only one correct answer to any question or problem.

The following precision is required:

Direction to the nearest:	1.0 degree (°)
Distance to the nearest:	0.1 nautical mile (M)
Speed to the nearest:	0.1 knots (kts)
Time to the nearest	1.0 minute (m)
Position to the nearest:	0.1 minute of Latitude (‘)
	0.1 minute of Longitude (‘)
	0.1micro-second of Time Difference (μsec)

I-1.2. Scope of Section I. Section I treats several basic concepts of coastal navigation, or piloting. These include dead reckoning, lines of position, estimated positions, running fixes, and relative bearings. In addition, determinations of time of sunrise and height of tide at any time are introduced.

I-1.3. Review of Dead Reckoning and Basic Piloting.

I-1.3.1. Dead Reckoning. “Dead reckoning” is a modernization of “deduced reckoning” and means, simply, the determination of position by extension of distance and direction from a last known position. Dead reckoning ignores any external influence (current) on the vessel. Direction is the course steered, or the intended track. Distance is a measure of how far one has traveled in a given period of time and is a function of speed. The most accurate, non-electronic measure of speed uses a speed curve; that is, speed is a function of engine rpm, assuming operating conditions are similar to those under which the curves were developed.

I-1.3.2. Lines of Position. A bearing taken on an object can be plotted as a line of position (LOP). In order to use the LOP for navigation the object must be charted. LOPs can be established using bearings from the steering compass, from a hand bearing compass, from a pelorus, or from radar. If the steering compass is used, deviation is a factor which must be considered in converting the bearing to True. It also will almost always require turning the vessel in the direction of the object and sighting across the lubber line. This is because the steering compass on most small vessels is located

where it cannot be sighted across except from astern looking forward. This is the least desirable method of determining a LOP because it means turning the vessel off course. Further, it would be very difficult to establish a second LOP, for a fix, from the exact spot or at the same time. When using the hand bearing compass, deviation is ignored. This is because the hand bearing compass can be used from anywhere on the vessel and using the compass in the same place everytime would be virtually impossible. The vessel's magnetic field would affect the compass differently each time it was used. Since deviation is the result of the interaction of the vessel's magnetic field with the Earth's magnetic field on the compass, its consideration is impractical. LOPs from hand bearing compasses are treated as magnetic bearings, to which only variation is applied to determine the true bearing. A hand-held fluxgate compass will eliminate the problem of deviation.

I-1.3.3. Relative Bearings. Relative bearings are measured clockwise from the bow of the vessel with a device called a pelorus. A pelorus consists of a sighting device which rotates on a compass rose whose 000° point is directly towards the bow; that is, parallel to the keel as in compass installation. The true direction of the LOP (true bearing to the sighted object) is found by adding the relative bearing to the true heading of the vessel at the instant of taking the sight.

I-1.3.4. Estimated Position. A single LOP tells you only that your vessel is somewhere on that LOP. If a single LOP is all that is possible, it may be beneficial for you to have an idea where you are. With only one LOP, the only method available is to establish an estimated position (EP). Once the LOP is plotted on the chart, plot the DR position for that time. You still know only that the vessel is on the LOP, but not where on the LOP it is. The EP does not pinpoint the vessel's actual location; it only provides a most likely position. The EP is based on the premise that the vessel's position is the point on the LOP closest to where the vessel should have been (DR position) if there had not been external forces working on it (current). That point is found by dropping a perpendicular from the DR position to the LOP (creating a line that passes through the DR position and intersects the LOP at a 90° angle). The EP is where the perpendicular intersects the LOP.

I-1.3.5. Fixes and Running Fixes. Be alert for an opportunity to take a second bearing on the same or a different object. A position can be established by advancing the first LOP to the time of the second. This establishes a running fix (RFIX). Because time elapses between the first and second LOPs, the RFIX is not as precise as a fix where both (or more) LOPs are determined at once. The more time between LOPs, the less accurate the fix. For one thing, current affects the movement of the vessel. Basic instruction in running fixes omits the effects of current. Later in this text the effects of current, and of changes in course will be introduced to the determination of running fixes. A running fix is determined by replotting the first LOP parallel to itself at a distance the vessel would have traveled in the time between sights and in the

direction the vessel traveled since the first sight. The RFIX is where the replotted LOP crosses the new LOP.

I-1.3.6. Sunrise and Sunset. Sunrise and sunset are determined using the tables in the National Oceanic and Atmospheric Administration, National Ocean Service publication, Tide Tables 1994, High and Low Water Predictions. These tables (4 and 5) give the time of sunrise and sunset at the standard meridian for various parallels of latitude. The standard meridian is the time meridian (the meridian that passes through the center of the time zone). The time meridian for various locations can be found in Table 1. Each time zone is 15° wide. The tables are set up for standard time in any time zone (they are based on the movement of the Earth around the sun as well as the rotation of the Earth). Table 5 allows conversion to times of sunrise and sunset for locations east and west of the time (standard) meridian. Do not interpolate times for different latitudes or different dates. Use the times for the closest date and closest latitude.

I-1.3.7. Height of Tide. Height of tide is a measure of the difference between high water or low water and mean low water (or mean lower low if mean lower low is datum) at various reference stations. The time and extent of high and low waters at many subordinate stations can be found from table 2. Table 3 allows the navigator to determine the height of tide at specific times at the subordinate stations. Note that plus time differences mean that events occur later than the reference station and plus height differences mean the height of tide is higher than at the reference station. Note also that asterisks in table 2 mean ratios; that is, the reference station value is multiplied by the asterisked number to determine the subordinate station value. Tide tables worksheets have been provided in this text to guide you through the step-by-step procedures needed to determine height of tide at any time.

I-1.4. First Leg of the Exercise

On 5 April you intend to depart your marina in New Bedford for Dutch Island Harbor, Conanicut Island. After conducting some personal business you will head for Tarpaulin Cove in Vineyard Sound where you plan to anchor for the night. Your vessel is a 46 ft twin engine trawler yacht, the Helena, call sign: Coast Guard Auxiliary Vessel 46143.

Daylight Savings Time is in effect. You plan to pass under the Acushnet River Bridge (between the two islands) at sunrise, 5 April. You want to follow the indicated channel to green buoy “11”, marked by a green light flashing at four second intervals. Upon reaching G “11” you intend to leave the channel and head south direct to R “8” Fl R 4sec GONG. You would like to hold your speed to 5 kts while in the narrow channel to G “11”.

You are equipped with radar, LORAN, a high-quality hand-bearing compass, and you have a pelorus to determine relative bearings. Variation for the whole area of the cruise is 15°00' W.

1. What time is sunrise in New Bedford?

   a. 0653
   b. 0521
   c. 0619
   d. 0553

2. What is the height of the tide at sunrise?

   a. 2.9 ft
   b. 1.0 ft
   c. 4.3 ft
   d. -0.4 ft

3. You find you cannot hold speed to 5 kts using both engines so you opt for a synchronized 1600 rpm power setting. This results in a speed of:

   a. 5.7 kts
   b. 6.0 kts
   c. 6.4 kts
   d. 5.4 kts

4. You pass under the bridge behind schedule at 0700 at a steady speed of 6.0 kts. What is your 0730 dead reckoning position and what is your ETA at G "11"?

   a. 40° 35.7' N, 70° 53.3' W, 0733
   b. 41° 35.7' N, 70° 53.3' W, 0733
   c. 40° 35.7' N, 71° 53.3' W, 0731
   d. 40° 35.7' N, 71° 53.3' W, 0735

5. You depart G "11" at 0735 with both throttles set to 1950 rpm. What is your speed?

   a. 7.4 kts
   b. 9.0 kts
   c. 7.7 kts
   d. 8.7 kts

6. What compass course do you steer for R “8”?

a. 188°
b. 198°
c. 158°
d. 210°

7. At 9 kts, how far is your 0800 DR position from G “11” and where is it?

a. 3.75 M, 40° 31.7' N, 70° 53.4' W
b. 4.50 M, 40° 31.0' N, 70° 53.4' W
c. 4.50 M, 41° 31.0' N, 70° 53.4' W
d. 3.75 M, 41° 31.6' N, 70° 53.4' W

8. What is your ETA at R “8”?

a. 0813
b. 0818
c. 0823
d. 0828

9. At 0759 you take a bearing on the tower on West Island, reading 054° directly off your hand-bearing compass. What is your estimated position?

a. 41° 32.1' N, 70° 53.5' W
b. 40° 31.6' N, 70° 53.0' W
c. 41° 31.8' N, 70° 52.8' W
d. 41° 31.6' N, 70° 53.0' W

10. At 0809 you spot the windmill near Round Hill Point and measure its relative bearing to be 122°. You cross check your steering compass and find that your heading at that moment is 214°C. What is your position and what kind of position is it?

a. 41° 30.0' N, 70° 52.2' W, RFIX
b. 41° 30.4' N, 70° 53.8' W, MLP
c. 41° 30.4' N, 70° 53.8' W, FIX
d. 41° 30.3' N, 70° 53.0’ W, RFIX

11. What is your new course to R “8”?

a. 188°
b. 197°
c. 174°
d. 224°

12. What time will you arrive at R “8”, maintaining your 9 kt speed?

a. 0827
b. 0818
c. 0814
d. 0823

It is important to note that the time between observations in your running fix problem was only 10 minutes, yet you would have been almost a mile off your destination buoy had you made one of the common errors with the first LOP, then done everything else correctly. In low visibility conditions, one mile off is the same as being lost. You should be able to see that a simple small error can be compounded into a real problem.

Subsequent sections will reinforce what you have learned in this chapter, while introducing you to new, and sometimes increasingly complex situations. You will have the opportunity to explore new techniques and procedures for handling them.

I-2. Section II. Second Leg of the Cruise

I-2.1. Lessons Learned on the First Leg. Several important points were made in Section I, some of which you will encounter again, in this and subsequent chapters. They include:

* In using the tables for sunrise and sunset, tides, and currents, do not interpolate. Use the position or value in the table that's closest to your own.

* When using a hand bearing compass, do not apply deviation.

* A line of position (LOP) represents a line that you are on, somewhere. You can't be anywhere except on that line.

* In determining your estimated position with only one LOP, you must first figure out where you should have been if there were no outside influences (current) at work. That is, you must determine the DR position that corresponds to the time you established your LOP (if you sight an object at 0810, where should you have been on your course line at 0810, knowing your speed and the time from your last known position (LKP)?).

* Your estimated position is the point on the LOP closest to your DR position. This is found by dropping a perpendicular from the DR position plot to the LOP. Dropping a perpendicular means that the line from the DR position to the LOP intersects the LOP at a 90° (right) angle.

* You must determine your heading at the time you take a relative bearing on an object.

* Running fixes are established by advancing the original LOP in the direction of travel for a distance equal to that traveled by the vessel between sights. That is, if you sight the second object, or the same object a second time, 10 minutes after the first sighting while on course 200° at a speed of 9 kts, you advance the first LOP 1.5 M in the direction of travel (200°) and redraw it parallel to itself (1.5 M = (10 m x 9 kts)/60 = 90/60). The intersection of the redrawn first LOP with the second LOP is the running fix without regard for current.

* The most important point to remember is that navigational errors are carried through until a positive fix can be established. The errors may be compounded. Whether compound or not, they can lead you into danger when you thought you were safe, and they can cause you to be lost when it's most important that you know where you are.

I-2.2. Review of Basic and More Advanced Piloting.

I-2.2.1. Ranges. A range is formed whenever two charted objects line up. Since the range is defined by the charted objects, it's not necessary to identify the range by bearing. Regardless, the range is a LOP if the vessel happens to be on it. It is used in determining EPs, fixes, and running fixes, just as any other LOP is used.

I-2.2.2. Electronic and Radar Fixes. Fixes can also be determined using two LORAN time differences when the area chart in use has a LORAN overlay printed on it. Fixes can be established using a radar bearing and distance to a charted object. The distance reading on the Plan Position Indicator (PPI) scope of the radar provides a circle of position that the vessel has to be on while the direction reading provides a relative bearing to the object. As in any other case where relative bearings are used, the LOP is defined by adding the radar bearing to the vessel's true heading at the instant at which the radar sighting is made. Since the vessel has to be on the circle of position and on the line of position, the fix is established where the two cross or, in the case of radar, at the point defined by measuring from the sighted object (on the chart) down the plotted LOP the distance read off the rarar range scale.

A reminder: LORAN is electronic or radio navigation based on the difference in time for pulsed signals to reach the receiver; RADAR is sophisticated piloting. It's accomplished electronically, but it is piloting, nevertheless.

I-2.2.3. Magnetic Fields and Deviation and Variation. If a vessel had no magnetic field of its own, the readings on the steering compass would correspond to charted headings, courses, or bearings when corrected for variation; that is, when converted to magnetic. Vessels do have magnetic fields and they act on the compasses (see the discussion of variation and deviation in Chapter 2). When the vessel is headed toward a charted object, the steering compass will normally read a few degrees off of the plotted heading. The difference is the vessel's deviation for that particular heading. If the compass reads more than the plotted heading, the deviation is west, if less, east.

I-2.3. Second Leg of the Cruise Problem

I-2.3.1. The Situation. Section I took us to R "8". Section II continues the cruise from that point WSW to buoy "1" ISO G 6sec. At 0816 you round R "8" and set a new course for "1" ISO, maintaining your speed of 9 kts.

I-2.3.2. The Exercise (Continued).

13. What is your new course?

a. 239°
b. 254°
c. 259°
d. 244°

14. What is your ETA at “1” ISO?

a. 0848
b. 0854
c. 0904
d. 0907

15. You decide to let your LORAN help you navigate so you set up “1” ISO as a waypoint. You select 9960-W and 9960-Y as your secondaries in the Northeast US 9960 chain. What time differences do you set into your LORAN?

a. 9960-W-43946.9 μsec, 9960-Y-14289.0 μsec
b. 9960-W-14288.8 μsec, 9960-Y-43946.9 μsec
c. 9960-W-14294.0 μsec, 9960-Y-43946.9 μsec
d. 9960-W-43947.0 μsec, 9960-Y-14294.0 μsec

16. At 0838 you notice you are exactly on the range formed by the tower on Gooseberry Neck and the tank at Acoaxet. What is your estimated position?

a. 41° 27.0' N, 70° 57.4' W
b. 41° 27.2' N, 70° 57.7' W
c. 41° 27.0' N, 71° 57.4' W
d. 41° 27.1' N, 70° 57.9' W

17. At 0848 you sight Buzzards Light bearing 231°M. What is your position?

a. 41° 26.6' N, 70° 59.4' W
b. 41° 26.7' N, 70° 59.8' W
c. 41° 27.5' N, 70° 58.4' W
d. 41° 27.1' N, 70° 58.9' W

You arrive at “1” ISO at 0904. You decide to stay there to check your navigation equipment. You take bearings of 359° on the tower on Gooseberry Neck and 104° on the monument on Cuttyhunk Island.

18. Is “1” ISO on station? Regardless, what kind of position was defined by the two LOP?

a. Yes, EP
b. Yes, MLP
c. No, FIX
d. Yes, FIX

19. You turn your vessel to sight the Gooseberry Neck tower over the steering compass lubber’s line and read 011°. What is your deviation?

a. 12° W
b. 3° E
c. 12° E
d. 3° W

20. Still holding a heading toward the Gooseberry Neck tower, what should your radar show as the bearing of the abandoned lighthouse off Sakonnet Point?

a. 280°
b. 295°M
c. 294°C
d. 281°R

21. What will the radar show the distance to the lighthouse to be?

a. 7.3 M
b. 7.6 M
c. 7.9 M
d. 8.2 M

22. The radar showed the correct range and bearing to the lighthouse. Does this establish your position? If so, what kind?

b. No
a. Yes, MLP
c. Yes, FIX
d. Yes, EP

This chapter has given you more practice in determining DR positions, estimated positions, running fixes, plus radar fixes.. You have also been introduced to LORAN fixes using time difference overlays.

I-3. Section III. Third Leg of the Cruise Exercise

I-3.1. Review. Section II took you from R “8” to “1” ISO where you checked your navigation equipment and got a feel for LORAN and radar as well as a taste of one method of determining compass deviation. The cruise continues to the west to a DR turning point, then south of west across Rhode Island Sound.

I-3.2. Review of Advanced Piloting.

I-3.2.1. Running Fixes With Turns. Running fixes are determined by advancing an early LOP to intersect a later LOP. Sometimes it’s necessary to change course one or more times between the two sightings. The principles involved are unchanged. The navigator still must advance the first LOP in the direction of travel for a distance equivalent to that traveled by the vessel in the time between sightings. If turns are involved, you can plot the distance traveled from the first LOP to the turn in the direction of travel. The plot is continued in the new direction for the distance traveled between the turn and the second sighting or the next turn, whichever occurs. This has the effect of determining the course made good (the straight line direction between the DR position at the time of the first LOP and the DR position at the time of the second LOP) for a distance made good (the straight line distance between the two positions). Note that the distance made good is not the distance traveled; that is, it is not a distance equal to the time traveled at the speed of travel. This can be done on a maneuvering board, plotting all the maneuvers, determining the resultant, and plotting it on the chart. This helps to keep from cluttering up the chart. The first LOP is redrawn parallel to itself through the point determined by the plot. The RFIX is where the redrawn first LOP intersects the second LOP.

I-3.2.2. Danger Bearings. Danger bearings are determined to help the vessel avoid dangerous areas. The danger can be rocks, shoals, or crab pots and anything in between. The requirements for danger bearings are simple. You must know what you want to avoid (and be able to locate it on the chart), and you must determine a reference object. A line is drawn on the chart from the reference object along the edge of the dangerous area. The mental process required to properly define and use a danger bearing is simple. Forget the plots. Assume the vessel is anywhere on the chart sailing towards the reference object. Is the vessel headed for the dangerous area? If yes, is the heading greater than or smaller than the bearing of the line plotted to define the area? If the heading is less than the bearing of the plotted line the line is defined as NLT (not less than) the bearing of the plotted line. Assume the plotted line defining the area bears 270° toward the reference object and your heading through the danger area to the reference object is 250°. The danger bearing is NLT 270°. If the reference object bears 275° over the bow, the vessel is headed for safe water.

I-3.3. Radar. Radar, though still relatively expensive, has come down so far in price that it is appearing on more and more small craft. It is within the reach of many Auxiliarists and the fundamentals of its use must be understood by the Navigation Specialist.

I-3.3.1. Collision Avoidance. The most important consideration in the use of radar, besides its use in piloting, is collision avoidance. The Navigation Rules require its use, when available, during conditions of reduced visibility. Radar information is displayed on a Plan Position Indicator, commonly referred to as a PPI scope. The vessel is at the center of the scope; all bearings are relative, 000° on the scope represents dead ahead. Most of the navigator's work is done on a maneuvering board. THE BOARD DOES NOT REPRODUCE THE PPI SCOPE DISPLAY. Plots on the maneuvering board are true plots. The primary concern of the operator is relative motion. What direction is the target moving relative to your vessel, and at what speed? What will the closest point of approach (CPA) be and when will it occur?

I-3.3.2. Maneuvering Board. The maneuvering board can also be used, in conjunction with the PPI scope display, to determine the true course and speed of a target. To determine relative course, speed, and CPA, convert the sightings (blips on the PPI scope) to true bearings at a distance corresponding to the PPI range scale. Plot the next sighting and the next and however many more are taken, in the same manner on the maneuvering board labeling each with the time of the sighting. Just as your vessel is always at the center of the PPI scope, it is always at the center of the maneuvering board. Connect the blip plots with a straight line. Its direction is the relative (to you) direction in which the target is traveling. Measuring the distance between the first and some later blip plot and dividing by the elapsed time between the first and later plot, will determine the relative speed of the target.

I-3.3.3. Closest Point of Approach. The CPA is the point at which the relative course line passes closest to the center of the board. The distance away is read directly off the board and the time is determined by using the relative speed and the distance to the CPA from the first, last, or other convenient blip plot.

I-3.3.4. True Course and Speed of Target. The true course and speed of the target can be determined through use of an "erm" diagram. This is nothing more or less than a graphic solution to a vector arithmetic problem. Plot your true course from the center of the maneuver board for a distance (magnitude) equal to your speed. Label the origin of the line (at the center of the board) "e." Label the end of the vector "r." At the end of this vector, at "r," plot the relative course of the target for a distance equal to its relative speed (the earlier relative direction plot can be moved over with parallel rules or other navigation aid). Label the end of this vector "m." Connect "e"

and “m.” The direction of vector “em” is the true course of the target. The magnitude of “em” is the true speed of the target.

I-3.3.5. Maneuvering to Avoid Collision. Consider one more thing in using RADAR for collision avoidance. If maneuvering is required to avoid collision or reduce its likelihood, the maneuvers must be large enough to show up on the other vessel’s RADAR (you must assume the other vessel has, and is using RADAR also). All turns must be at least 60° and should be to starboard The convention calls for a right turn and the other vessel has a right to expect your vessel to comply; however, safety of the vessel takes precedence over conventions; that is, turns could be to port.

I-3.4. Third Leg of the Cruise Problem

I-3.4.1 The Situation. You decide to leave “1” ISO at 0930 and practice your coastal navigation for the rest of the trip to Dutch Island Harbor. You decide to head 277° for 30 minutes, then turn towards WOr “ F” BELL where you will intersect the range formed by the two towers on Beavertail Point. You want to avoid Elisha Ledge and you do not want to pass over the unexploded depth charge at 41° 23.4' N, 71° 20.4' W. You continue to cruise at 9 kts.

I-3.4.2. The Exercise Continued.

23. What is your 1000 DR turning point?

    a. 41° 26.5' N, 70° 08.2' W
    b. 40° 26.5' N, 71° 08.2' W
    c. 40° 26.5' N, 70° 08.2' W
    d. 41° 26.5' N, 71° 08.2' W

24. What is your ETA at WOr “F”?

    a. 1052
    b. 1122
    c. 1152
    d. 1022

At 0950 you check your radar and notice that the green and red buoy C that marks Elisha Ledge, and which should be 2.5 M almost dead ahead (slightly off the starboard bow), does not show up on the scope. You check the NOTAMs and learn that the buoy has been removed for repairs. You also learn that there are some uncharted rocks between the Ledge and Sakonnet Point. Concerned about your proximity to Elisha Ledge, you attempt to establish your position.

25. At 0955, in patchy fog, you observe the tower on Gooseberry Neck bearing 071°M. Nothing else is visible. What is your estimated position?

a. 41° 26.6' N, 71° 07.3' W
b. 41° 26.7' N, 71° 07.0' W
c. 41° 26.4' N, 71° 07.7' W
d. 41° 26.3' N, 71° 07.1' W

26. You recognize that if you continue on course 277° for much longer, you will be standing into danger. How far are you from Elisha Ledge?

a. 1.6 M
b. 1.8 M
c. You don't know
d. You don't know, but no closer than 0.9 M

27. Considering that you do not want to pass over Elisha Ledge or through the waters between it and Sakonnet Point, what is the danger bearing for Elisha Ledge, using the abandoned lighthouse as a reference.

a. No less than (NLT) 288°
b. NLT 280°
c. No more than (NMT) 280°
d. NMT 288°

28. Looking at your EP and your probable distance from the Ledge, you decide to continue on course for four minutes, then turn to your preplanned heading of 254° for WOr "F". At 0959 you make the turn and at 1005 you observe the abandoned lighthouse bearing 308°M. Where does your running fix locate you?

a. 9960-W-25667.7 µsec, 9960-X-14331.3 µsec
b. 9960-W-14331.3 µsec, 9960-X-25667.7 µsec
c. 9960-W-14335.0 µsec, 9960-X-25671.6 µsec
d. 9960-W-14329.5 µsec, 9960-X-43959.7 µsec

29. What is your new course to, and ETA at WOr "F"?

a. 268°, 1116
b. 254°, 1117
c. 253°, 1121
d. 256°, 1126

At 1010, your position from LORAN is 41° 26.1' N, 71° 10.4' W, on course and on time. At 1020, you notice a fast moving blip on radar. You watch this target and plot its movement as follows. Your own heading at each plot time is 253°.

1020	301°R	11.4 M
1030	301°R	7.6 M
1040	302°R	3.8 M

30. What time will the closest point of approach (CPA) occur and how close will it be?

a. 1050, 0.1M
b. 1054, 0.1M
c. 1051, 0.5M
d. 1050, 0.4M

31. What is the true course and speed of the target vessel?

a. 350°, 19.7 kts
b. 014°, 22.8 kts
c. 142°, 18.0 kts
d. 121°, 22.8 kts

Considering that the CPA of the overtaking vessel allows no room for error, you decide to take evasive action. At 1040 you turn 60° to starboard and slow to 6 kts. You plot the change; you will cross the track about 4 M behind the target.

Section III has introduced you to three difficult concepts; danger bearings, turns in the middle of a running fix, and relative motion. Danger bearings should become second nature to you depending on where you operate. Almost all of us have shoal water areas that we want to avoid. On the lower Chesapeake Bay there are areas with heavy concentrations of crab pots. Danger bearings are the surest means of avoiding these and other hazards. We teach running fixes without complications of currents and maneuvers; however, the real world includes those complicating factors and it's necessary to know how to deal with them. As radar becomes more common on Auxiliary vessels, a knowledge of these very basic radar practices will become increasingly valuable to you. Navigation, including coastal piloting, often involves practices and procedures not taught routinely. The Navigation Specialist needs to be comfortable with the unexpected and the unusual.

I-4. Section IV. Fourth Leg of the Cruise Exercise

I-4.1. Situation at End of Third Leg. Section III took you through a turn to avoid a hazard while determining a running fix, followed by identification and avoidance of a moving hazard (a fast moving overtaking vessel). Section IV continues the voyage from a radar fix following your evasive maneuver, on across Rhode Island Sound to the line of white and orange lettered buoys South of Beavertail Point, then North and up the West Passage to Dutch Island Harbor. This chapter brings in two new concepts, distance at which objects can be seen and the various aspects of current sailing.

I-4.2. Review of Visibility of Objects and Current Sailing.

I-4.2.1. Distance at Which Objects Can be Seen. The distance at which an object can be seen is a function of it's height, the height of the observer, the curvature of the Earth, and the visibility. It is also a function of atmospheric conditions. Normal atmospheric condition includes a visibility of 10 nautical miles. Under normal conditions, light rays are *refracted* as they pass through the atmosphere. This refraction results in a slight downward curvature, following the Earth's curvature. The result is that we can see objects slightly over the horizon. The formula for determining the distance at which a light, or an object can be seen, is:

(1) $d = 1.17\sqrt{h}$ where h = the height of the object in feet
d = the distance in nautical miles

or (2) $d = 1.17(\sqrt{h} + \sqrt{h'})$ where h' = the height of eye of the observer

This, (2), is the same equation used to determine the distances in the Geographical Range Table found in COMDTPUB P16502.2, Light List, Volume II, 1992, page xxviii. The distance at which any object or light can be seen is the "d" based on its height plus the "d" resulting from the height of the eye of the observer.

I-4.2.2. Intensity, Location (Height), and Luminous Ranges. Charts and the Light List show the distance at which a light can be seen. This distance is the nominal range and is a function of the intensity of the light. It does not consider the horizon, or curvature of the Earth. Obviously, the curvature of the Earth does affect the distance at which the light can be seen. You must determine the geographic distance, using the second equation, above. If the nominal range is greater than the geographic range, the geographic range is the limit. That's all the further the light can be seen because of the Earth's curvature. If the nominal range is less than the geographic range, then it is the limit. That's all the further the light can be seen because of its intensity. Remember the luminous range. Atmospheric visibility conditions can dramatically increase or decrease the distance at which a light can be seen.

I-4.3. Current Sailing. Current is usually thought of as movement of water. This is true, but current has a second meaning of importance to you, the navigator. As dead reckoning is the projection of a last known position by direction and distance without regard for current, the force that causes your vessel to be other than where you predicted it to be **is** current. In this sense, current is everything that combines to cause your vessel to be elsewhere. This includes movement of the water, leeway, steering errors, fouled bottoms, and anything else that influences the location of the vessel. It is this meaning of current that applies to piloting.

I-4.3.1. Vector Arithmetic. Current problems are solved through vector arithmetic and are best done graphically on a maneuvering board. This helps keep your chart free of clutter and allows for diagrams of convenient size. In doing vector arithmetic it's important to remember that every vector has a magnitude and a direction. In current problems the magnitude is speed. Every vector has a head and a tail. The tail is at the origin of the vector; the head is the arrow head indicating the magnitude. In solving current problems we have three kinds of vectors: the course vector, the track vector, and the current vector. Knowing any two, you can solve for the third. Track is your intended path through the water before you set out and your actual path through the water after you have completed the passage. Because current problems do not normally include turns your actual track is also your course made good (CMG). Course is what you intend to steer or did steer. Your speed through the water (speed at which you intend to, or do run on your course or speed at which you intend to follow your track is the speed of advance (SOA). The actual speed of travel along your actual track is the speed over the ground. Speed made good (SMG) is the straight line distance from your LKP to your present position divided by the total time it took to go from one to the other. Current vectors can be drawn to or from either end of the course or track vector; however, for the sake of simplicity this discussion will consider them to be drawn to or from the head only. There is one exception to this rule which will be discussed later. There are several aspects of current and its effects that you must be familiar with:

1. You are not where you expected to be (DR position). Why not?

2. You want to follow a specific track and make good a certain speed in the face of an anticipated current. What course must you steer and what is your SOA to fulfill your desires?

3. You want to steer a certain course and run at a specific speed through the water, letting an anticipated current carry you where it will. What is your track and SMG?

4. You want to follow a specific track and make good a specific speed, compensating for an anticipated current. You establish a fix off the track. What was the actual current encountered? What was your actual CMG and SMG?

5. You want to follow a specific track at a specified speed through the water. What course must you steer and what is your anticipated SOA along the track line (in this case, anticipated SOA is used rather than anticipated SMG because SMG refers to actual speed over the ground. As long as it is anticipated, it is considered SOA)?

6. You plan a voyage from A to B, laying out a desired track and plotting DR positions for every thirty minutes on the half hour. You anticipate a current and steer a course at a speed intended to compensate for it. Does your DR plot change? If so, how?

I-4.3.2. Fair and Foul Currents. It is easier to grasp current problems if you think in terms of fair or foul currents. A fair current is one that gives you a boost, no matter how slight; a foul current slows you down, no matter how slightly.

I-4.3.3. Fix Not at DR Position. In situation 1, you are at a fix that is different from your DR position for that time. Current is the cause. The direction from your DR position to your fix is the set, or direction, of the current. The distance from your DR position to your fix, divided by the time from your LKP to the fix is the drift, or speed, of the current.

I-4.3.4 Course to Steer to Follow Desired Track. In situation 2, the current tends to move you away from your track so you must steer into the current (crab) to compensate. The current vector is drawn <u>to</u> the head of the track vector; That is, the anticipated current vector is drawn in the direction of its set with a magnitude equal to its drift (this much is true of every current vector) so that the head of the current vector meets the head of the track vector. The course vector is drawn from the tail of the track vector (origin, or center, of the maneuvering board) to the tail of the current vector. Its direction is the course that must be steered and its magnitude (length) is the speed which must be maintained to allow the vessel to follow the intended track at the desired SOA. If the current is fair, the SOA is less than the desired speed along the track; if foul, it is greater.

I-4.3.5. Hold Course and Speed in the Face of the Current. In situation 3, the current will move you off the track in the direction of the set for a distance appropriate to the drift over the time involved. The anticipated current vector is drawn <u>from</u> the head of the course vector. The track vector is drawn from the tail of the course vector (origin of the maneuvering board) to the head of the current vector. The direction of the track vector is the expected track (CMG) of the vessel, the magnitude is the expected SMG. Once again, a foul current will slow you down; a fair current will speed you up.

I-4.3.6. Inability to Track as Desired After Compensating for Current. Situation 4 is one that trips up many navigators. You want to follow a specific track at a prescribed speed, compensating for a reported current. You set up your current diagram as in situation 2, and steer the indicated course at the indicated speed. If the anticipated current is an actual current you will follow the track line at the desired speed. A fix determines that you are off the track line. A dead reckoning position, corresponding to the time of the fix is established on the course vector. The actual current encountered is represented by the vector between this DR position and the fix. The CMG and SMG are determined from the actual track vector (origin to the fix).

I-4.3.7. Track at Specified Turns (Speed Through the Water). Situation 5 is the exception wherein the current vector is drawn from the tail of the track vector. In this case, the track vector is drawn in direction only, since the magnitude (SOA) is not known. The current vector is drawn from the tail of the track vector; that is, it originates at the origin of the maneuver board, also. An arc with radius equal to the actual speed through the water, centered at the head of the current vector, is struck across the track vector. The course vector is drawn from the head of the current vector to the intersection of the arc with the track vector. The course which must be steered is indicated by the direction of this vector and the speed along the track line is indicated by the now defined magnitude of the track vector.

I-4.3.8. Revised DR Plot Based on Current Compensating Course and Speed. Situation 6 is a special case. The desired track is drawn and dead reckoning positions plotted on the chart. You decide to compensate for a reported current and determine a course to speed and a speed to run. A new DR plot is made on the course being steered at the SOA. Remember, DR plots ignore current. Your plot represents what you are doing (steering a course), not what you want to do (following a track).

I-4.4. Fourth Leg of the Cruise Problem.

I-4.4.1. The Situation Updated. Following your evasive maneuver to avoid the fast mover you are heading away from your pre-planned course to WOr “F” at 6 kts. At 1100 you fix your position using RADAR ranges to the cupola on Brenton Point (4.8 M) and the WADK transmitter tower (4.0 M). You confirm your fix with a LORAN position of 41° 25.9' N, 71° 15.1' W. You turn to intercept the Beavertail Point tower “range” at WOr “G”, instead of WOr “F” as originally planned, resuming your speed of 9 kts.

I-4.4.2. The Exercise Continued

32. What is the compass course to WOr “G”?

a. 251°C
b. 266°C
c. 281°C
d. 221°C

33. What is the ETA at WOr “G”?

a. 1147
b. 1210
c. 1150
d. 1206

34. Where will Helena be when the bow lookout (height of eye 8 ft) sights Point Judith Neck Light, which is on because visibility is limited to 5.5 miles? Disregard the effects of current?

a. 41° 26.7' N, 71° 10.2' W
b. 41° 25.4' N, 71° 17.1' W
c. 41° 25.5' N, 71° 16.5' W
d. Can be seen from the 1100 fix

35. What time should you sight the light?

a. 1107
b. 1132
c. 1100
d. 1010

36. At 1142, while heading 252°, you sight Brenton Reef Light bearing 083° relative, and Pt. Judith Light bearing 355° relative. What is your position?

a. 41° 21.2' N, 71° 22.3' W
b. 41° 24.0' N, 71° 22.5' W
c. 40° 24.0' N, 71° 22.5' W
d. 41° 23.8' N, 71° 22.2' W

37. What was your course made good (CMG) and you speed made good (SMG)?

a. 263°, 8.3 kts
b. 248°, 9.0 kts
c. 261°, 9.0 kts
d. 248°, 8.3 kts

38. What is the total current that moved you off course?

a. 112° set, 1.0 kts drift
b. 1.0 kts set, 112° drift
c. 292° set, 1.0 kts drift
d. 1.0 kts set, 292° drift

39. What is your new course to WOr “G”?

a. 281°
b. 287°
c. 251°
d. 266°

40. Considering the current, what true course must you steer at 9 kts in order to maintain the desired track to WOr “G”?

a. 269°
b. 285°
c. 245°
d. 266°

41. What is your new ETA at WOr “G”?

a. 1152
b. 1149
c. 1147
d. 1155

42. You cross the Beavertail Point towers “range” at 1155 with the tank on Pt. Judith Neck bearing 269°. What actual current did you encounter?

a. 115° set, 3.6 kts drift
b. 3.6 kts set, 115° drift
c. 295° set, 3.6 kts drift
d. 3.6 kts set, 295° drift

43. At 1155 you turn north on the “range”. You wish to track the range with a speed of advance (SOA) of 9 kts. What true course must you steer, and at what speed to do this?

a. 024°, 8.2 kts
b. 343°, 6.8 kts
c. 343°, 11.9 kts
d. 339°, 6.8 kts

44. You decide to turn to go up the West Passage when the spire north of The Bonnet bears 345° true. What will the relative bearing of the spire be when you reach the turning point?

a. 343°R
b. 321°R
c. 002°R
d. 017°R

45. What is your ETA at the turning point?

a. 1205
b. 1201
c. 1209
d. 1212

You reach your turning point on schedule, make the turn, and proceed on to Dutch Island Harbor. You are moored and shut down at 1300.

This section introduced the range at which a light can be detected as a function of its height, the height above water of the observer, the curvature of the Earth, and the nominal range in conditions of other than normal visibility. It also introduced current sailing. You identified currents working on your vessel, determined courses to steer under varying speed conditions (maintaining a speed through the water or a speed of advance), and determined actual currents when allowing for assumed currents. Since current will be working on your vessel just about anytime you sail, it is important that you understand them, know how they affect you, and how to counter or compensate for the effects.

I-5. Section V. The Final Leg, The End of the Cruise.

I-5.1. Review of Advanced Piloting, Current Sailing, and Tides and Currents. Section IV dealt primarily with current sailing in its various aspects. Section V concludes the voyage, It covers determination of distance from an object of known height, and application of current sailing and position determination through a running fix under the influence of current. It will also demonstrate that you don't have to have a DR plot to determine a running fix. Finally, this section will introduce the concept of doubling the angle on the bow as a means of determining position and other relationships of interest to the navigator. In Section I you determined height of tide at a given time at a set point. In this section you will determine the depth of the water at a given time and place, as well as current speed and direction.

I-5.1.1. Distance by Vertical Angle. The distance of an observer from an object of known height can be determined with the formula:

$d = h/(6076 \tan ø)$ where d = distance in nautical miles
h = height of the object in feet
ø = measured angle subtended by the object in degrees

The angle, ø, is measured with a sextant and will normally be less than a degree. Regardless, the sextant gives values in degrees and minutes. The minutes are converted to fractional degrees by dividing by 60; for example, 27.2 minutes equals 27.2/60, or 0.45, degrees and 1° 27.2' = 1.45°. This is important because calculators use degrees, not degrees and minutes in determining trigonometric functions, such as tangents. The constant, 6076, is the number of feet in a nautical mile and is the conversion factor that allows the answer to be determined directly in miles. The key to determining distances in this type of problem is that the object sighted must be of <u>known</u> height. The height is often shown on the chart, particularly when the object is a light. When dealing with a light, charted heights indicate the height of the light, not the structure. This means that the measured angle is from the surface of the water to the center of the light housing.

I-5.1.2. Two Advanced Running Fixes.

I-5.1.2.1. Running Fix With Current. This section deals with two more aspects of running fixes. In the first instance you are somewhere south of Sakonnet Point, in Rhode Island Sound, following a known course at a known speed when you take a bearing on a charted object. You know you are somewhere on this LOP, but you don't even have a DR plot to give you an idea of where. You don't need the DR plot unless your estimated position is important to you. In the described conditions it

should not be. You proceed on course, maintaining your speed, and take a bearing on a second object. You know only that you are now on the second LOP, but where? You know a current is running and you have information regarding its set and drift. Advance your first LOP in the direction of travel for a distance equivalent to the time between LOPs at the speed you are running. Then advance the LOP in the direction of the current set for a distance equivalent to its drift over the time between bearings. Redraw your first LOP through this point. Your running fix is where the two LOPs intersect. You have considered current and your running fix is far more accurate than if you had followed what you have practiced up to now and ignored the current.

I-5.1.2.2. Doubling the Angle on the Bow. The final variation of running fixes is a situation wherein you determine your position after doubling the angle on your bow; that is, if you sight an object that bears 22.5° relative, you will have doubled the angle on your bow when it bears 45° relative. The geometry of this condition will provide you an accurate running fix. Consider a 30° - 60° situation. If your first relative bearing is 30° and your second is 60°, you have an isosceles triangle. The 60° bearing is external to the triangle which means the internal angle is 120°. All the angles internal to a triangle total 180°. Your first bearing, 30°, and the 120° internal angle from the second bearing total 150°. The third angle, then, has to be 30°. Whenever you have a triangle with two equal angles, you have an isosceles triangle and the sides opposite the equal angles are also equal. These sides happen to be your course line and the second LOP. This means that when you have determined how far you traveled between the two LOPs (you know your speed and the time between sightings) you will know how far you are from the object on the second LOP. That point is your running fix.

I-5.1.2.3. The 7/10 th and the 7/8 th Rules. Both the 22.5° - 45° and the 30° - 60° triangles have an additional property of help to you. The first invokes the seven tenths rule and the second the seven eighths rule. In the 22.5° - 45° case, the distance from the object when abeam will be 7/10 of the distance traveled between sightings. In the 30° - 60° case, the distance when abeam will be 7/8 the distance traveled between sightings. Running fixes through doubling the angle on the bow can be determined relatively easily if you have a pelorus and can preplan the relative bearings you will use. Set up the pelorus for the first bearing, mark when the object bears, then set up the device for the second bearing, marking when it occurs.

I-5.1.3. Depth of Water. In the first section you determined height of tide at a certain time. In this section you determine depth of water. Charted depths are at datum; that is, mean low or mean lower low water. Height of tide is the height above or below datum. Merely add the two (if below datum the height of tide will be given as a negative value; adding a negative is the same as subtracting).

I-5.1.4. Tidal Currents. Current problems are handled in exactly the same manner as height of tide problems. It is important to remember that the maximum flood occurs about halfway between low and high water as the tide is coming in. Maximum ebb occurs about halfway between high and low water as the tide is going out. Minimum before the flood is slack water at low water and minimum before the ebb is slack water at high water. The reference stations for currents are not the same as the tidal reference stations. All of the tide and current tables provided you contain instructions on their use. These are directly quoted extracts from the tables as printed in the NOAA Tide Tables and Current Tables, 1994.

I-5.2. Final Leg of the Cruise Problem.

I-5.2.1. The Final Situation. The exercise resumes after the conclusion of your business in the Dutch Island Harbor area and rejoins the cruise underway somewhere south of Sakonnet Point in Rhode Island Sound. It will continue into Vineyard Sound and will end when you anchor in Tarpaulin Cove.

I-5.2.2. The Exercise Concluded.

46. You moored at Dutch Island Harbor at 1300. You figure it will take you three and a half hours to make the passage to Tarpaulin Cove. You want to arrive before darkness sets in (30 minutes after sunset). How much time do you have to conduct your business?

a. 1613
b. About 2 3/4 hours
c. About 3 1/4 hours
d. 1943

47. You completed your business and got underway before your time limit had expired. At 1630 you are clear of Brenton Reef Light and into Rhode Island Sound on course 098° at speed 12 kts. At 1658, the abandoned lighthouse off Sakonnet Point bears 037°. At 1728, Buzzards Light bears 067°. Enroute to this sighting you learn that the current in your area is running 153° at a speed of 2.2 kts. What is your position?

a. 41° 21.6' N, 71° 09.1' W
b. 41° 20.5' N, 71° 08.4' W
c. 41° 22.3' N, 71° 06.7' W
d. 41° 20.5' N, 70° 08.4' W

48. At 1745, still holding course 098° and 12 kts, you use your sextant to measure the vertical angle to the top of Buzzards Light. You read 0° 27'. At the same time you see

the monument on Cuttyhunk Island bearing 049° and you observe buoy RB “VS” about 1° to the right of that LOP. What is your position?

a. 41° 21.7' N, 71° 01.8' W
b. 40° 21.7' N, 71° 01.8' W
c. 41° 23.5' N, 70° 59.3' W
d. 41° 23.5' N, 71° 59.3' W

49. At 1855 you sight the 78 ft high light on the southwest edge of Tarpaulin Cove bearing 330° relative (angle on the bow 30° left). Your heading is 056° and speed remains 12 kts. You set your polarus to sight the light when it bears 300° relative (angle on the bow 60° left). At 1904 you sight the light over your preset pelorus. How far are you from the light?

a. 1.5 M
b. 1.8 M
c. 2.1 M
d. 0.9 M

50. What is your position?

a. 41° 26.4' N, 70° 45.3' W
b. 40° 26.4' N, 70° 45.3' W
c. 41° 24.5' N, 70° 45.1' W
d. 41° 24.5' N, 71° 45.1' W

51. When will you be abeam of the light and how far from it?

a. 1903, 1.8 M
b. 1908, 0.9 M
c. 1909, 1.6 M
d. 1912, 1.6 M

You slow to 8 kts while turning to a heading of 337°. You drop anchor at 1922, about 200 yards NE of buoy GR “C”.

52. How deep is the water when you anchor?

a. 16.44 ft
b. 15.5 ft
c. 14.9 ft
d. 17.14 ft

53. How fast, and in what direction is the current running ?

d. 1.2 kts, 055°

54. If you had wanted to anchor when the current was running no faster than 0.5 kts, what time should you have dropped the hook?

a. Between 2200 and 2308
b. Between 2205 and 2313
c. Between 2020 and 2118
d. Between 2136 and 2352

You decide to anchor with the currently running current and secure for a well earned rest. Tomorrow is another day.

This section has further expanded your understanding of running fixes by providing you two more variations on a theme. You were introduced to a running fix under the influence of current and you found that you could predetermine where you would be for the second LOP when doubling the angle on the bow. You also learned that you don't need to plot a course line to find your position. You were exposed to determination of distance from objects using vertical angles, and you were introduced to the means of finding speed and direction of tidal currents. The initial leg of your journey included determination of the time of sunrise and height of tide; the final leg included finding the time of sunset and depth of water.

Every situation on the examination is covered at least once in this cruise exercise; most are treated more than once. The cruise also includes some other situations you probably will encounter in real life.

I-6. Section VI. Summary and Review

The cruise exercise is over. The following questions are intended to serve as a review of what you have learned and practiced in the exercise. If you know the answers to the questions and can translate that knowledge to accurate chart plots, you should have no problem with the examination.

1. When using Table 4, Sunrise and Sunset, in Tide Tables 1994, you

   a. Interpolate for local latitude
   b. Interpolate for the date
   c. Interpolate for both local latitude and date
   d. Do not interpolate

2. Times of sunrise and sunset in Table 4 are for local mean time at the standard meridian for your area. The standard meridian can be found in

   a. Tables 1, 2, and 4
   b. Table 1
   c. Tables 1 and 2
   d. Tables 2 and 4

3. Time corrections to Table 4 are based on the difference between the local meridian and the standard meridian.

   a. Sunrise is earlier if the local meridian is west of the standard meridian.
   b. Sunset is later if the local meridian is east of the standard meridian.
   c. Sunrise is earlier and sunset is later if the local meridian is east of the standard meridian.
   d. Both sunrise and sunset are earlier if the local meridian is east of the standard meridian.

4. Height of tide

   a. Is the same as depth of water at a substation.
   b. Occurs at a substation at the same time as at the reference station.
   c. Tables show high water can be lower than datum.
   d. Is expressed as a ratio when difference in height is asterisked (*) for the substation.

The following statements are true or false:

5. Dead reckoning positions are based on direction and distance traveled from a known position.

6. Distance traveled (Nautical Miles) = {Speed (mph) x Time (minutes)}/60

7. Distance on a chart is best measured using the distance bar graphs in the chart margin.

8. When using the latitude scale to measure distance it is best to use the area of the scale corresponding to the middle of the line being measured.

9. DR plots are identified on the chart by a dot under a semicircle, labeled with the time.

10. Charting convention puts the course above the track line (in degrees True) and the speed (in knots) under the track line.

11. Lines of Position are identified by the direction from the vessel to the object above the LOP (in degrees Magnetic) and the time of the sighting below the LOP.

12. When determining an estimated position, you must

a. Determine a LOP and a DR position corresponding to the time of the LOP.
b. Plot the EP where the single LOP crosses the plotted course line.
c. Draw a line from the DR position to the LOP perpendicular to the course line.
d. Continue the DR plot from the EP.

13. A fix

a. Consists of only two LOPs intersecting.
b. Consists of two or more LOPs or COPs or a combination of LOPs and COPs intersecting.
c. Is a point on one LOP closest to the DR plot on the course line.
d. Is a last resort means of finding location.

14. A fix that does not coincide with a DR plot for the time of the fix indicates

a. Faulty navigation.
b. The existence of current.
c. Compass error.
d. The vessel is standing into danger.

15. When determining a running fix

a. The second LOP is advanced the distance the vessel has traveled between the first and second LOPs, in the direction of travel.
b. Assume no current is running.
c. The first LOP is advanced in a direction perpendicular to its direction for a distance equal to that traveled in the time between the first and second LOPs.
d. The first LOP is advanced, in the direction of travel, the distance the vessel has traveled between the first and second LOPs.

The following statements are true or false.

16. Variation is the angle between the true North Pole and the magnetic North Pole at your location.

17. Variation differs from vessel to vessel in the same general area.

18. Deviation must be taken into account when using a hand bearing compass.

19. The difference between the ship's compass reading on a range of two charted objects and the chart magnetic bearing for the same range is deviation.

20. Deviation varies from vessel to vessel in the same general area.

21. Once established for a range, the deviation on your vessel is constant, while in that area, regardless of heading.

22. Variation is constant on your vessel in a given area, regardless of heading.

23. Radar bearings are magnetic.

24. A radar bearing to an object and the radar distance to the same object constitute a fix.

25. The radar bearings must be converted to True bearings to determine a fix.

26. A radar range (distance to target) defines a circle of position (COP).

27. Danger bearings are of academic interest but have no practical application in near shore coastal navigation.

28. Danger bearings require a reference object to sight on.

29. A danger bearing is expressed as NLT 280°. This means that if you are steering for the reference object on a heading of 275° and turn to 240° you are standing into danger.

30. When using a COP to establish a fix, there is more than one possible location.

31. When using radar you must consider your vessel to be at the center of the screen and 000° on the scope refers to dead ahead.

32. An erm diagram is required to determine the closest point of approach (CPA) of a target.

33. Stationary targets will appear to be moving on the radar screen.

34. If the range to a target is decreasing on the screen, and the bearing to the target is unchanged or nearly so, there is danger of collision.

35. When maneuvering to avoid a collision you may turn in any direction as long as your turn is at least 30°.

36. When plotting relative motion, radar bearings are converted to True bearings on the maneuver board.

37. The radar plot represents the true course and speed of the target.

38. When determining the distance at which an object can be seen, the height of eye is assumed to be 15 ft.

39. The distance at which an object can be seen in nautical miles is 1.17 times the square root of the height of the object in feet.

40. If you allow for current and steer a course so to make good a given track, and find you are still off your track when a fix is taken, you determine the real current from your dead reckoning position on your given track.

41. If you wish to make good a specific speed and track in the face of an expected current, you construct a vector from the origin of the maneuver board in the direction you intend to travel and at a length corresponding to the desired speed. You construct a second vector at the end of the first corresponding to the direction and speed of the current. The vector from the origin to the end (head of the arrow) of the second vector represents the course you must steer and the speed you must attain.

42. If you wish to follow a given track and to maintain your set speed through the water, you construct the current vector from the origin and swing an arc from its end (head) equal in length to your speed. You then construct a vector from the head of the current vector to the point where the arc intersects your track vector. The course you must steer corresponds to the direction of the vector. The speed you will make good is shown by the length of the track vector from the origin to the point of intersection.

43. You must plot your course line and establish DR positions in order to establish a running fix.

44. Running fixes are always established assuming no current.

45. When determining distance using the vertical angle from the surface to the top of the object, the formula is d = h / 6076(tan ø), where d is the distance in nautical miles and h is the height of the object in feet.

46. In the formula in the statement above, 6076 is the number of feet in a nautical mile.

47. An object is sighted 30° off the starboard bow. Fifteen minutes later the object is 60° off the starboard bow. The distance to the object from the first sighting is the same as the distance traveled between the sightings, if the course has been unchanged.

48. Position can be established from doubling the angle on the bow.

49. A position determined by doubling the angle on the bow is a

a. Estimated Position
b. Fix
c. Running Fix
d. Special Position

50. A current reaches its maximum speed

a. At the time of high water.
b. At the time of low water.
c. About half way between high and low water.
d. When the tide is coming in.

51. You depart point A at 0908 on course 184° at speed 9 kts. Point B is 6 M away. What time will you arrive?

52. You depart point B at 1030. Point C is 10 M away at 295°. An island lies between the two points. You maneuver around the island making a series of course changes holding your speed constant at 10 kts. You arrive at point C at 1230. What was your speed made good (SMG)? What was your course made good (CMG)?

53. You are steering 190° according to your steering compass. Variation in your area is 10° W. Your compass deviation card shows deviation to be 2° E at 180° when converting from compass to magnetic and 4° W at 195°. What is your true heading?

54. You are headed 45°C when you sight an object whose relative bearing is 45°. Your deviation card shows compass to magnetic corrections of 4° W at 45°, 7° W at 60°, 3° W at 75°, 1° E at 90°, and 5° E at 105°. Variation is 12°W. What is the true bearing of the object.

55. You sight an object 22.5° off the port bow while traveling 237° at 9 kts. Twenty minutes later the object is 45° off the port bow. Course and speed are unchanged. How far away is the object at the second sighting?

APPENDIX A
TABLES

This appendix contains the following:

Please note that the Tide Tables and the Tidal Current Tables are numbered sequentially in each book and each is identified by its number and title, without identifying the book concerned. The tables in this appendix are extracts of the tables in the books and are identified in the same manner. This is to help Navigation Specialist candidates become familiar with the Tide Tables and Tidal Current Tables. Care must be exercised to ensure that the appropriate table is being used.

TABLE 1. — DAILY TIDE PREDICTION

Newport, R.I., 1994

Times and Heights of High and Low Waters

April

	Time	Height		
	h m	ft	cm	
1	0505	-0.3	-9	**16**
F	1140	3.4	104	
	1711	-0.1	-3	
2	0009	3.9	119	
Sa	0609	0.1	3	
	1242	3.2	101	
	1819	0.2	6	
3	0112	3.6	110	
Su	0728	0.3	9	
	1346	3.2	98	
	1947	0.4	12	
4	0216	3.4	104	
M	0854	0.4	12	
	1448	3.2	98	
	2122	0.4	12	
5	0317	3.4	104	
Tu	1001	0.3	9	
	1546	3.4	104	
	2230	0.3	9	
6	0413	3.4	104	
W	1050	0.2	6	
	1637	3.5	107	
	2320	0.1	3	
7	0502	3.4	104	
Th	1127	0.2	6	
	1723	3.7	113	
	2358	0.0	0	

Time meridian 75° W. 0000 is midnight. 1200 is noon
Heights are referred to mean lower low water which is the chart datum of soundings

TABLE 2. - TIDAL DIFFERENCES AND OTHER CONSTANTS

Time Differences. – To determine the time of high water or low water at any station listed in this table there is given in the columns headed "Differences, Time" the hours and minutes to be added to or subtracted from the time of high or low water at some reference station. A plus (+) sign indicates that the tide at the subordinate station is later than at the reference station and the difference should be added, a minus (-) sign that it is earlier and should be subtracted.

Height Differences. – The height of the tide, referred to the datum of charts, is obtained by means of the height differences or ratios. A plus (+) sign indicates that the difference should be added to the height at the reference station and a minus (-) sign that it should be subtracted.

For some subordinate stations there is given in parentheses a ratio as well as a correction in feet. In those instances, each predicted high and low water at the reference station should first be multiplied by the ratio and then the correction in feet is added to or subtracted from each product as indicated. (In some instances, only a ratio is given, indicated by an asterisk (*). In those instances the height at the reference station is multiplied by the ratio to obtain the height at the subordinate station).

TABLE 2. - TIDAL DIFFERENCES AND OTHER CONSTANTS

NO.	PLACE	POSITION Lat.		Long.		DIFFERENCES Time High Water		Low Water		Height High Water	Low Water
		°	'	°	'	h.	m.	h.	m.	ft	ft
	Vineyard Sound					on NEWPORT, p. 40					
	Woods Hole, Little										
1087	Harbor.....	41	31	70	40	+0	32	+2	21	*0.40	*0.40
1093	Tarpaulin Cove.....	41	28	70	46	+0	11	+1	23	*0.54	*0.54
	Buzzards Bay										
1133	New Bedford.....	41	38	70	55	+0	07	+0	07	*1.05	*1.05

TABLE 3. – HEIGHT OF TIDE AT ANY TIME

Time from the nearest high water or low water

Duration of Rise and Fall	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.
	4	**20**	1	18	1	27	1	35	1	44	1	53	2	01	2	10
	4	**40**	1	24	1	33	1	43	1	52	2	01	2	11	2	20
	5	**00**	1	30	1	40	1	50	2	00	2	10	2	20	2	30
	5	**20**	1	36	1	47	1	57	2	08	2	19	2	29	2	40
	5	**40**	1	42	1	53	2	05	2	16	2	27	2	39	2	50
	6	**00**	1	48	2	00	2	12	2	24	2	36	2	48	3	00
	6	**20**	1	54	2	07	2	19	2	32	2	45	2	57	3	10
	6	**40**	2	00	2	13	2	27	2	40	2	53	3	07	3	20
	7	**00**	2	06	2	20	2	34	2	48	3	02	3	16	3	30
	8	**00**	2	24	2	40	2	56	3	12	3	26	3	44	4	00

Correction to height

Range of Tide	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
	1.5	0.3	0. 4	0.4	0. 5	0. 6	0. 7	0.
	2.0	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	2.5	0.5	0.6	0.7	0.9	1.0	1.1	1.2
	3.0	0.6	0.8	0.9	1.0	1.2	1.3	1.5
	3.5	0.7	0.9	1.0	1.2	1.4	1.6	1.8
	4.0	0.8	1.0	1.2	1.4	1.6	1.8	2.0
	4.5	0.9	1.1	1.3	1.6	1.8	2.0	2.2
	5.0	1.0	1.2	1.5	1.7	2.0	2.2	2.5
	5.5	1.1	1.4	1.6	1.9	2.2	2.5	2.8

Obtain from the predictions the high and low water, one of which is before and one after the time for which the height is required. The difference between the times of occurrence of these tides is the duration of rise or fall, and the difference between their heights is the range of tide for the above table. Find the difference between the nearest high or low water and the time for which the height is required.

Enter the table with the duration of rise or fall, printed in heavy face type, which most nearly agrees with the actual value, and on that horizontal line find the time from the nearest high or low water which agrees most nearly with the corresponding actual difference. The correction sought is in the column directly below, on the line with the range of tide.

When the nearest tide is high water, subtract the correction.

When the nearest tide is low water, add the correction.

TABLE 4. - SUNRISE AND SUNSET, 1994

Date		40° N				42° N				44° N			
		Rise		Set		Rise		Set		Rise		Set	
		h.	m.	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.
	27	05	53	18	19	05	52	18	20	05	51	18	20
Apr.	1	05	45	18	24	05	43	18	25	05	42	18	27
	6	05	37	18	29	05	35	18	31	05	33	18	33
	11	05	29	18	34	05	27	18	36	05	24	18	39
	16	05	21	18	39	05	19	18	42	05	16	18	45
	21	05	14	18	44	05	11	18	47	05	08	18	51
	26	05	07	18	49	05	03	18	53	05	00	18	57
May	1	05	01	18	54	04	56	18	58	04	52	19	03

Local mean time. To obtain standard time of rise or set, see table 5.

TABLE 5. – REDUCTION OF LOCAL MEAN TIME TO 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
° ' ° '	minutes	° ' °
2 38 to 2 52	11	10 00
2 53 to 3 07	12	10 23 t
3 08 to 3 22	13	10 38 t
3 23 to 3 37	14	10 53
3 38 to 3 52	15	11 0
3 53 to 4 07	16	11
4 08 to 4 22	17	
4 23 to 4 37	18	
4 38 to 4 52	19	12
4 53 to 5 07	20	12 2
5 08 to 5 22	21	12 3
5 23 to 5 37	22	12

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 greater .....

TABLE 1. - DAILY CURRENT PREDICTIONS

POLLOCK RIP CHANNEL, MASSACHUSETTS, 1994

F - Flood, Dir. 035° True E - Ebb, Dir. 225° True

APRIL

Day	Slack h. m.	Maximum h. m.	knots
1	0033	0315	2.0E
F	0627	0949	2.2F
	1314	1551	1.8E
	1905	2220	1.8F
2	0133	0414	1.8E
Sa	0728	1059	2.0F
	1418	1656	1.6E
	2010	2335	1.7F
3	0238	0521	1.6E
Su	0834	1216	1.9F
	1525	1810	1.5E
	2121		
4		0054	1.7F
M	0346	0636	1.5E
	0945	1331	1.9F
	1633	1928	1.5E
	2232		
5		0206	1.7F
Tu	0454	0753	1.5E
	1054	1438	2.0F
	1737	2039	1.5E
	2338		
6		0309	1.8F
M	0557	0901	1.6E
	1158	1536	2.1F
	1834	2138	1.6E

Time meridian is 75° W. 0000 is midnight. 1200 is noon.

TABLE 2. - CURRENT DIFFERENCES AND OTHER CONSTANTS

NO.	PLACE	POSITION Lat.	POSITION Long.	TIME DIFFERENCES Min before Flood	TIME DIFFERENCES Flood	TIME DIFFERENCES Min. before Ebb	TIME DIFFERENCES Ebb	SPEED RATIOS Flood		SPEED RATIOS Ebb	
		° ' N	° ' W	h m	h m	h m	h m				
	VINEYARD SOUND Time meridian, 75°W			on POLLOCK RIP CHANNEL, pg 28							
1946	Tarpaulin Cove, 1.5 miles east of.....	41 28.3	70 43.5	+2 49	+2 07	+2 12	+2 33	1.0	055°	1.4	232°
	BUZZARDS BAY <7>										
2106	New Bedford Harbor and approaches			Current weak and variable							
2116	West Island, 1 mile southeast of.....	41 34.0	70 48.6	-0 43	-0 43	-1 28	-1 42	0.4	079°	0.5	203°
	NARRAGANSET BAY <8>										
2211	Brenton Point, 1.4 n.mi. southwest	41 25.9	71 22.6	-1 03	-0 38	-1 20	-1 04	0.2	347°	0.4	170°

TABLE 3. – SPEED OF CURRENT AT ANY TIME

TABLE A

Interval between slack and maximum current

Interval between slack and desired time	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.	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*	*f.*
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 40	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	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
1 20	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4
1 40	—	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5
2 00	—	—	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6
2 20	—	—	—	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7
2 40	—	—	—	—	1.0	1.0	1.0	0.9	0.9	0.8	0.8
3 00	—	—	—	—	—	1.0	1.0	1.0	0.9	0.9	0.8
3 20	—	—	—	—	—	—	1.0	1.0	1.0	0.9	0.9
3 40	—	—	—	—	—	—	—	1.0	1.0	1.0	0.9
4 00	—	—	—	—	—	—	—	—	1.0	1.0	1.
4 20	—	—	—	—	—	—	—	—	—	1.0	1.0
4 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 4. — DURATION OF SLACK

The predicted times of slack water given in this publication indicate the instant of zero speed, which is only momentary. There is a period each side of slack water; however, during which the current is so weak that for practicable purposes it may be considered negligible.

The following tables give, for various maximum currents, the approximate period of time during which weak currents not exceeding 0.1 to 0.5 knot will be encountered. This duration includes the last of the flood or ebb and the beginning of the following ebb or flood, that is, half of the duration will be before and half after the time of slack water.

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 places 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 of not more than*				
	0.1 knots	*0.2 knots*	*0.3 knots*	*0.4 knots*	*0.5 knots*
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

(NOTE: TABLE B NOT USED SINCE NO EXERCISES REQUIRE IT).

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 5. ROTARY TIDAL CURRENTS

Gooseberry Neck, 2 miles SSE of
Buzzards Bay entrance
Lat 41° 27' N, Long 71° 01' W

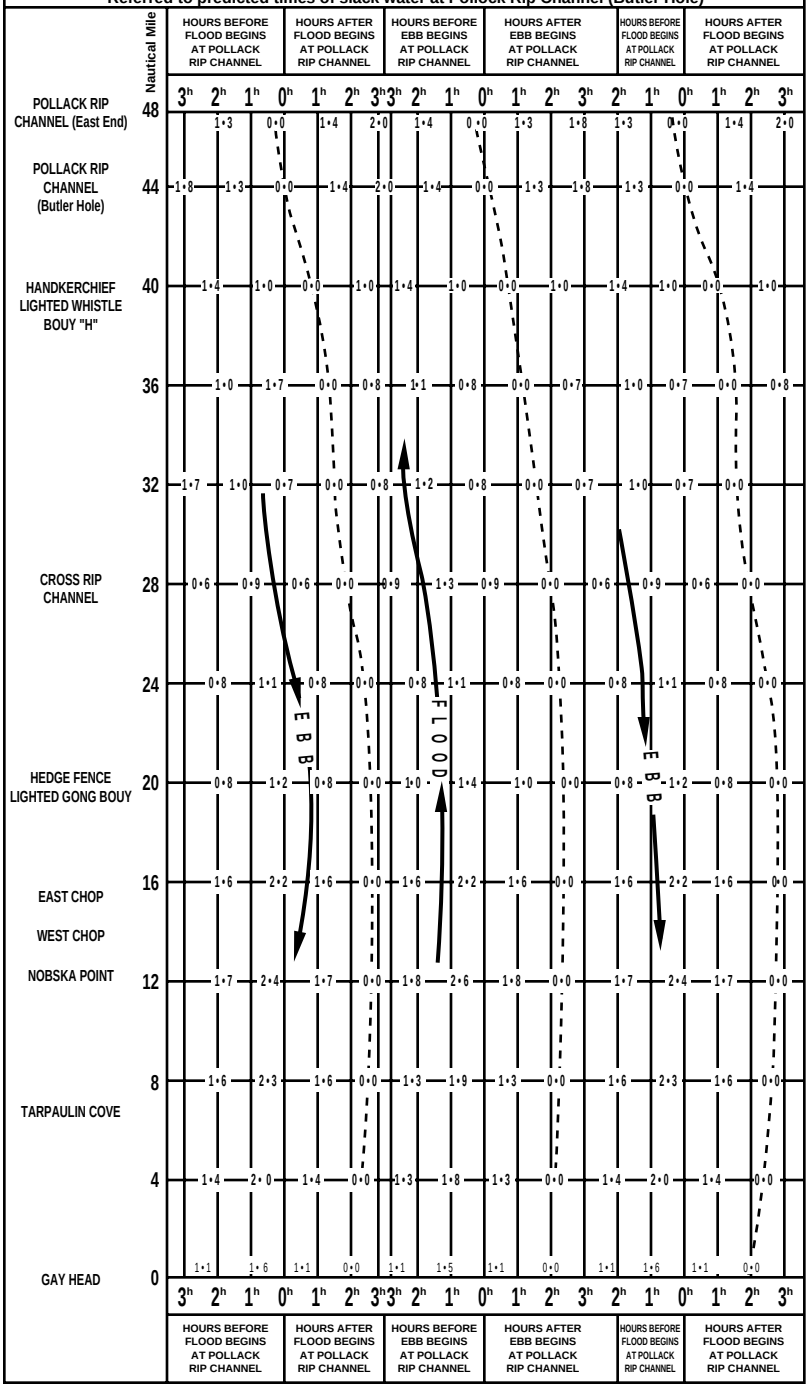
	Time	Direction (true)	Velocity
		Degrees	Knots
	0	52	0.6
Hours	1	65	0.4
after	2	108	0.2
maximum	3	168	0.3
flood	4	210	0.4
Pollock Rip	5	223	0.5
Channel	6	232	0.5
see page 28	7	249	0.3
	8	274	0.2
	9	321	0.2
	10	16	0.3
	11	38	0.5

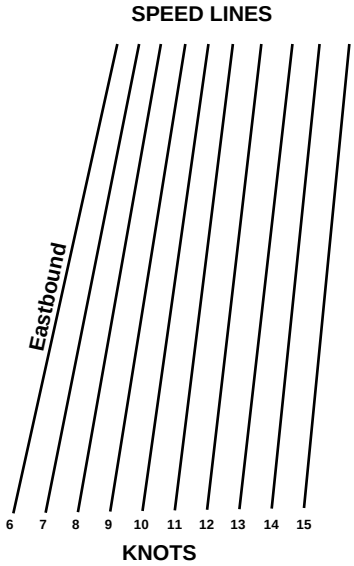
Average deviation of current to the right of wind direction
[A minus sign (-) indicates that the current sets to the left of the wind]

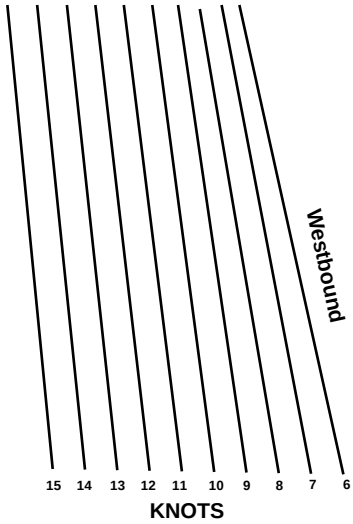
Wind from...	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Brento n Reef	34	25	22	19	25	1	-7	8	27	48	23	41	41	31	21	24

CURRENT DIAGRAM
VINEYARD AND NANTUCKET SOUNDS

Referred to predicted times of slack water at Pollock Rip Channel (Butler Hole)



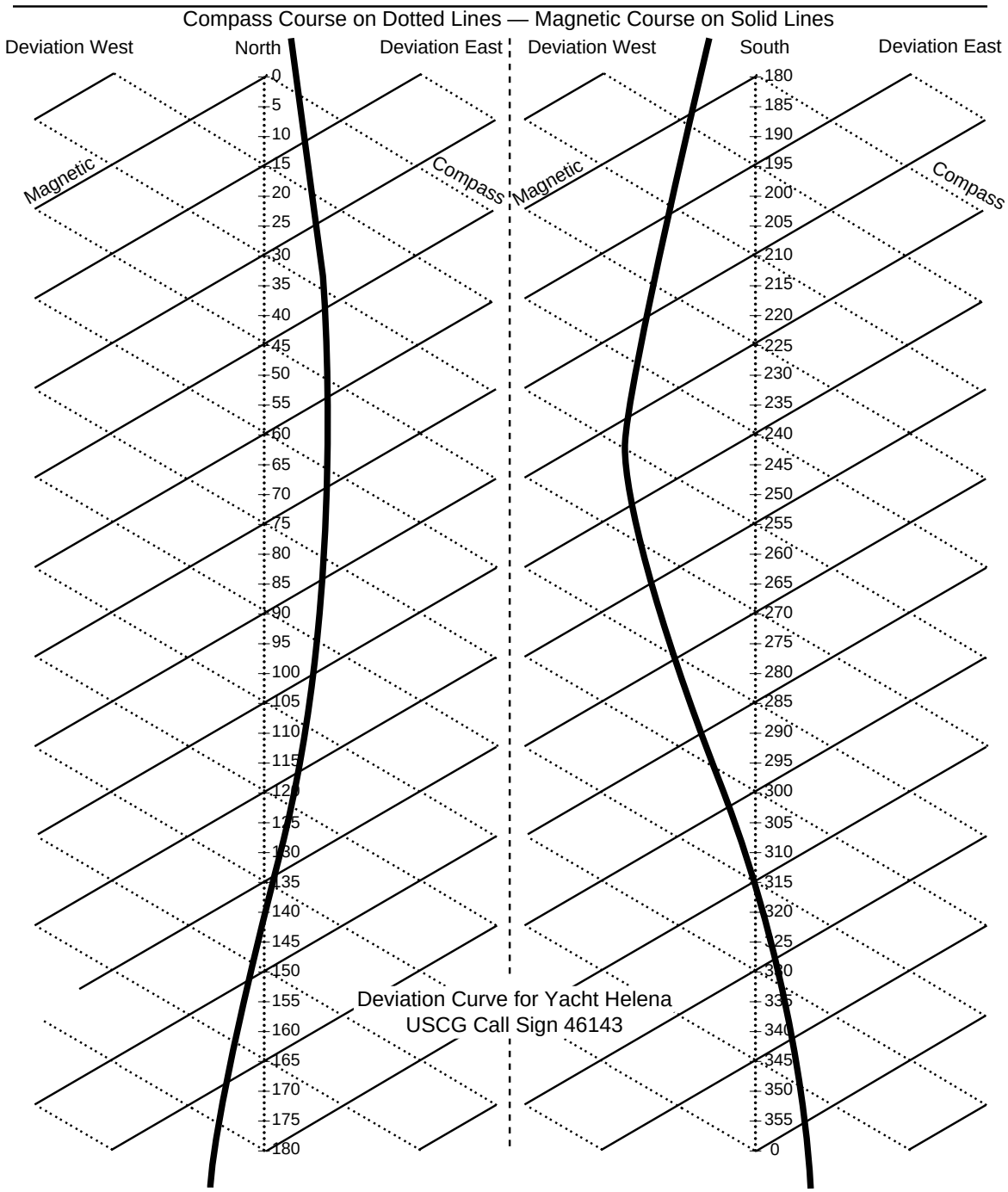


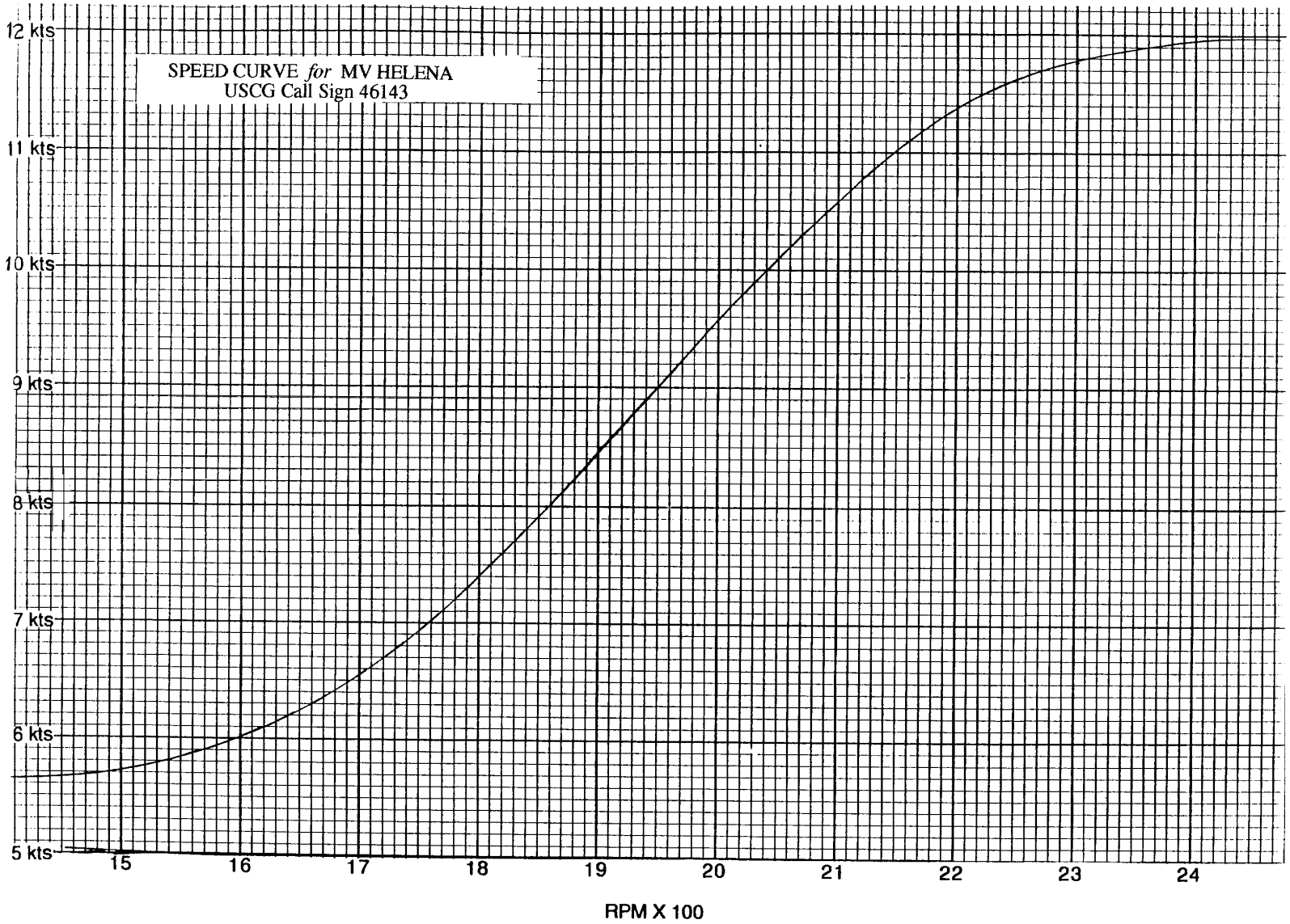


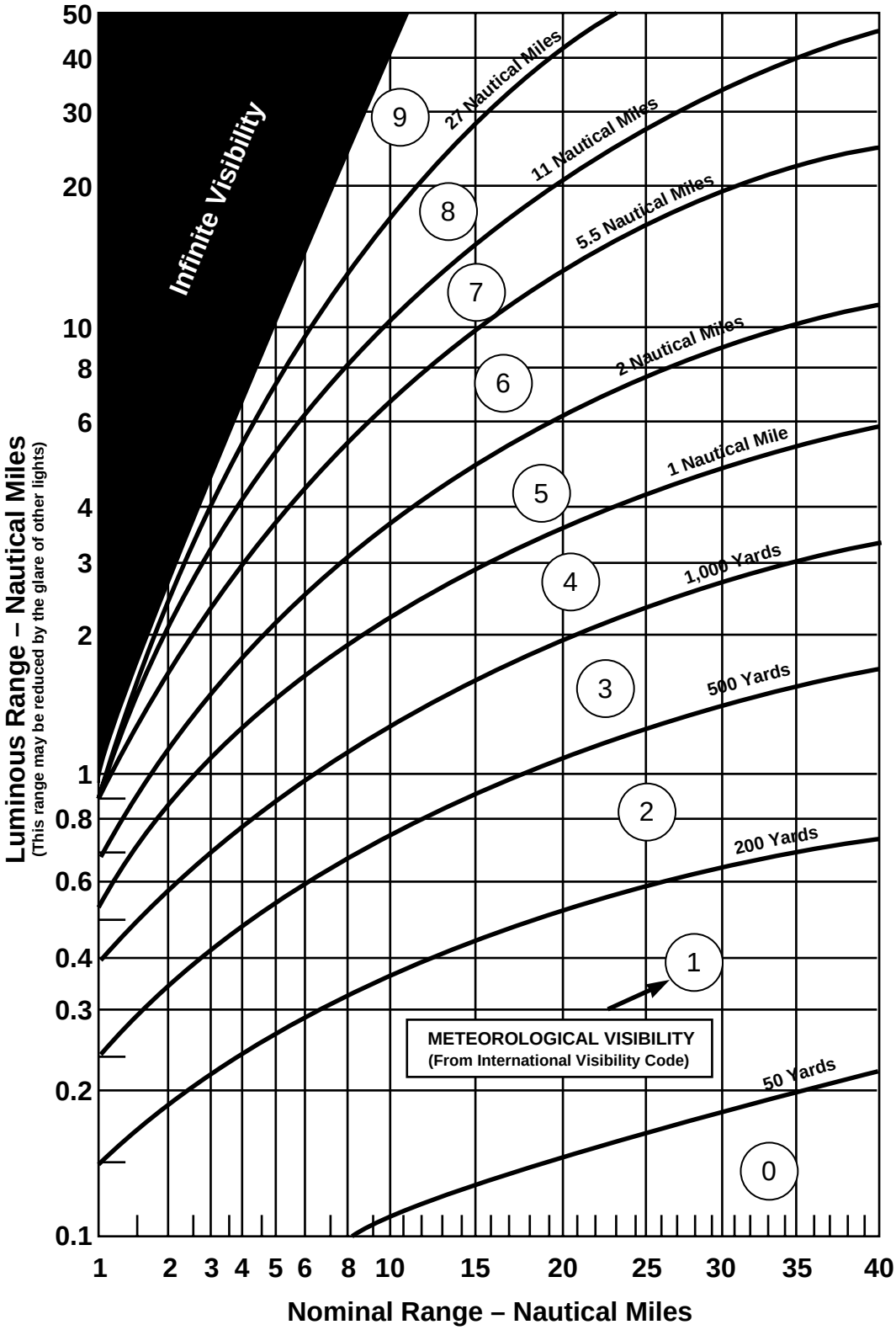
DEVIATION TABLE

USCG Auxiliary Facility Helena, USCG Call Sign 46143

Correcting Compass to Magnetic		Uncorrecting Magnetic to Compass	
Compass Heading	Deviation	Magnetic Heading	Deviation
000°	6°E	000°	7°E
015°	10°E	015°	9°E
030°	12°E	030°	10°E
045°	13°E	045°	12°E
060°	13°E	060°	12°E
075°	12°E	075°	12°E
090°	11°E	090°	11°E
105°	10°E	105°	10°E
120°	5°E	120°	7°E
135°	1°E	135°	2°E
150°	3°W	150°	3°W
165°	6°W	165°	8°W
180°	9°W	180°	10°W
195°	10°W	195°	12°W
210°	12°W	210°	14°W
225°	14°W	225°	16°W
240°	15°W	240°	17°W
255°	17°W	255°	16°W
270°	17°W	270°	14°W
285°	14°W	285°	11°W
300°	9°W	300°	6°W
315°	3°W	315°	2°W
330°	3°E	330°	2°E
345°	5°E	345°	5°E
000°	6°E	000°	7°E


Compass Course on Dotted Lines — Magnetic Course on Solid Lines
Deviation West
North
Deviation East
Deviation West
South
Deviation East
Magnetic
Compass
Magnetic
Compass
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
0
Deviation Curve for Yacht Helena
USCG Call Sign 46143


SPEED CURVE *for* MV HELENA
USCG Call Sign 46143
12 kts
11 kts
10 kts
9 kts
8 kts
7 kts
6 kts
5 kts
15
16
17
18
19
20
21
22
23
24
RPM X 100


Infinite Visibility
27 Nautical Miles
11 Nautical Miles
5.5 Nautical Miles
2 Nautical Miles
1 Nautical Mile
1,000 Yards
500 Yards
200 Yards
50 Yards
9
8
7
6
5
4
3
2
1
0
METEOROLOGICAL VISIBILITY
(From International Visibility Code)
Luminous Range – Nautical Miles
(This range may be reduced by the glare of other lights)
50
40
30
20
10
8
6
4
3
2
1
0.8
0.6
0.4
0.3
0.2
0.1
1
2
3
4
5
6
8
10
15
20
25
30
35
40
Nominal Range – Nautical Miles

APPENDIX B
ANSWERS

CHAPTER 1, Introduction and Basic

1-1. b (1.2)
1-2. a (1.3)
1-3. d (1.4)
1-4. c (1.5)
1-5. T (1.5.1)
1-6. F (1.5.2)
1-7. c (1.6)
1-8. c (1.5.2)
1-9. b (1.5.1)
1-10. b (1.5)
1-11. F (1.6.2)
1-12. F (1.6.2)
1-13. T (1.6.1)
1-14. d (1.6.1)
1-15. a (1.6.2)
1-16. c (1.7)
1-17. T (1.7)
1-18. F (1.7.1 to 1.7.3)
1-19. T (1.7.4.2)
1-20. F (1.7.4.4)
1-21. T (1.7.4.8)
1-22. d (1.7.4.5)
1-23. a (1.7.4.1)
1-24. d (1.7.4.7)
1-25. b (1.6.1)
1-26. c (1.8)
1-27. d (1.9)
1-28. b (1.10.1.1)
1-29. a (1.10.2.1)
1-30. b (1.10.2.2)
1-31. a (1.10.2.1)
1-32. d (1.10.2.1)
1-33. a (1.10.1.5)
1-34. F (1.11.1)
1-35. T (1.11.4)
1-36. d (1.11.5)
1-37. c (1.11.5)
1-38. a (1.11.5)

PROBLEMS

1-1. 39° 08' = 38° 68'
38° 68' - 27° 16' = 11° 52'
11° = 660'
660' + 52' = 712' = 712M
or
11° 52' = 11.8666667°
11.8666667° x 60 = 712' = 712M

1-2. 12° 27.8' - (-8° 12.6') = 20° 40.4'
20° 40.4' = 20.673333° = 1240.4' = 1240.4M

1-3. 57' 48" = 57.8'
57.8' - 0.9' = 56.9' = 56.9M

1-4. The shortest range is the limit; the light can be seen 16.7M

1-5. Enter Luminous Range diagram at 18 miles on the nominal range scale. Draw a line up to the 5.5 mile visibility curve. Where the line intersects the curve, draw a line horizontally to the luminous range scale and read between 11 and12 miles. This is less than the geographical range; therefore, it is the distance at which the light can be seen. Diagram on page B-4.

1-6. $d = 1.17\sqrt{h} + 1.17\sqrt{h'}$

$= 1.17(\sqrt{170} + \sqrt{13}) = 1.17(13.04 + 3.6) = 19.5M$

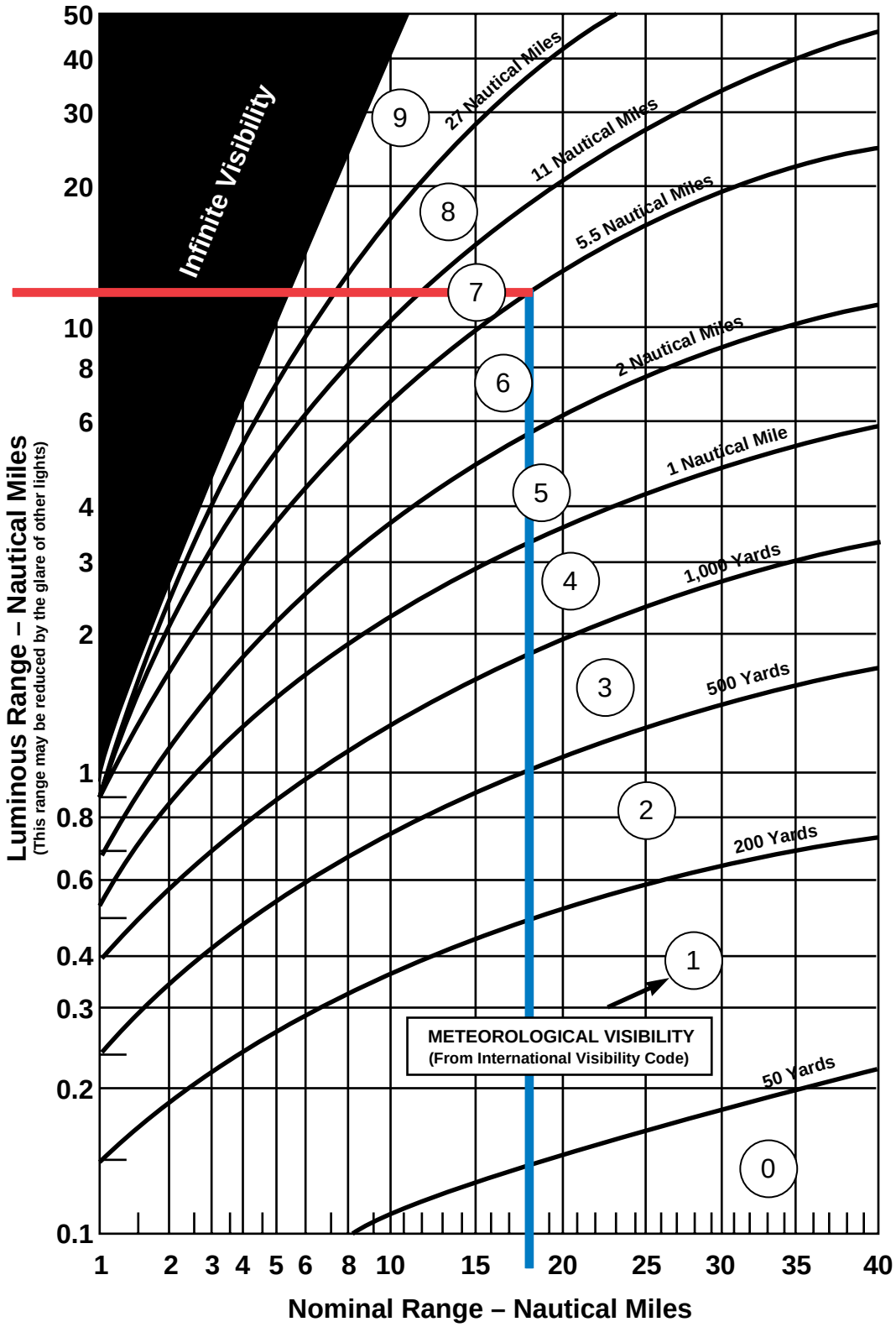
Enter Luminous Range diagram at 18 miles on the nominal range scale. Draw a vertical line to a point exactly halfway between the 11 and 27 mile visibility curves (19 mile visibility). Read 26 miles on the luminous range scale. The geographic range is only 19.5 miles; therefore, it is the distance at which the light can be seen. Diagram on page B-5.

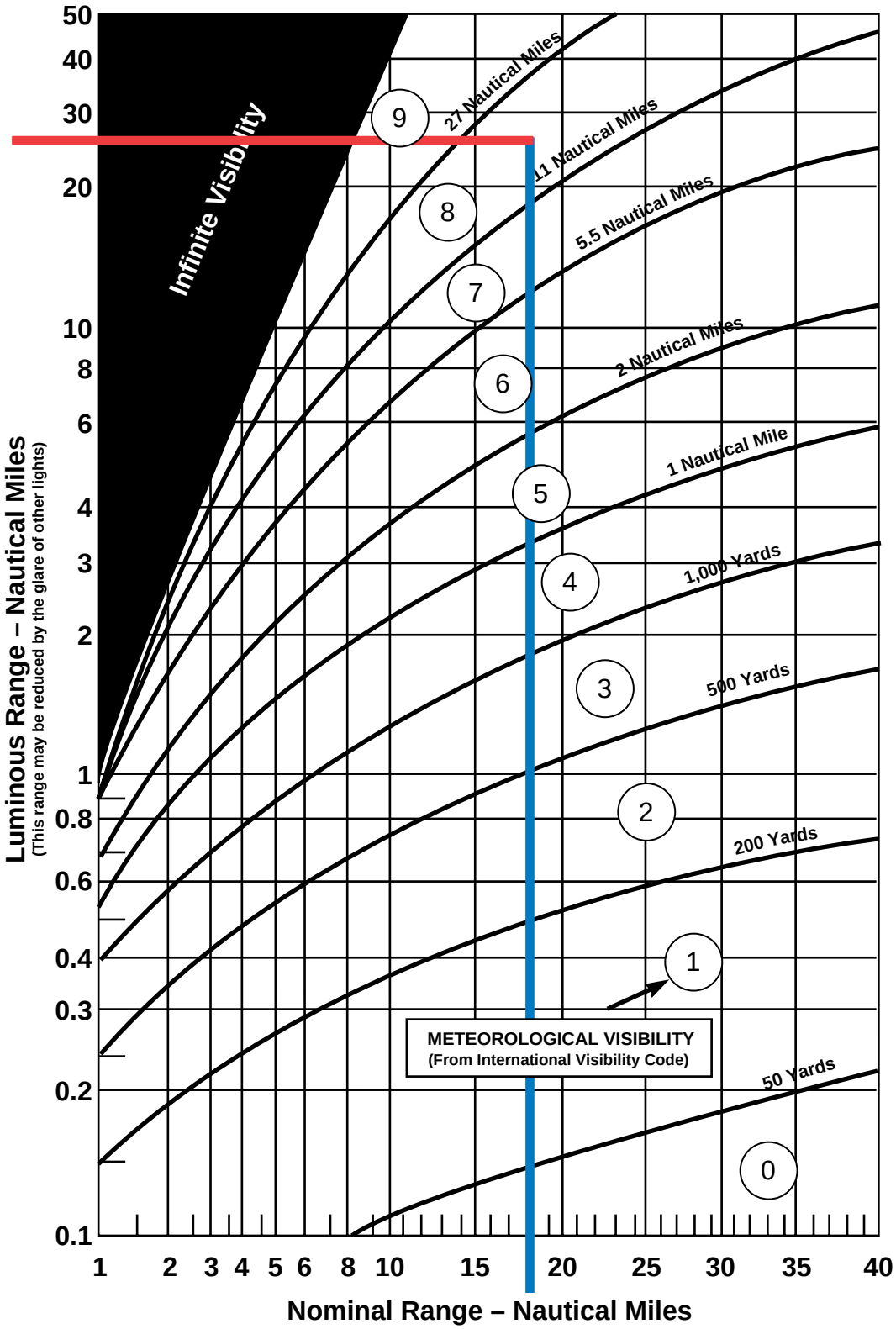
1-7. 063° + 027°R = 090°

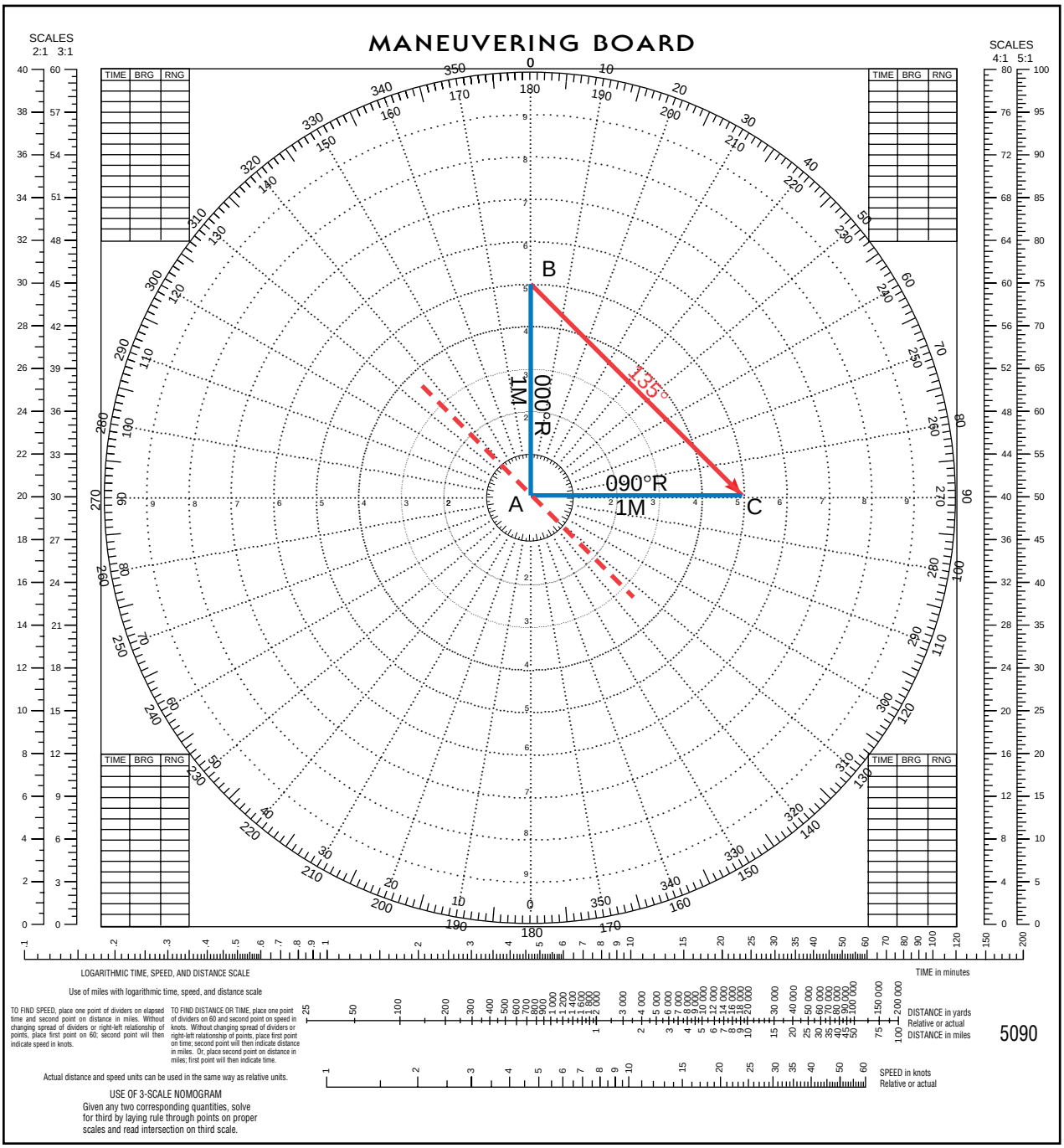
1-8. 335°M + 000°R = 335°M

1-9. 127° + 197°R = 324°T to the antenna.
324° - 185°R = 139°T heading of the vessel at the time of the second bearing.

1-10. See diagram on page B-6


Infinite Visibility
27 Nautical Miles
11 Nautical Miles
5.5 Nautical Miles
2 Nautical Miles
1 Nautical Mile
1,000 Yards
500 Yards
200 Yards
50 Yards
9
8
7
6
5
4
3
2
1
0
METEOROLOGICAL VISIBILITY
(From International Visibility Code)
Luminous Range – Nautical Miles
(This range may be reduced by the glare of other lights)
50
40
30
20
10
8
6
4
3
2
1
0.8
0.6
0.4
0.3
0.2
0.1
1
2
3
4
5
6
8
10
15
20
25
30
35
40
Nominal Range – Nautical Miles


Infinite Visibility
27 Nautical Miles
11 Nautical Miles
5.5 Nautical Miles
2 Nautical Miles
1 Nautical Mile
1,000 Yards
500 Yards
200 Yards
50 Yards
9
8
7
6
5
4
3
2
1
0
METEOROLOGICAL VISIBILITY
(From International Visibility Code)
Luminous Range – Nautical Miles
(This range may be reduced by the glare of other lights)
50
40
30
20
10
8
6
4
3
2
1
0.8
0.6
0.4
0.3
0.2
0.1
1
2
3
4
5
6
8
10
15
20
25
30
35
40
Nominal Range – Nautical Miles


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME
BRG
RNG
A
B
C
1M
000°R
1M
090°R
135°
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
5090
Actual distance and speed units can be used in the same way as relative units.
SPEED in knots
Relative or actual
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.

CHAPTER 2, The Compass and Other Navigators Tools

2-1. b (2.1.4)
2-2. a (2.1.4)
2-3. a (2.1.4)
2-4. d (2.1.2.2)
2-5. c (2.1.4)
2-6. b (2.1.3.1.2)
2-7. a (2.1.6.2.2)
2-8. d (2.1.6.4)
2-9. T (2.1.2.1)
2-10. F (2.1.2)
2-11. F (2.1.1.1)
2-12. F (2.1.1.1)
2-13. T (2.1.1.1)
2-14. b (2.1.7)
2-15. c (2.1.6.4)
2-16. a (2.2.1)
2-17. a (2.2.1)
2-18. d (2.2.1)
2-19. c (2.2.1)
2-20. a (2.1.6.2.3)
2-21. b (2.1.6.2.3)
2-22. c (2.1.6.4)
2-23. T (2.2.3)
2-24. F (2.2.4)
2-25. T (2.2.6)

PROBLEMS

2-1. Heading 210° Magnetic, Variation is already included.
Compass 207° is less, 210° - 207° = 3° E deviation

2-2. Uncorrecting, west is added, east is subtracted
203°T + 9° W Var = 212°M - 4° E Dev = 208°C

2-3. Uncorrecting; 063°M + 12° W Dev = 075°C

2-4. Uncorrecting; 357°T + 6° W Var = 363°M = 003°M

2-5. Correcting; 228°C - 3° W Dev = 225°M
225°M + 10°E Var = 235°T

2-6. Uncorrecting; 096°T + 8° W Var = 104°M
Correcting; 111°C - 7° W Var = 104°M

2-7. Vessel heading is 045°C, ∴ deviation is 12° E
Tower is bearing 075°C
Variation is 10° W
075°C + 12° E Dev - 10° W Var = 077°T

2-8. Use the Napier Diagram (in Appendix D):
Construct a line parallel to the solid lines through 305° on the center vertical scale. Where that line intersects the deviation line, construct a line parallel to the dotted lines back to the center vertical scale. Read 310°, the compass course to be steered to maintain a magnetic course of 305°. the deviation is 5°W. Diagram on page B-10

2-9. Charted magnetic bearing is 102°M
Compass bearing is 097°C
East is least; ∴, when compass is less than charted bearing deviation is east, 102°M - 097°C = 5° E Dev

2-10. Steering compass reading, 228°, is higher (better) than charted magnetic bearing, 224°; therefore, deviation is west.
228°C - 224°M = 4° W Dev

2-11. Deviation for 300°C = 9° W
Deviation for 315°C = 3° E
Interval is 6°; 307°C is 7° more than 300°C

$$\frac{X}{6} = \frac{7}{15}$$

$$15x = 42$$

$$x = 2.8 = 3°$$

Deviation is decreasing from 9° W toward 3°W as heading swings from 300°C to 315°C ; therefore, the change is subtracted from 9° W.
Deviation for 307°C is 6° W

Deviation for 300°M = 6° W
Deviation for 315°M = 2°W
(continued on page B-9)

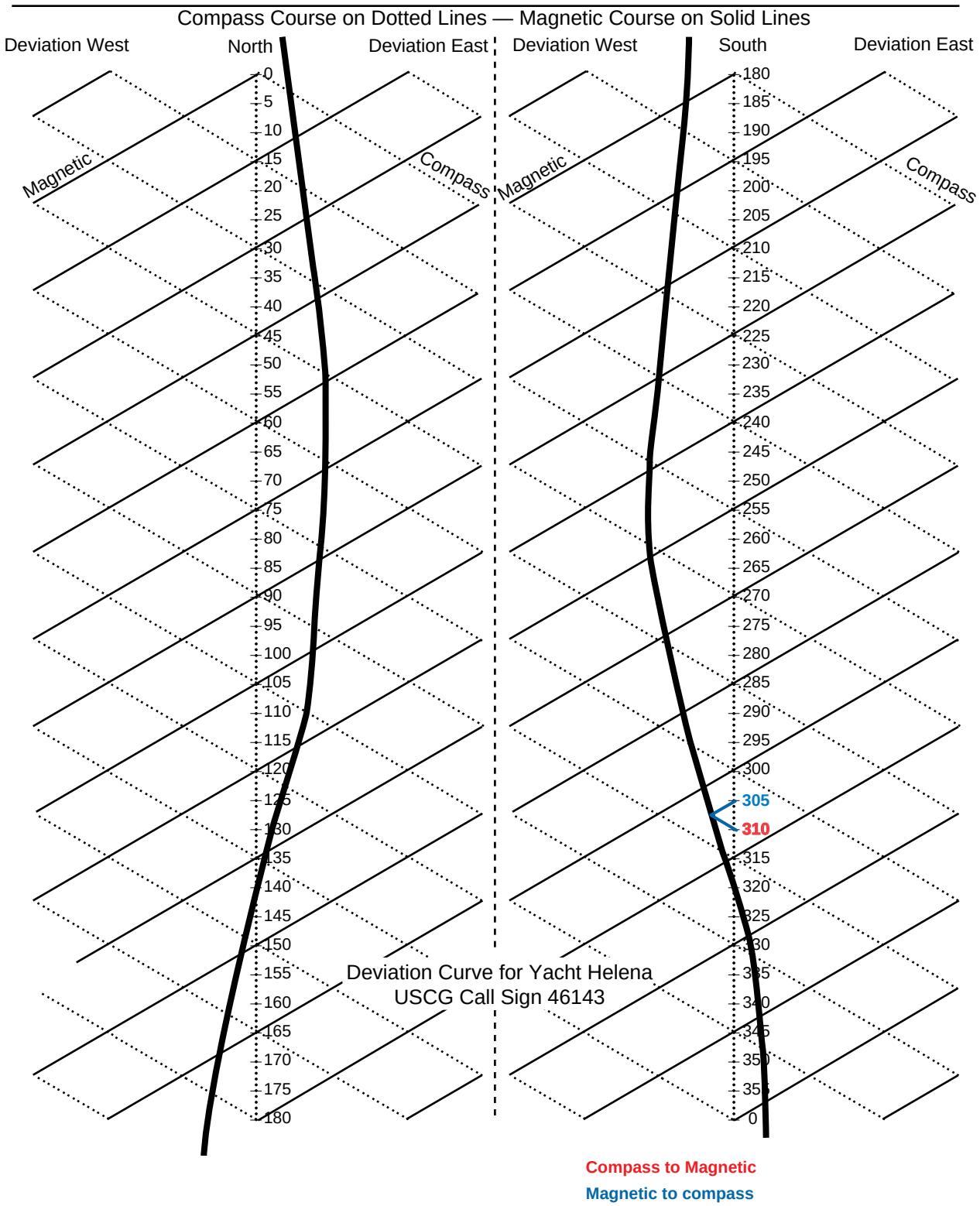
Interval is 4°

$$\frac{X}{4} = \frac{7}{15}$$

$$15x = 28$$

$$x = 1.9 = 2°$$

Deviation decreases, 307° is closer to 300°, deviation is less than deviation for 300°; therefore, the change is subtracted.
Deviation for 307°M is 4° W


Compass Course on Dotted Lines — Magnetic Course on Solid Lines
Deviation West
North
Deviation East
Deviation West
South
Deviation East
Magnetic
Compass
Magnetic
Compass
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
0
Deviation Curve for Yacht Helena
USCG Call Sign 46143
Compass to Magnetic
Magnetic to compass

CHAPTER 3, Dead Reckoning

3-1. a (3.1)
3-2. d (3.1)
3-3. b (3.1)
3-4. a (3.1.1.2)
3-5. F (3.1.1.2)
3-6. F (3.1.2.1)
3-7. F (3.1.2.1)
3-8. T (3.1.2.1)
3-9. T (3.2.1.2)
3-10. c (3.2.1.4)
3-11. a (3.2.1.5)
3-12. d (3.2.1.5)
3-13. a (3.2.1.8)
3-14. b (3.2.1.9)
3-15. c (3.2.1.10)
3-16. c (3.2.1.11)
3-17. b (3.2.1.12)
3-18. a (3.2.1.12.1 through 3)
3-19. T (3.2.1.13)
3-20. b (3.2.1.14)
3-21. d (3.2.1.15)
3-22. a (3.2.1.17)
3-23. d (3.2.1.1)
3-24. F (3.2.1.1.1)
3-25. F (3.2.4)
3-26. F (3.3)
3-27. T (3.3.1)
3-28. F (3.3)

PROBLEMS

3-1. Average speed through the water is:
(total distance)/(total time)

$$\frac{14.05x60}{78} = 10.8 \text{ kts}$$

3-2. Length of path over the ground = 14.05M

3-3. Speed of advance is speed through the water = 10.8 kts

3-4. Speed made good is:
(length of CMG)/total time

$$\frac{12.8x60}{79} = 9.7 \text{ kts}$$

3-5. Course made good is straight line direction between St. Albans and Westcott = 083°

Problem 3-1 through 3-5 situation diagramed on page B-13

3-6. Procedure for developing speed curve. Distance = 1M

RPM	Time Out	Speed Out	Time In	Speed In	Avg Speed
2500	3.68	16.3	5.48	10.9	13.6

A vessel runs on course 148°, covering 3.7M in 13 minutes.
It turns to course 088°, for 19 minutes at 14 knots

3-7. The course made good is the resultant of the first leg, 3.7M at

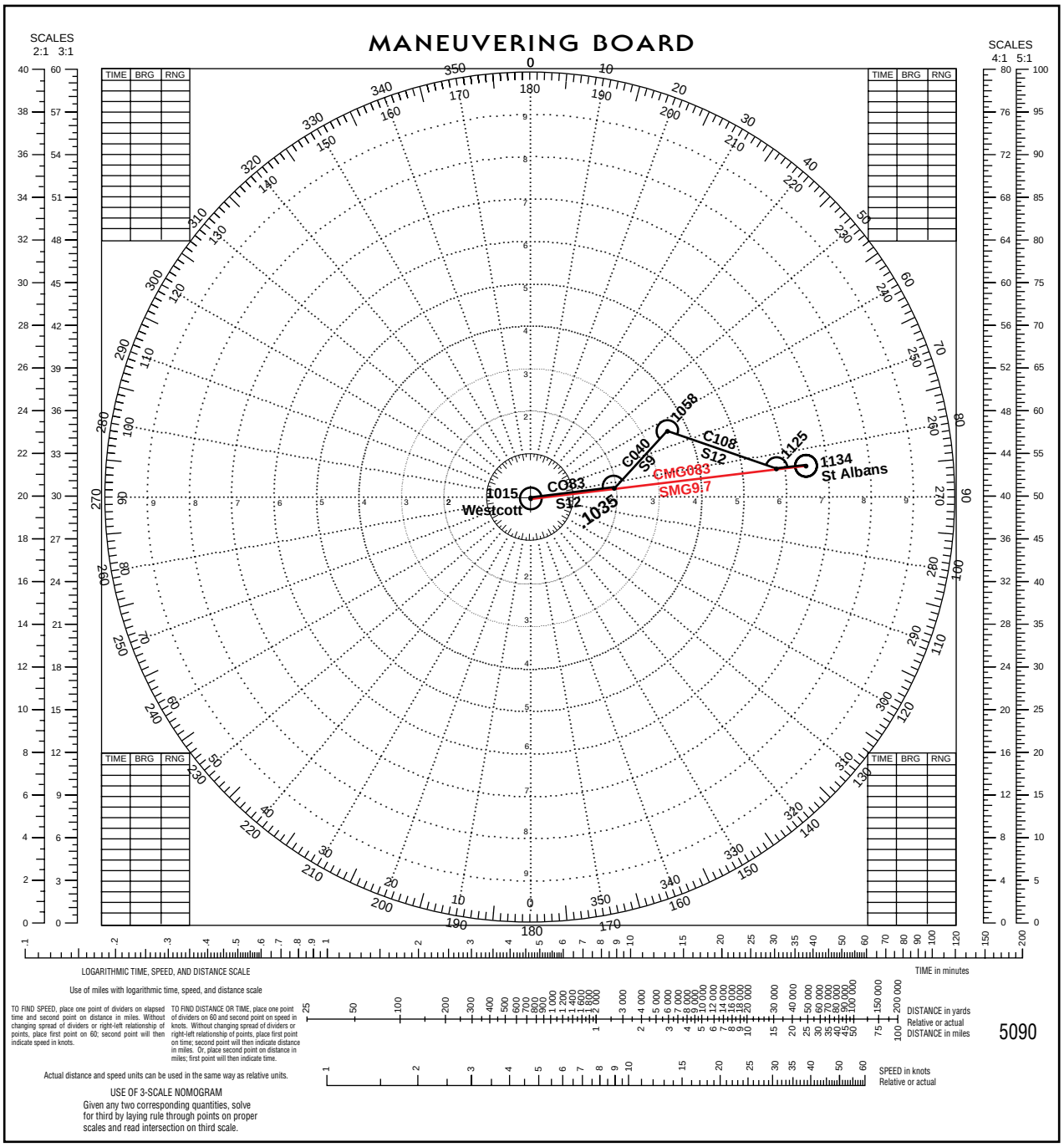
148° and the second leg, $\frac{14x19}{60}$ = 4.4M at 088°
CMG = 115°

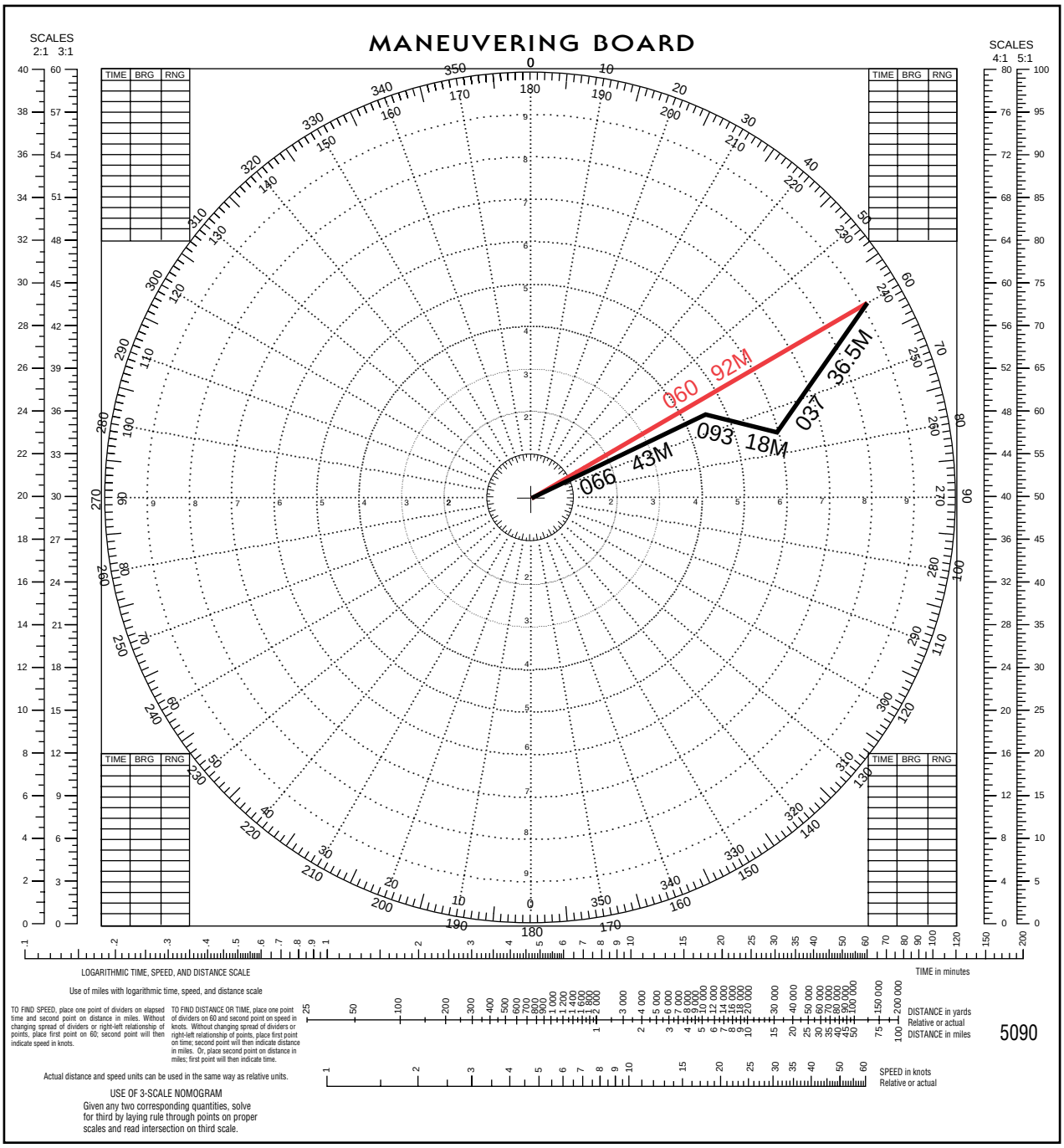
3-8. Speed made good is straight line distance from start to finish divided by total time = 7M / 32m = 13.1 kts

3-9. Speed for 1st leg is 3.7M / 13 = 17.1 kts.
1st leg is labeled C148° above the line and S17.1 below.

3-10. 9 kts at 45m = $\frac{9x45}{60}$ = 6.75M

3-11. Solution on page B-14


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME
BRG
RNG
1015
Westcott
S12
C083
1035
C040
S9
1058
C108
S12
1125
1134
St Albans
CMG083
SMG9.7
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME
BRG
RNG
066
43M
093
18M
037
36.5M
060
92M
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
5090
Actual distance and speed units can be used in the same way as relative units.
SPEED in knots
Relative or actual
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.

CHAPTER 4, Piloting I

4-1.	c	(4.1)
4-2.	b	(4.1.2)
4-3.	F	(4.2)
4-4.	d	(4.3.1)
4-5.	c	(4.3.1)
4-6.	a	(4.3.2)
4-7.	c	(4.2.3)
4-8.	T	(4.2.3)
4-9.	F	(4.4.1)
4-10.	F	(4.4.1)
4-11.	d	(4.2.1)
4-12.	a	(4.4.2.1)
4-13.	d	(4.4.3.1)
4-14.	F	(4.4.3.1)
4-15.	c	(4.4.2)
4-16.	b	(4.4.2.2)
4-17.	F	(4.5)
4-18.	F	(4.5)

PROBLEMS

4-1. Vessel heading is 057°C, deviation for 045°C = 13° E, for 060°C = 13°E. By examination, deviation for 057°C = 13° E. Variation = 10° W. Bearing of lighthouse = 062°R

057°C + 13° E - 10° W + 062°R = 122°

4-2. Vessel heading = 126°M, deviation for 120°M = 7°E, for 135°M = 2°E

$\frac{x}{5} = \frac{6}{15'}$, 15x = 30, x = 2° change

Deviation for 126°M = 5°E.

237°C + 5°E - 10° W = 232°

Vessel heading = 304°C, speed = 10.6 kts. Variation = 10° W. Deviation for 300°C = 9° W, for 315° = 3° W;

$\frac{x}{6} = \frac{4}{15}$, 15x = 24, x = 1.6 = 2° change

Deviation for 304°C = 7°W

4-3. Monument bears 015°C.
015°C - 7° W - 10° W = 358°

4-4. Tower bears 082°M (disregard deviation)
082°M - 10° W = 072°

4-5. Speed at 2100 rpm = 10.6 kts

$$\frac{10.6x23}{60} = 4.1\text{M}$$

CHAPTER 5, Piloting II

5-1.	b	(5.1.1)
5-2.	T	(5.1.3)
5-3.	F	(5.1.2)
5-4.	T	(5.1.1)
5-5.	c	(5.1.3)
5-6.	d	(5.1.4)
5-7.	T	(5.1.5)
5-8.	a	(5.1.5)
5-9.	c	(5.1.5)
5-10.	b	(5.1.6.2)
5-11.	d	(5.1.6.2)
5-12.	F	(5.1.6.2)
5-13.	F	(5.1.6.3)
5-14.	a	(5.1.6.4)
5-15.	c	(5.2.1)
5-16.	a	(5.2.2)
5-17.	a	(5.2.3.1)
5-18.	c	(5.2.3.1)
5-19.	F	(5.2.3.2)
5-20.	F	(5.2.3.2)
5-21.	F	(5.3.1)
5-22.	T	(5.3.3)

PROBLEMS

5-1. 330°R is 30° off the port bow (000°R = 360°R is dead ahead) Double the angle off the bow = 60° Left of 360°R = 300°R

5-2. Helena on course 212°; Osprey Point Light bears 177°
Relative bearing of the light is 325°R or 35° Left.
13m 12s later light bears 142°. Relative bearing is 290°R = 70° Left. Angle on the bow is doubled.

Helena travels $\frac{13.2x10}{60}$ = 2.2M between sightings.
Distance from the Light at the second sighting is equal to the distance traveled between sightings.
Light is 2.2M away

5-3. 1st leg, C068°, speed 15 kts for 8 minutes = 2M
2nd leg, C089°, speed 15 kts for 6 minutes = 1.5M

3rd leg, C110°, speed 10 kts for 18 minutes = 3M
Resultant lies 092°
Solution to Problems 5-3 and 5-4 diagramed on page B-19

5-4. Distance over CMG = 6.2M

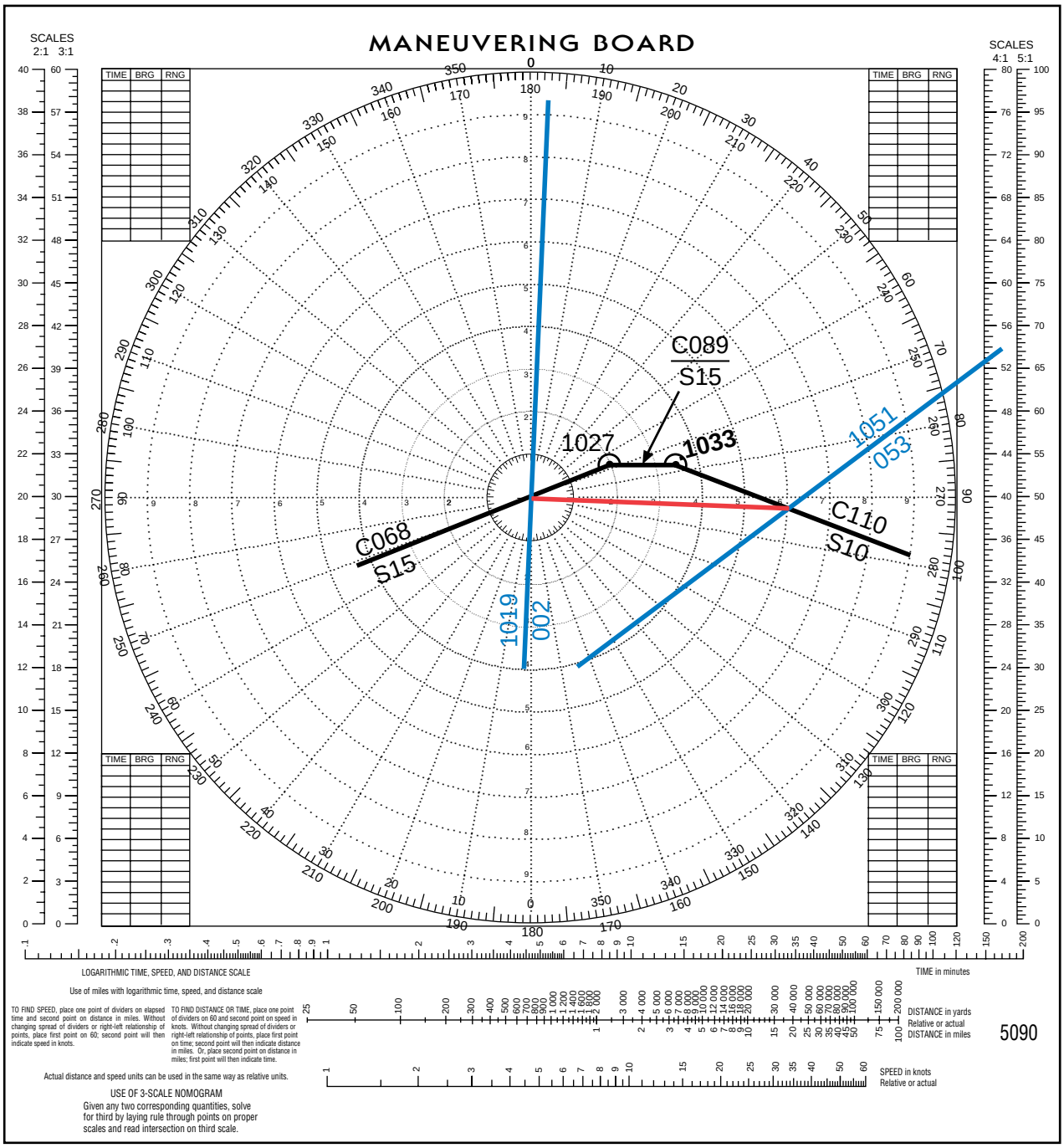
5-5. Vessel travels 24 minutes at 20 knots between observations on the same object, an antenna. The angle on the bow of the second observation is twice the first. Vessel traveled 8.0M; the antenna is 8.0M away.

5-6. The vessel is in danger while on heading 312° heading for the buoy (bearing 000°R). Once the vessel turns away, it is no longer standing into that danger.

5-7. d = h/(6076 tanø)
ø = 22' = 0.3667°
tanø = .0064
6076 tanø = 38.88
d = 112/38.88 = 2.9M

5-8. $d = 1.17(\sqrt{h} + \sqrt{h'})$
$d = 1.17(\sqrt{112} + \sqrt{14})$
$= 1.17(10.58 + 3.74)$
$= 1.17(14.32)$
$= 16.8M$

5-9. Nominal range is 24M. Work in reverse.
$24 = 1.17(10.58 + \sqrt{h'})$
$24 = 12.38 + 1.17\sqrt{h'}$
$1.17\sqrt{h'} = 24 - 12.38 = 11.62$
$\sqrt{h'} = \frac{11.62}{1.17} = 9.93$
$h = 9.93^2 = 98.6$ ft

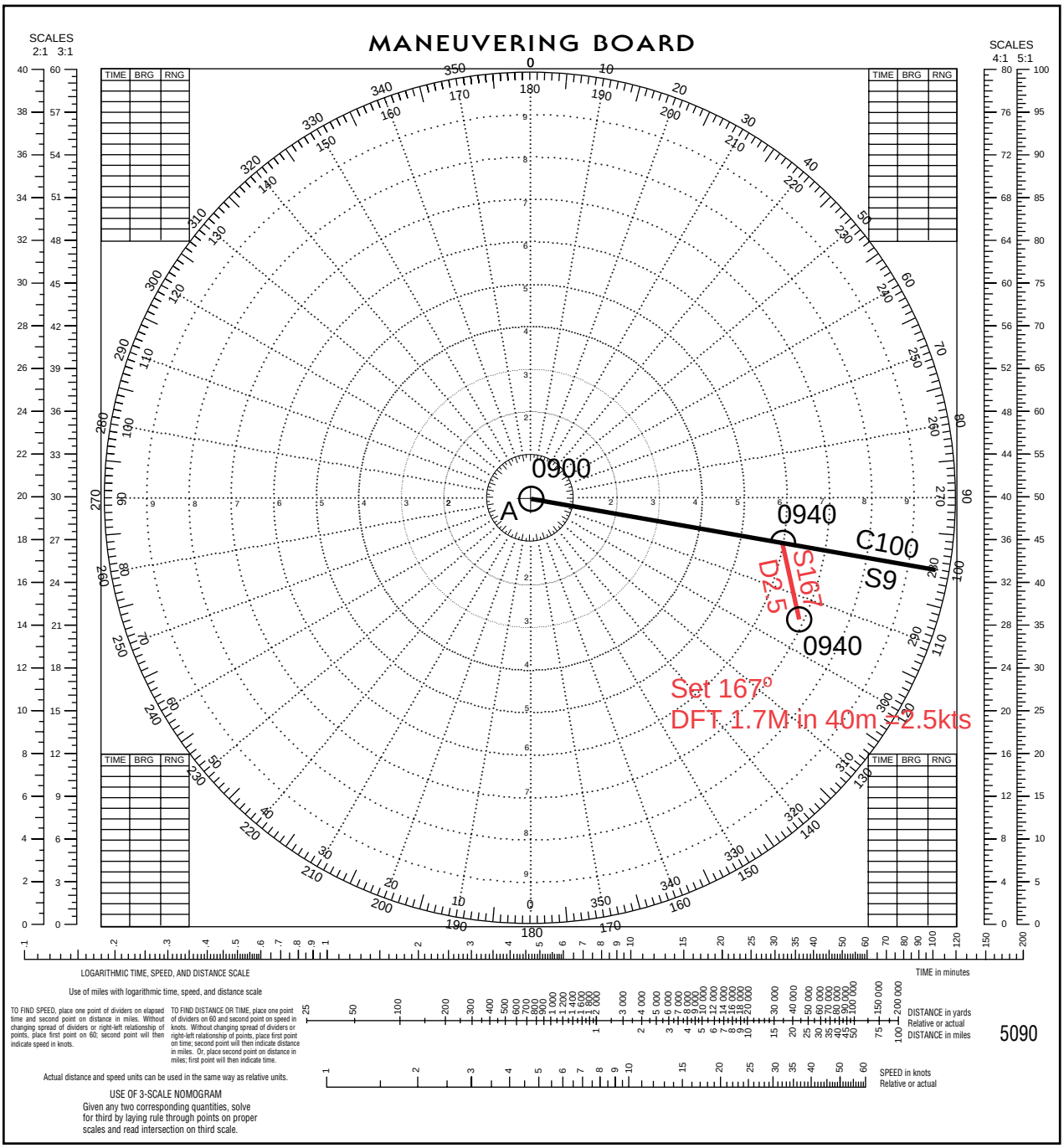

MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME BRG RNG
C089
S15
1027
1033
1051
053
C110
S10
C068
S15
1019
002
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090

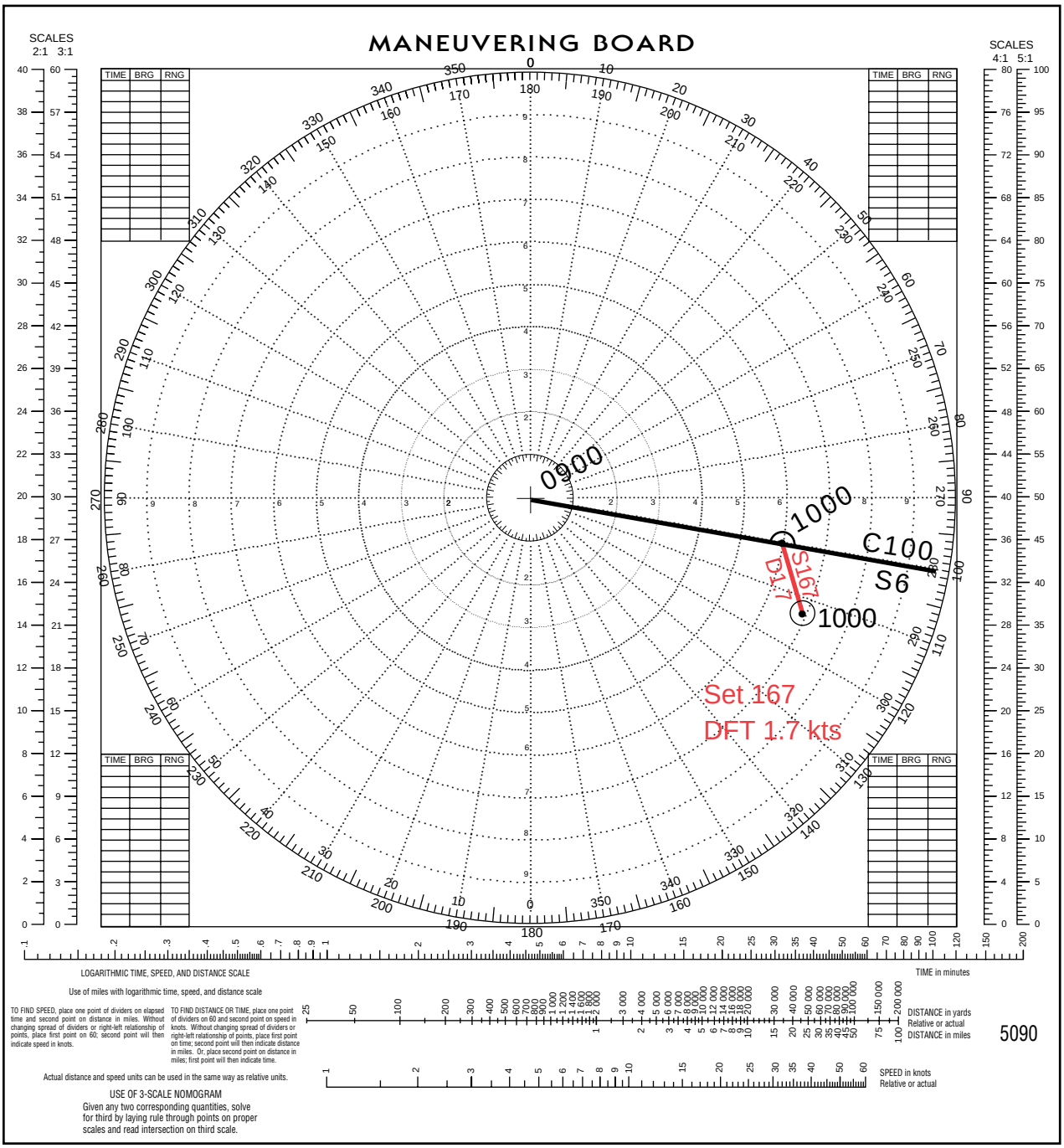
CHAPTER 6, Current Sailing

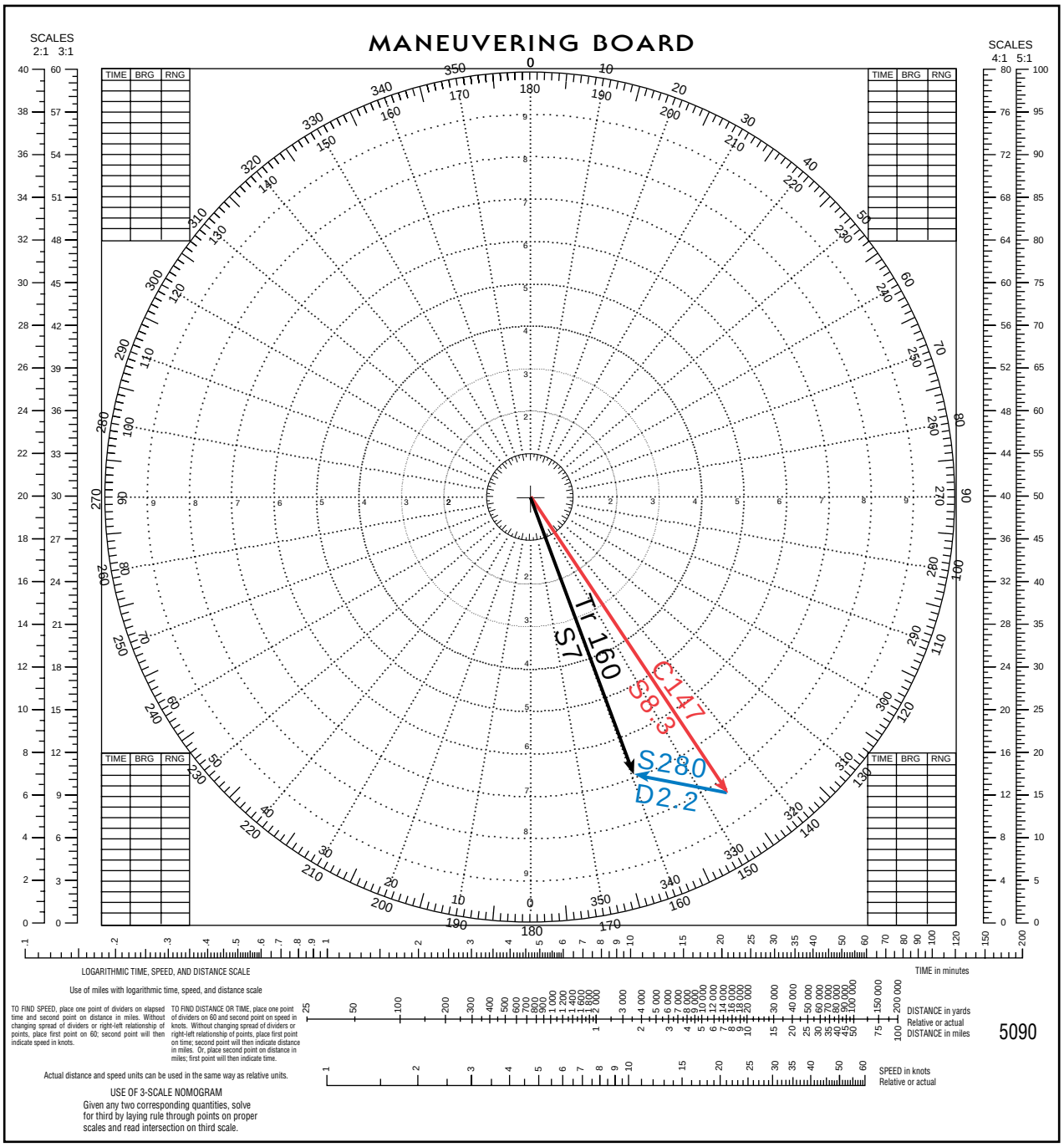
6-1. c (6.1.1)
6-2. a. current, ocean, tidal river
b. wind direction and strength
c. wave and swell action
d. inaccurate steering
e. compass error not neutralized
f. rpm calibration inaccuracies
g. knot meter inaccuracies
h. fouled hull, or propeller
i. nonstandard trim of the vessel
j. propeller slip
k. set of sails
l. any other force affecting speed or direction of motion (6.1.1)
6-3. b (6.1.2.2)
6-4. F (6.1.2.3)
6-5. F (6.1.2.4)
6-6. F (6.1.2.4)
6-7. T (6.1.2.4)
6-8. c (6.1.4.1)
6-9. a (6.1.4.2)
6-10. c (6.2.1)
6-11. d (6.2.1)
6-12. d (6.2.2)
6-13. a (6.2.3.2.1)
6-14. c (6.2.3.2.5/6.2.3.2.4)
6-15. T (6.2.3.2.6)
6-16. T (6.2.3.2.4)
6-17. T (6.2.3.2.5)
6-18. d (6.2.3.2.2)
6-19. b (6.3)
6-20. F (6.4.1)
6-21. F (6.4.2)
6-22. T (6.4.2)
6-23. b (6.4.5)
6-24. a (6.4.5)

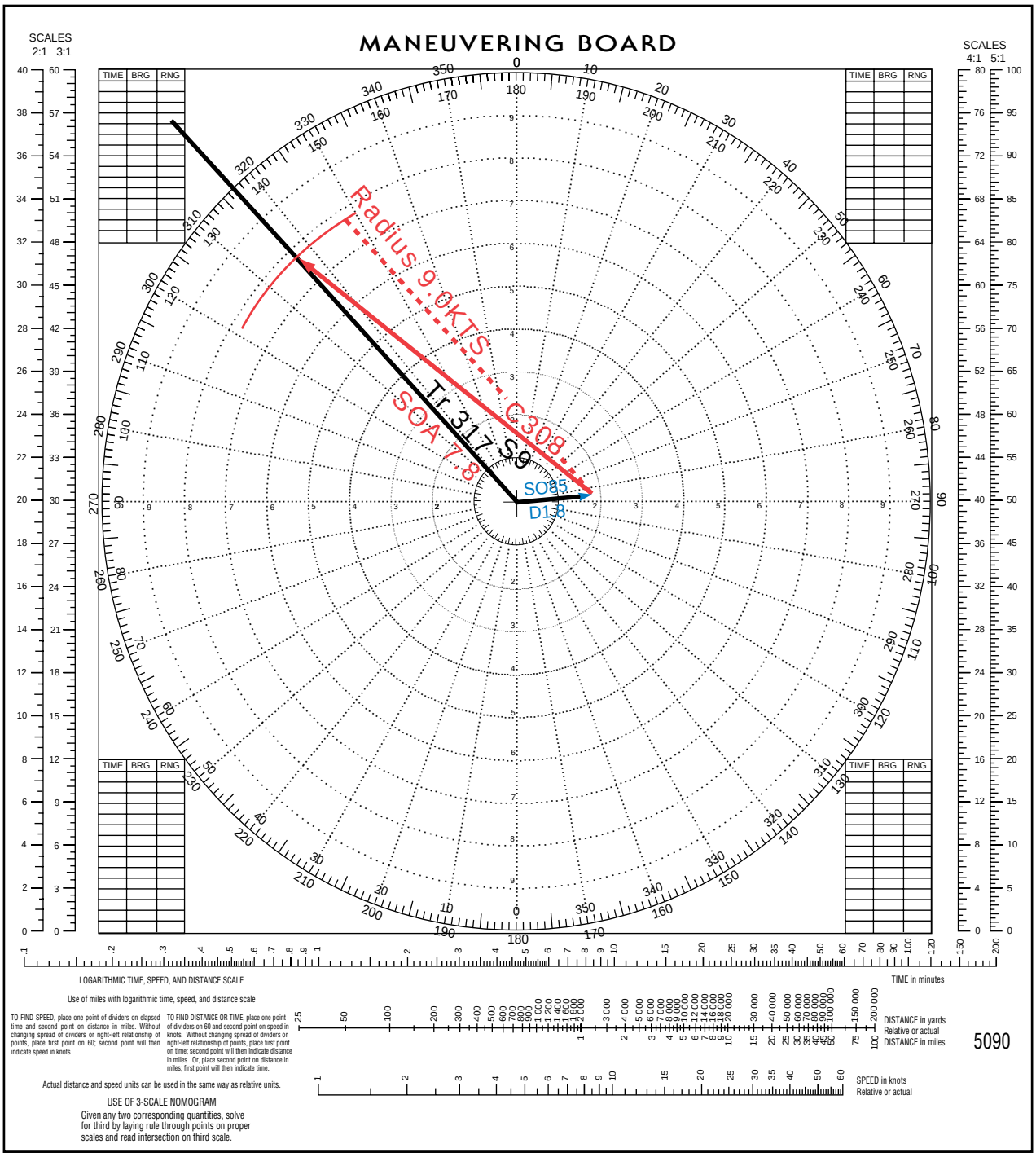
PROBLEMS

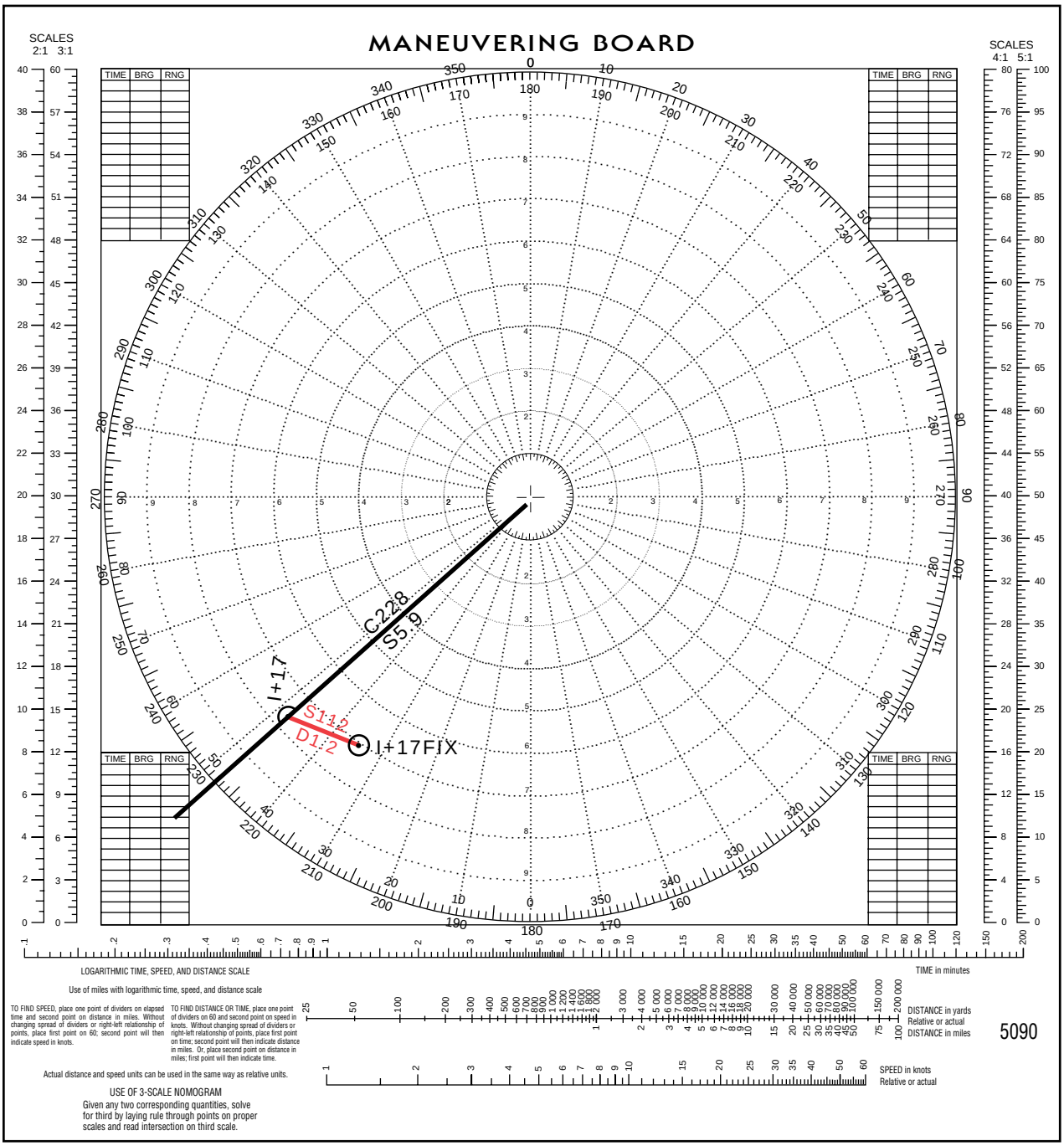
6-1 to 6-7. Solutions are provided in following pages (B-21 through B-26)


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME BRG RNG
0900
A
0940
C100
S9
S161
D2.5
0940
Set 167°
DFT 1.7M in 40m =2.5kts
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME
BRG
RNG
0900
1000
C100
S6
S167
D1.7
1000
Set 167
DFT 1.7 kts
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090

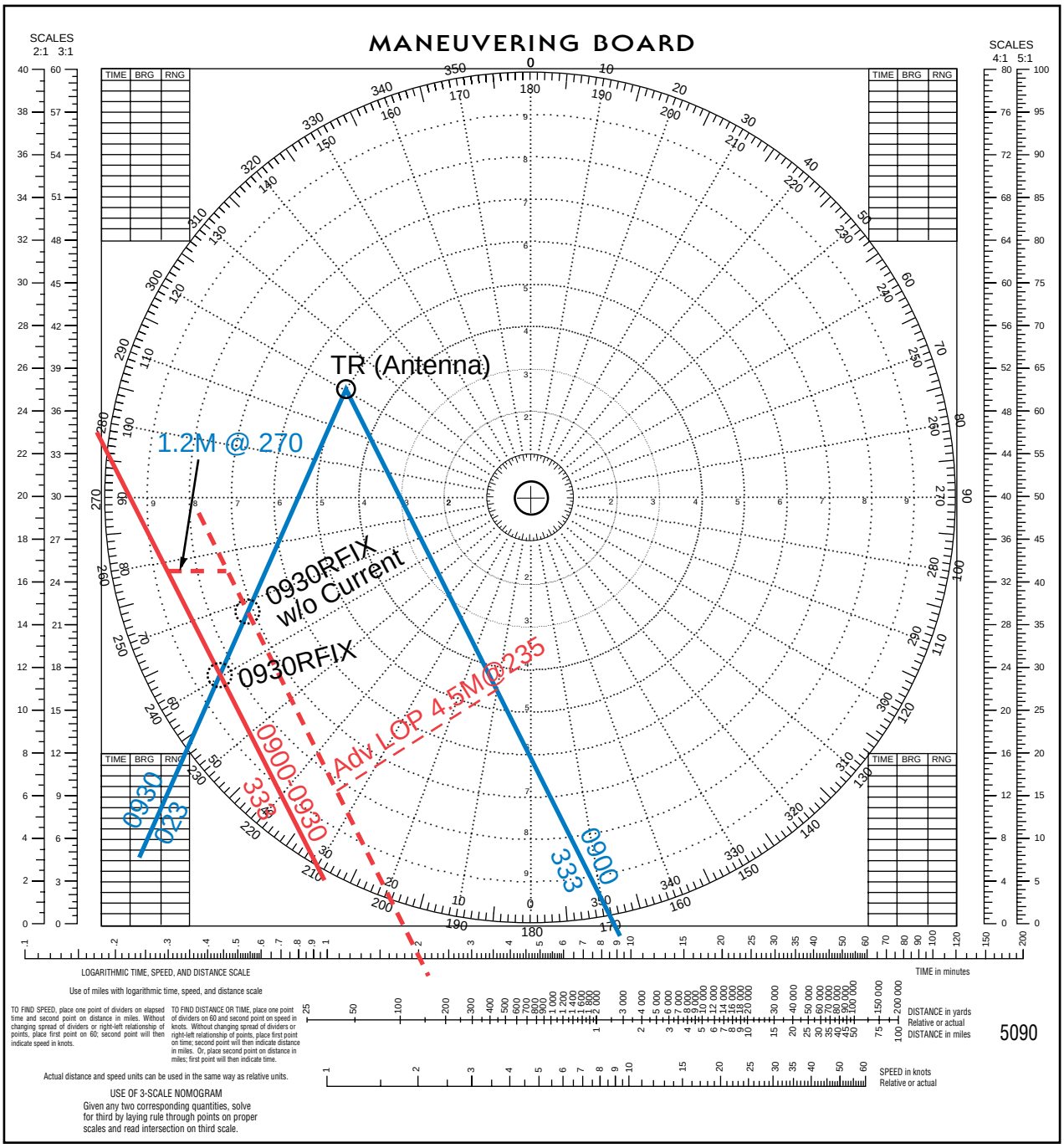

MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME
BRG
RNG
Tr 160
S7
C147
S8.3
S280
D2.2
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME BRG RNG
Radius 9 KTS
C308
SOA 7.8
Tr 317
S9
SO85
D1.8
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090



5.9 kts for 1h 17m (77m) = 7.6M

1.5 M in 77m = 1.2 kts


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME BRG RNG
TR (Antenna)
1.2M @ 270
0930RFIX
w/o Current
0930RFIX
Adv LOP 4.5M@235
0900-0930
333
0930
623
0900
333
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.
Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090

CHAPTER 7, Tides and Currents - Tides

7-1.	F	(7.2.1)
7-2.	T	(7.2.3)
7-3.	c	(7.2.4)
7-4.	d	(7.3.2)
7-5.	a	(7.3.1)
7-6.	c	(7.2.3)
7-7.	b	(7.3.3)
7-8.	a	(7.5.3.1)
7-9	d	(7.5.3.1)
7-10.	b	(7.5.3.1)
7-11.	F	(7.2.3)
7-12.	F	(7.2.3)
7-13.	d	(Sunrise/Sunset Worksheet)
7-14.	d	(Sunrise/Sunset Worksheet)
7-15.	b	(7.5.3.1)
7-16.	T	(7.5.3.1)
7-17.	F	(7.5.3.1)
7-18.	T	(7.5.3.1)

PROBLEMS

7-1. Worksheet on page B-28

7-2. From Table 1, Annex A, page A2: the ranges are 3.2 ft (3.4 - 0.2), 3.3 ft (0.2 to 3.5), and 3.4 ft (3.5 to 0.1). Maximum range is 3.4 ft

7-3. From Table 1, Annex A: durations are 6h 25m, 5h 56m, and 6h 25m. Longest duration is 6h 25m

7-4. Worksheet on page B-29

7-5 Worksheet on page B-30

7-6 Worksheet on page B-31

TIME OF SUNRISE OR SUNSET WORKSHEET

Location: Woods Hole, Little Harbor
Position latitude: 41° 31' N Date: 1 April
Position longitude: 70° 40' W

From Table 4 - Nearest date: 1 Apr Nearest latitude 42°N
Time of sunrise or sunset at nearest date and latitude: 0543

Longitude of time meridian: 75° W
Position longitude: 70°40' W
Difference in longitude: 4° 20'

From Table 5 - Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): 17m

Time of sunrise or sunset at position: 0526

Note: If local meridian is east of standard (time) meridian (longitudinal difference is - in the western hemisphere, + in the eastern), subtract the correction (event occurs earlier). If local meridian is west of standard meridian, add the correction.

Table 5 says to subtract or add corrections to local mean time. Local mean time in each time zone is the time of the standard meridian as given in Table 4; therefore, applying the correction provides the time of the event at the local meridian (position).

For Daylight Savings Time, add one hour to the time.

DST in eff 1st Sun in Apr, 3 Apr
EST in eff 1 Apr

HEIGHT OF TIDE WORKSHEET

Substation Tarpaulin Cove Date 6 Apr

Reference Station Newport

HW time difference + 0 11 Diff. in height of HW * 0.54

LW time difference + 1 23 Diff. in height of LW * 0.54

Ref. Sta. Newport Sub Sta. _____

LW				
HW	0413-0513	3.4	0524	1.8
LW	1150	0.2	1313	0.1
HW	1737	3.5	1748	1.9
LW	070020	0.1	070143	0.1
HW				

Height of tide at any time

Location Tarpaulin Cove Time 1506 Date 6 Apr

Duration of Rise or Fall	4h 35m
Time from Nearest Tide	1h 53m
Range of Tide	1.8
Height of Nearest Tide	0.1
Correction from Table 3	0.7
Height of Tide at _____	0.8

Depth of water at any time

Charted Depth of Water	
Height of Tide at _____	
Depth of Water at _____	

TIME OF SUNRISE OR SUNSET WORKSHEET

Location: Tarpaulin Cove
Position latitude: 41° 28' N Date: 6 April
Position longitude: 70° 46' W

From Table 4 - Nearest date: 6 Apr Nearest latitude 42°N
Time of sunrise or sunset at nearest date and latitude: 1831

Longitude of time meridian: 75° W
Position longitude: 70° 46' W
Difference in longitude: 4° 14'

From Table 5 - Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): 17m

Time of sunrise or sunset at position: 1814

Note: If local meridian is east of standard (time) meridian (longitudinal difference is - in the western hemisphere, + in the eastern), subtract the correction (event occurs earlier). If local meridian is west of standard meridian, add the correction.

Table 5 says to subtract or add corrections to local mean time. Local mean time in each time zone is the time of the standard meridian as given in Table 4; therefore, applying the correction provides the time of the event at the local meridian (position).

For Daylight Savings Time, add one hour to the time.

DST in effect on 3 Apr
Sunset at Tarpaulin Cove, 6 Apr: 1914 EDT

HEIGHT OF TIDE WORKSHEET

Substation Woods Hole, Little Harbor Date 2 April

Reference Station Newport

HW time difference +0 32 Diff. in height of HW *0.40

LW time difference +2 21 Diff. in height of LW *0.40

Ref. Sta. Newport Sub Sta. Little Harbor

LW				
HW	0009	3.9	0041	1.6
LW	0609	0.1	0830	0
HW	1242	3.2	1314	1.3
LW	1819	0.2	2040	0
HW				

Height of tide at any time

Location Little Harbor Time 1100 Date 2 April

Duration of Rise or Fall	4h 44m
Time from Nearest Tide	2h 14m
Range of Tide	1.3
Height of Nearest Tide	1.3
Correction from Table 3	0.7
Height of Tide at 1100	0.6

Depth of water at any time

Charted Depth of Water	24 ft
Height of Tide at 1100	0.6
Depth of Water at 1100	24.6 ft

CHAPTER 8, Tides and Currents - Currents

8-1. d (8.2.3)
8-2. a (8.2.3)
8-3. F (8.2.3)
8-4. T (8.2.3)
8-5. F (8.2.4)
8-6. F (8.2.4)
8-7. F (8.2.4)
8-8. b (8.2.4)
8-9. c (8.2.4)
8-10. c (8.2.4)
8-11. a (8.2.5.2)
8-12. b (8.2.5.2)
8-13. c (8.3.4)
8-14. c (8.3.4)
8-15. c (8.3.4)
8-16. T (8.3.5)
8-17. F (8.3.5.1)
8-18. F (8.3.5.2)
8-19. T (8.4)
8-20. F (8.5.1)

PROBLEMS

8-1. Worksheet on page B-34

8-2. From Table 1 (pg A-7, Appendix A), Tidal Current Predictions, maximum currents in Pollock Rip Channel on 6 April are 2.1 knots flooding and 1.6 knots ebbing. From Table 2 (pg A-8), speed ratios for Tarpaulin Cove are 1.0 for the flood and 1.4 for the ebb. 2.1 x 1.0 = 2.1; 1.6 x 1.4 = 2.24 = 2.2 kts maximum current

8-3. Worksheet on page B-35

8-4. Rotary Current

Last slack water on 2 April occurs at 2010, maximum flood occurs at 1059, 9 hours earlier

From Table 5 (page A-11), the current at Gooseberry Neck 9 hours after the maximum flood is 0.2 kts at 321°

8-5 NE wind is 045°, blowing towards 225°. Current sets 22° to the right of the wind. From page 8-11 of the workbook, current resulting from a 50 mph wind is 0.6 kts

Current is 0.6 kts at 247°

8-6. Worksheet on page B-36

Flood or ebb begin at the preceding slack water. The slack closest to 0700 EST (0800 EDT) occurs at 0557 (0657 EDT) and the current is ebbing. The vessel, then, leaves Cross Rip Channel about 1 hour after the ebb begins. Current averages about 0.8 kts fair. Average SOG = 7.8 kts

8-7. Worksheet on page B-37

Three hours before the flood or three hours after the ebb will give approximately equal results. Note that 0900 EST is both three hours before the flood and three hours after the ebb. 1000 or 2200 EDT

TIDAL CURRENT WORKSHEET

Locality: Brenton Point, 1.4M SW Date: 3 April

Reference Station: Pollock Rip Channel

Time Diff.:	Min. before Flood	-1 03
	Flood	-0 38
	Min. before Ebb	-1 20
	Ebb	-1 04
Speed Ratio:	Flood	0.2
	Ebb	0.4
	Flood Direction:	347°
	Ebb Direction:	170°

Ref. Sta: PRC		Locality: BP		Locality:	
0238:0338	S	0218	S		
0621	1.6 E	0517	0.6E		
0934	S	0831	S		
1316	1.9F	1238	0.4F		
1625	S	1505	S		
1910	1.5E	1806	0.6E		
2221	S	2118	S		
040154	1.7F	040116	0.3F		

Velocity of Current at any Time; 1015

Interval between slack and desired time	1h 44m	
Interval between slack and max. current	4h 07m	
Max. current:	0.4F	
Factor, Table 3	0.6	
Velocity	0.2F	
Direction	347°	

Duration of Slack

Times of max. current			
Max. current			
Desired max.			
Period - Table 4			
Sum of periods			
Average period			
Times of slack			
Duration of period (± ___m)			

TIDAL CURRENT WORKSHEET

Locality: West Island, 1M SE

Date: 1 April

Reference Station: Pollock Rip Channel

Time Diff.:	Min. before Flood	-0 43
	Flood	-0 43
	Min. before Ebb	-1 28
	Ebb	-1 42
Speed Ratio:	Flood	0.4
	Ebb	0.5
	Flood Direction:	079°
	Ebb Direction:	203°

Ref. Sta: PRC		Locality: WI		Locality:	
0033	S	312305Mar	S		
0315	2.0E	0133	1.0E		
0627	S	0544	S		
0949	2.2F	0906	0.9F		
1314	S	1146	S		
1551	1.8E	1409	0.9E		
1904	S	1822	S		
2220	1.8F	2137	0.7F		

Velocity of Current at any Time; _____

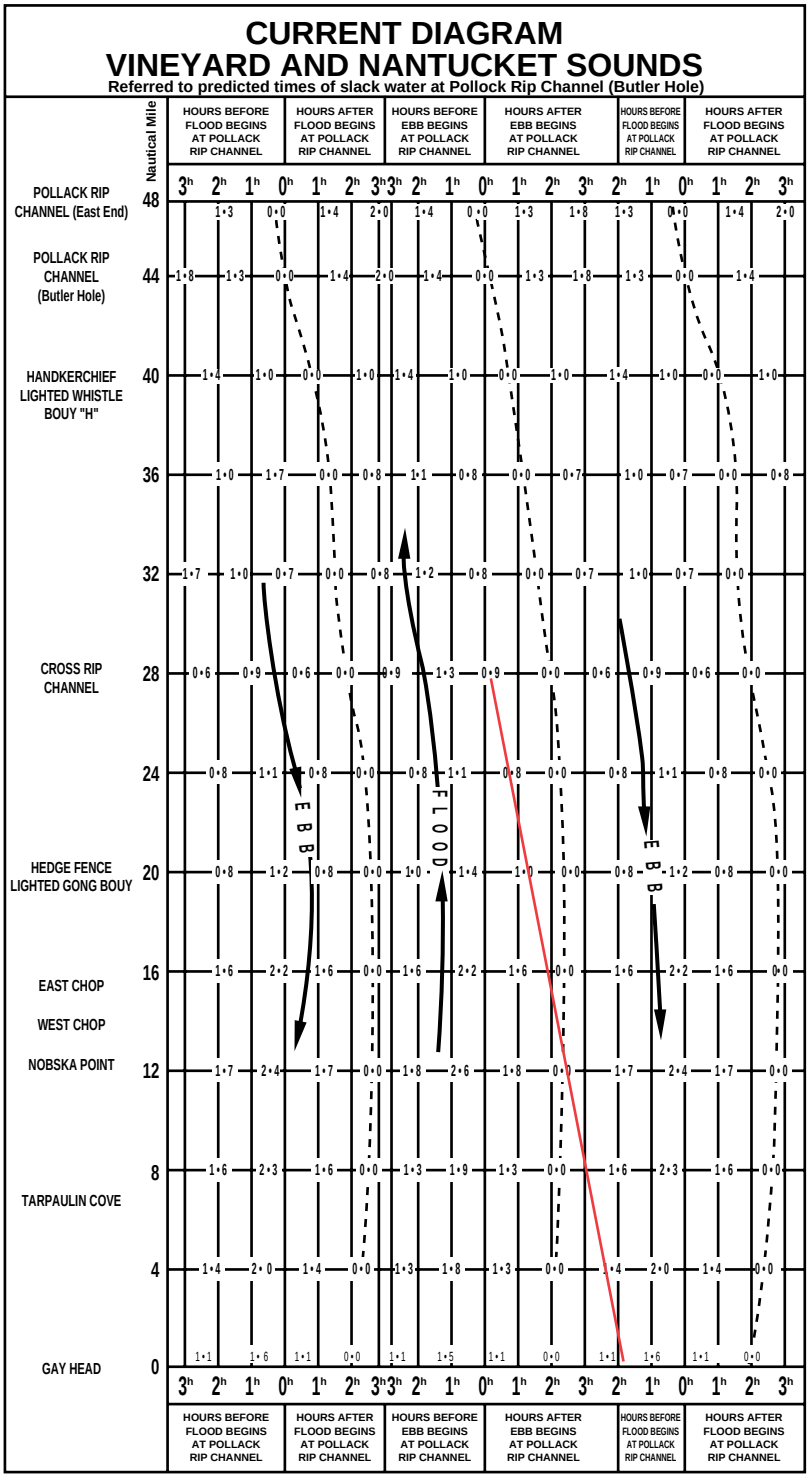
Interval between slack and desired time		
Interval between slack and max. current		
Max. current:		
Factor, Table 3		
Velocity		
Direction		

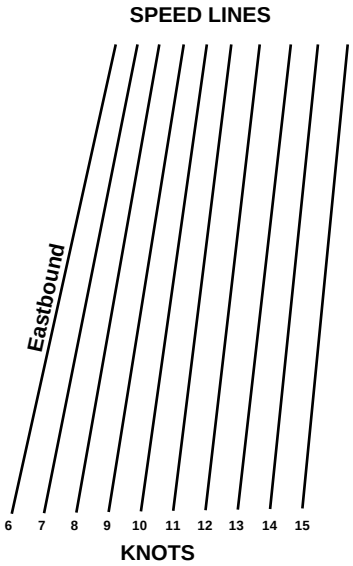
Duration of Slack

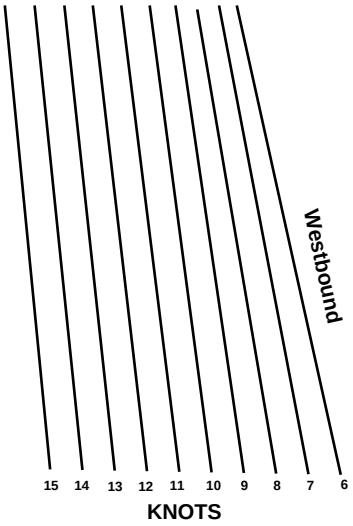
Times of max. current	0133	0906	1409
Max. current	1.0	0.9	0.9
Desired max.	0.3	0.3	0.3
Period - Table 4	70m	70m	70m
Sum of periods	140	140	
Average period	70	70	
Times of slack	0544	1146	
Duration of period (±35 m)	0509-0619	Ext into p.m.	

CURRENT DIAGRAM
VINEYARD AND NANTUCKET SOUNDS

Referred to predicted times of slack water at Pollock Rip Channel (Butler Hole)

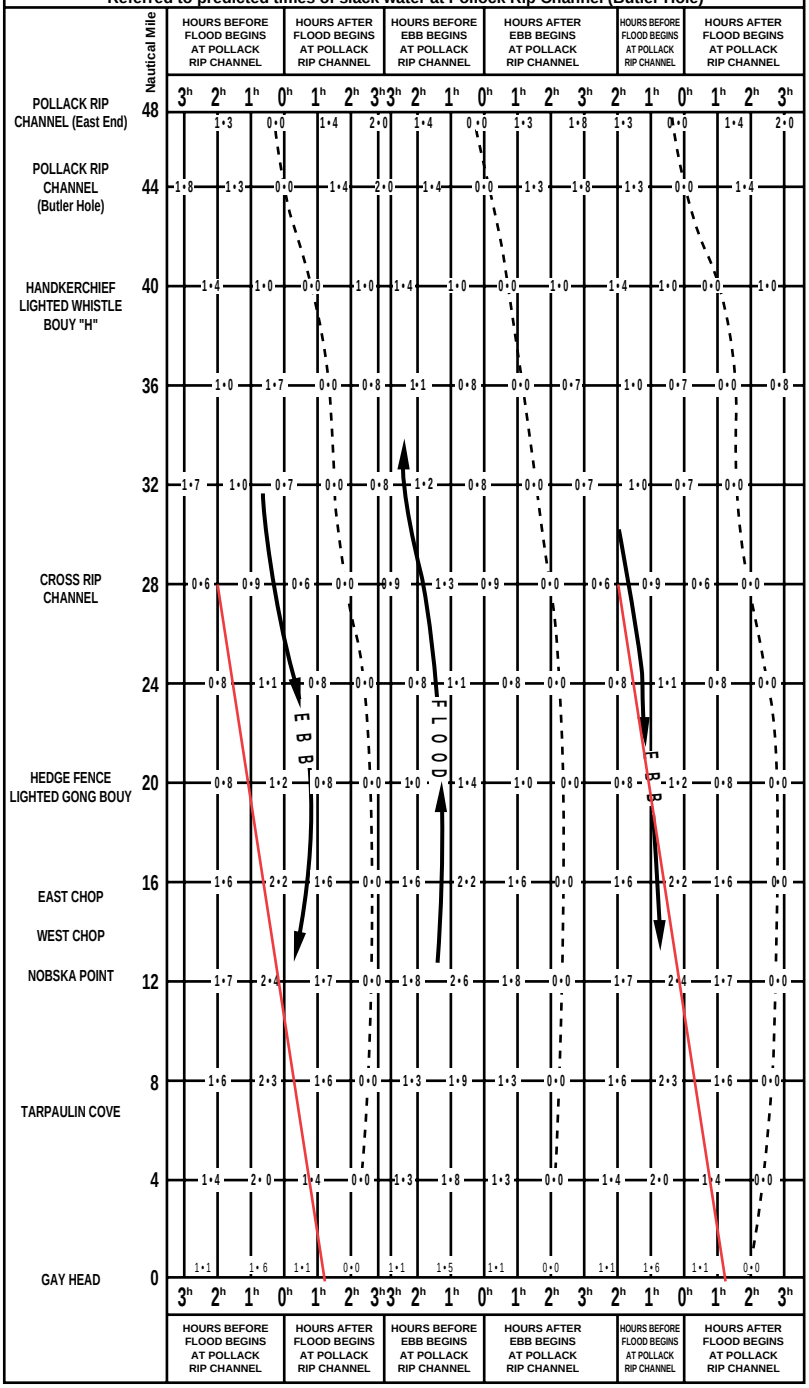


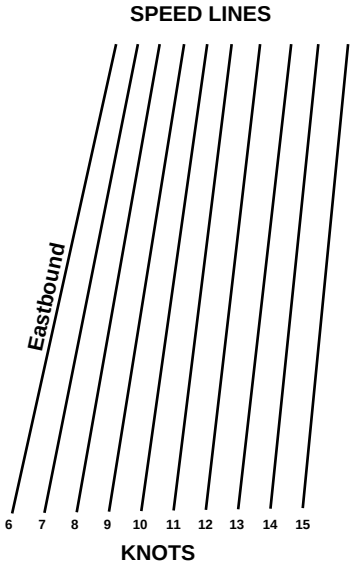


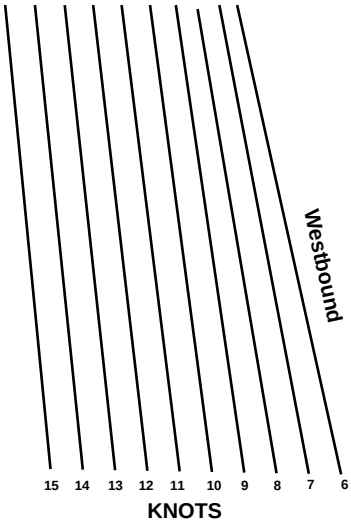


CURRENT DIAGRAM
VINEYARD AND NANTUCKET SOUNDS

Referred to predicted times of slack water at Pollock Rip Channel (Butler Hole)







CHAPTER 9, Electronic (Radio) Navigation

9-1.	c	(9.1.2)
9-2.	b	(9.1.3.2)
9-3.	b	(9.1.3.3)
9-4.	F	(9.1.3.3.1)
9-5.	T	(9.1.3.4)
9-6.	T	(9.1.3.5)
9-7.	T	(9.2.2)
9-8.	F	(9.2.2)
9-9.	c	(9.2.4)
9-10.	a	(9.2.4)
9-11.	a	(9.2.5)
9-12.	c	(9.2.5)
9-13.	b	(9.2.6)
9-14.	a	(9.2.9)
9-15.	d	(9.2.7)
9-16.	T	(9.2.9)
9-17.	F	(9.3.1)
9-18.	F	(9.3.1)
9-19.	F	(9.3.2)
9-20.	F	(9.3.2)
9-21.	T	(9.3.2)
9-22.	a	(9.3.3)
9-23.	b	(9.3.3)
9-24.	b	(9.3.3.2)

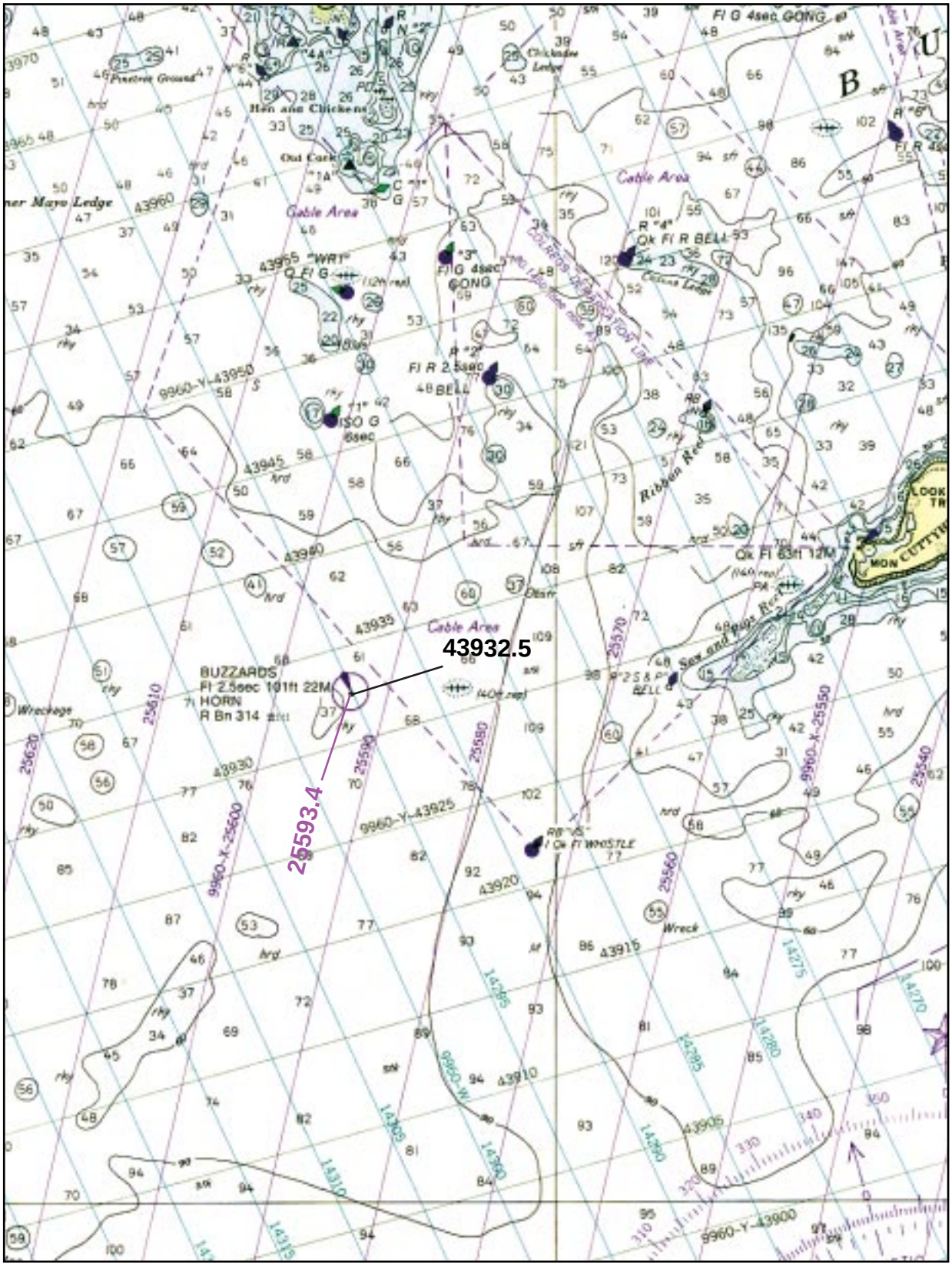
PROBLEMS

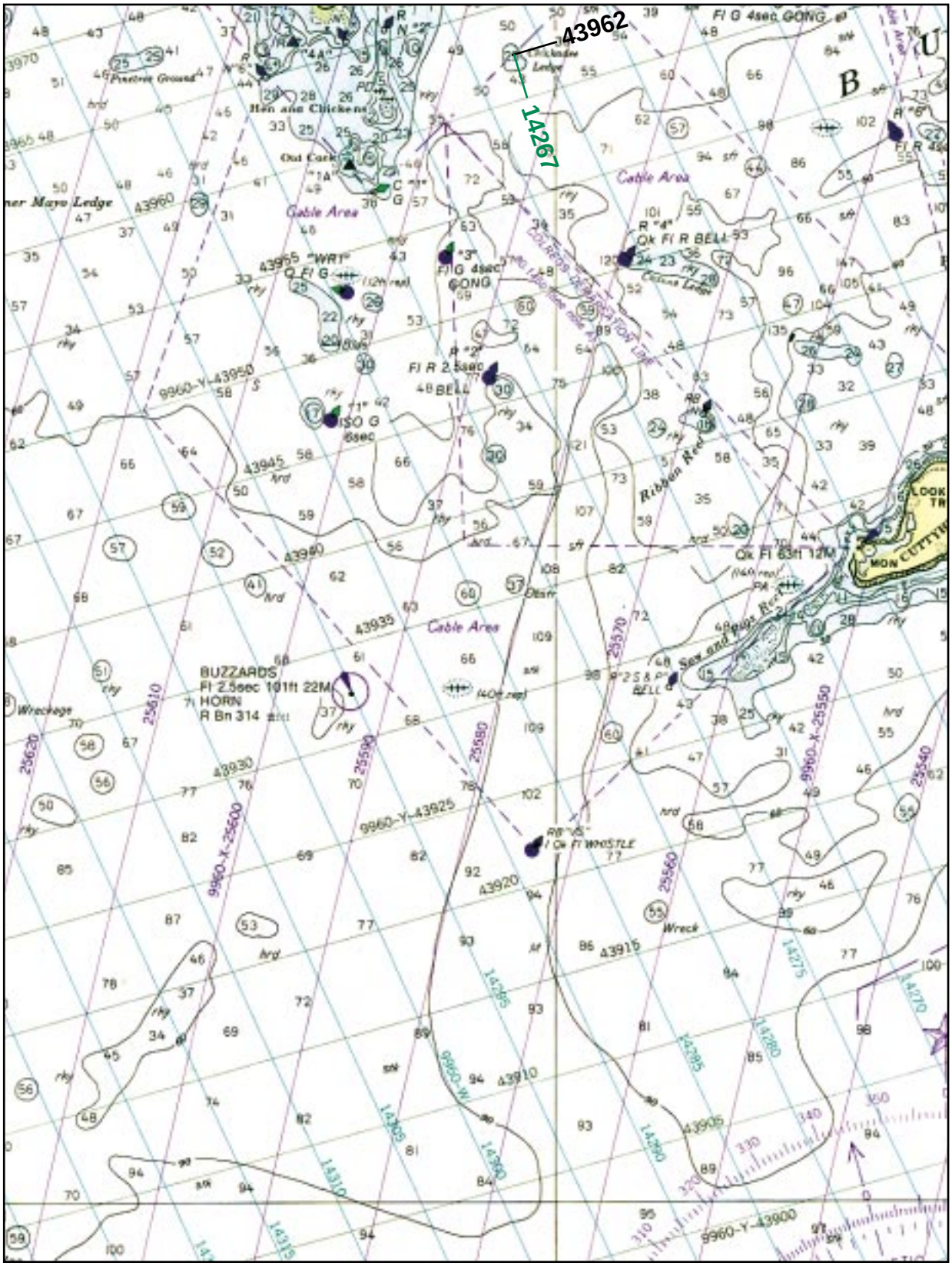
9-1. Chart segment on page B-39

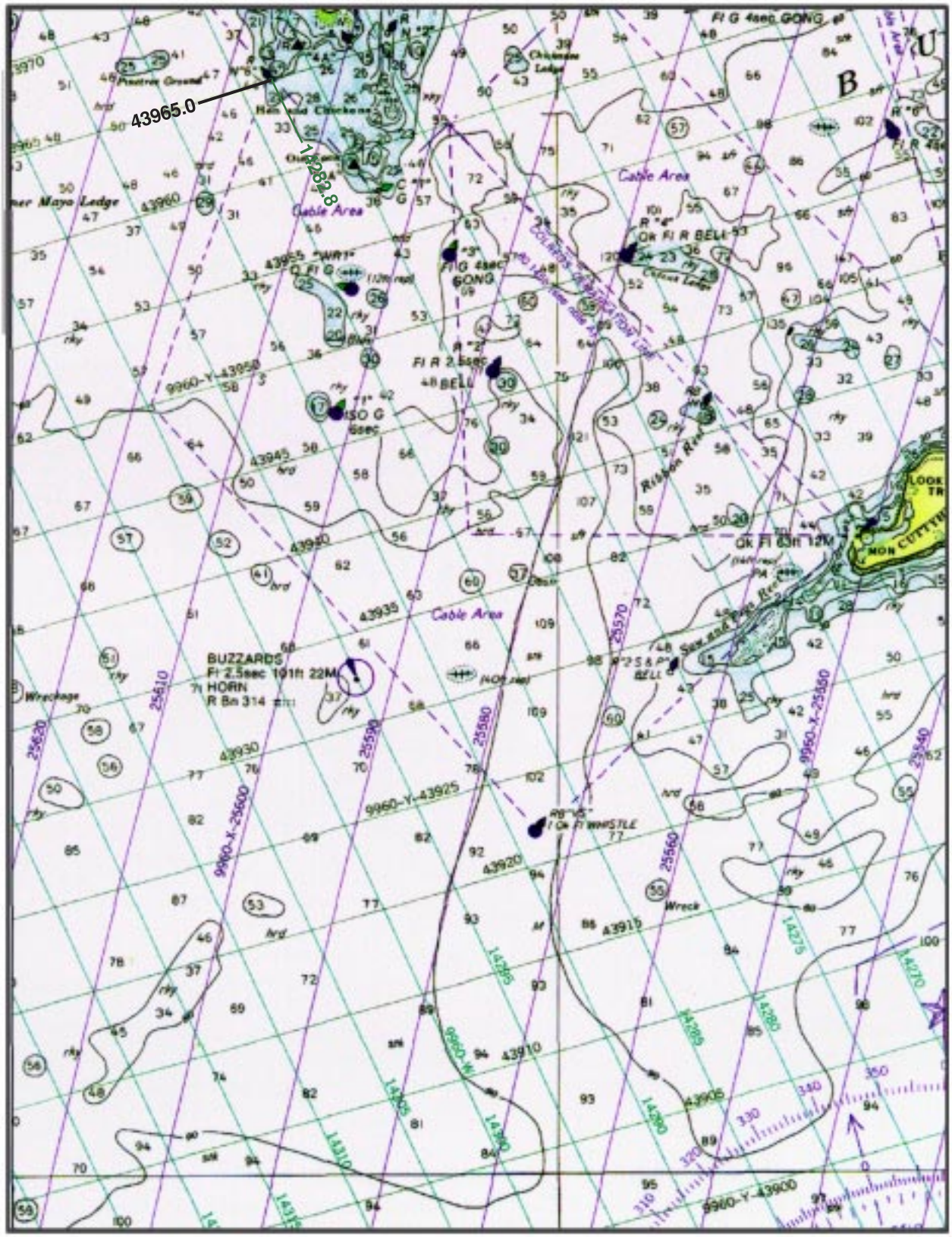
9-2. Chart segment on page B-40

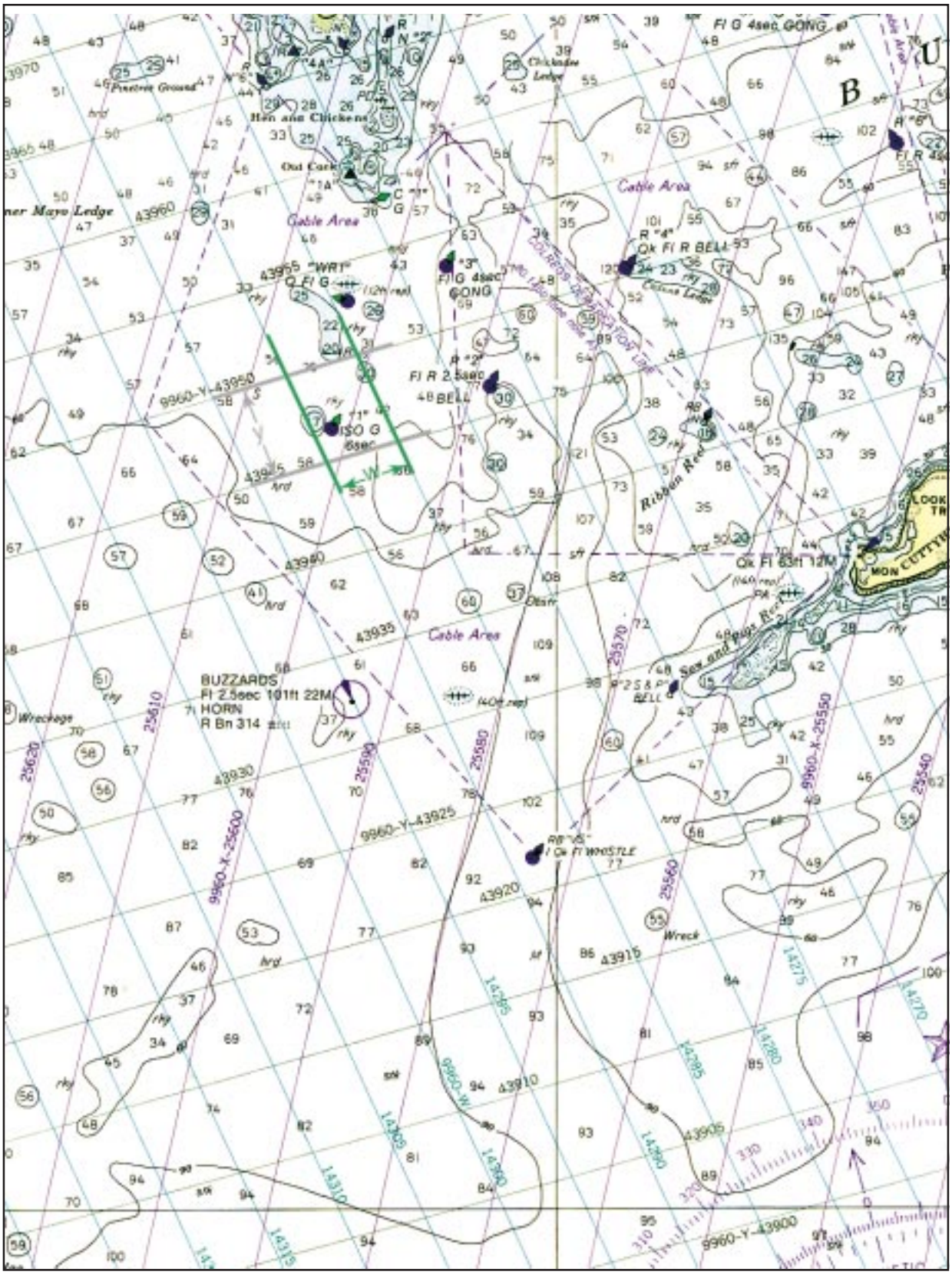
9-3. Chart segment on page B-41

9-4. Chart segment on page B-42


43932.5
25593.4
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Cable Area
Ribbon Reef
Hen and Chickens
Prentice Ground
Chickadee Ledge
Fl G 4sec GONG
Qk Fl R BELL
Fl R 2.5sec
BELL
ISO G
6sec
Qk Fl 63ft 12M
Qk Fl WHISTLE
Wreck
Wreckage
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25550
43960
43945
43930
43920
43910
43905
43935
43915
25610
25620
25580
25570
25560
25540
14275
14280
14285
14290
14295
14300
14305
14310
14315


43962
14267
Fl G 4sec GONG
Prentice Ground
Hen and Chickens
Out Cork
Cable Area
Fl G 4sec GONG
Fl R 2.5sec
48 BELL
ISO G
6sec
Qk Fl R BELL
Ribbon Reef
Qk Fl 6sec 12M
MON CUTTY
Sea and Pigs Rock
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Qk Fl WHISTLE
Wreck
Wreckage
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25550
9960-W-14310


43965.0
14282.8
Cable Area
Cable Area
Cable Area
Fl G 4sec GONG
Fl R 2.5sec BELL
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Wreck
Wreck
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25560
43945
43940
43935
43930
43920
43915
43910
43905
25610
25590
25580
25570
25560
25550
25540
14275
14270
14290
14280
14310
14305


Fl G 4sec GONG
Hen and Chickens
Out Cock
Cable Area
Fl R 2.5sec
48 BELL
ISO G
6sec
Ribbon Reef
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Wreck
Wreckage
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25550

CHAPTER 10, Radar Piloting and Relative Motion

10-1. b (10.1.2)
10-2. b (10.1.3, comment following Rule 7)
10-3. a (10.1.3, comment following Rule 19)
10-4. d (10.2.1)
10-5. transmitter, modulator, antenna, receiver, indicator (10.2.2)
10-6. indicator, Plan Position Indicator, PPI (10.2.2)
10-7. F (10.2.2)
10-8. T (10.2.3.1)
10-9. F (10.2.3.2)
10-10. c (10.2.3.1)
10-11. a (10.3.1.2)
10-12. b (10.3.1.4)
10-13. d (10.3.1.1)
10-14. d (10.4.1)
10-15. c (10.4.1)
10-16. b (10.4.1)
10-17. b (10.4.2)
10-18. F (10.4.2)
10-19. F (10.4.2)
10-20. T (10.4.3)
10-21. F (10.4.3.1)
10-22. F (10.4.4)
10-23. T (10.4.4)
10-24. b (10.4.4)
10-25. d (10.4.5.1)
10-26. c (10.4.5.1)
10-27. c (10.4.5.2)
10-28. a (10.4.5.2)
10-29. d (10.5.)
10-30. T (10.5.2)
10-31. F (10.5.3)

PROBLEMS

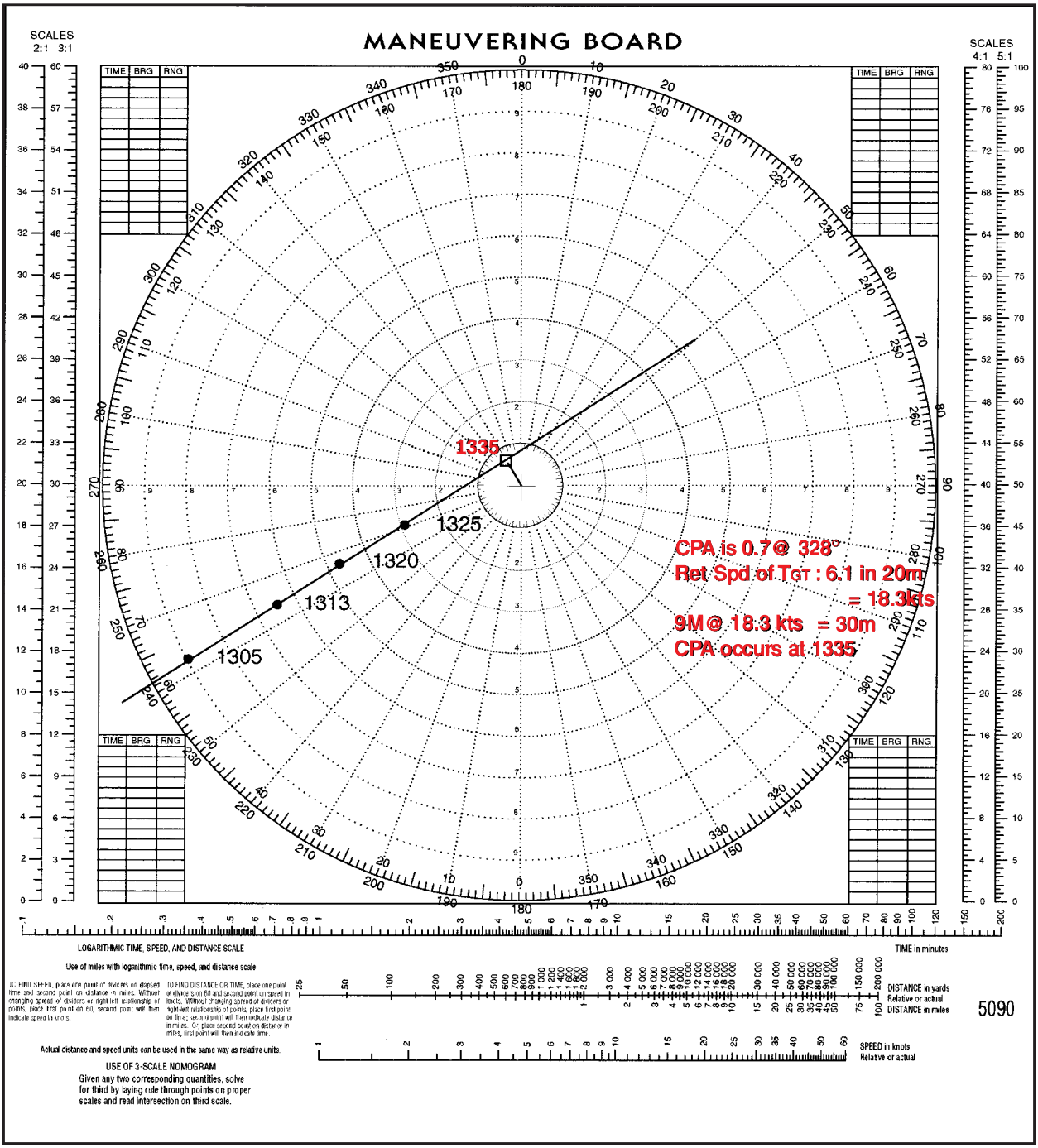
10-1. Vessel is steaming 280° at 9 kts. Convert all radar bearings to true. Plotted on page B-45

1305 322°R 9.0 M = 242° 9.0 M
1313 324°R 6.5 M = 244° 6.5 M
1320 327°R 4.4 M = 247° 4.4 M
1325 331°R 3.0 M = 251° 3.0 M

10-2. Relative speed of target is 6.1 M in 20m = 18.3kts.
Distance to CPA is 9 M. 9 M at 18.3kts = 30m
CPA occurs at 1335
Solution diagrammed on page B-45

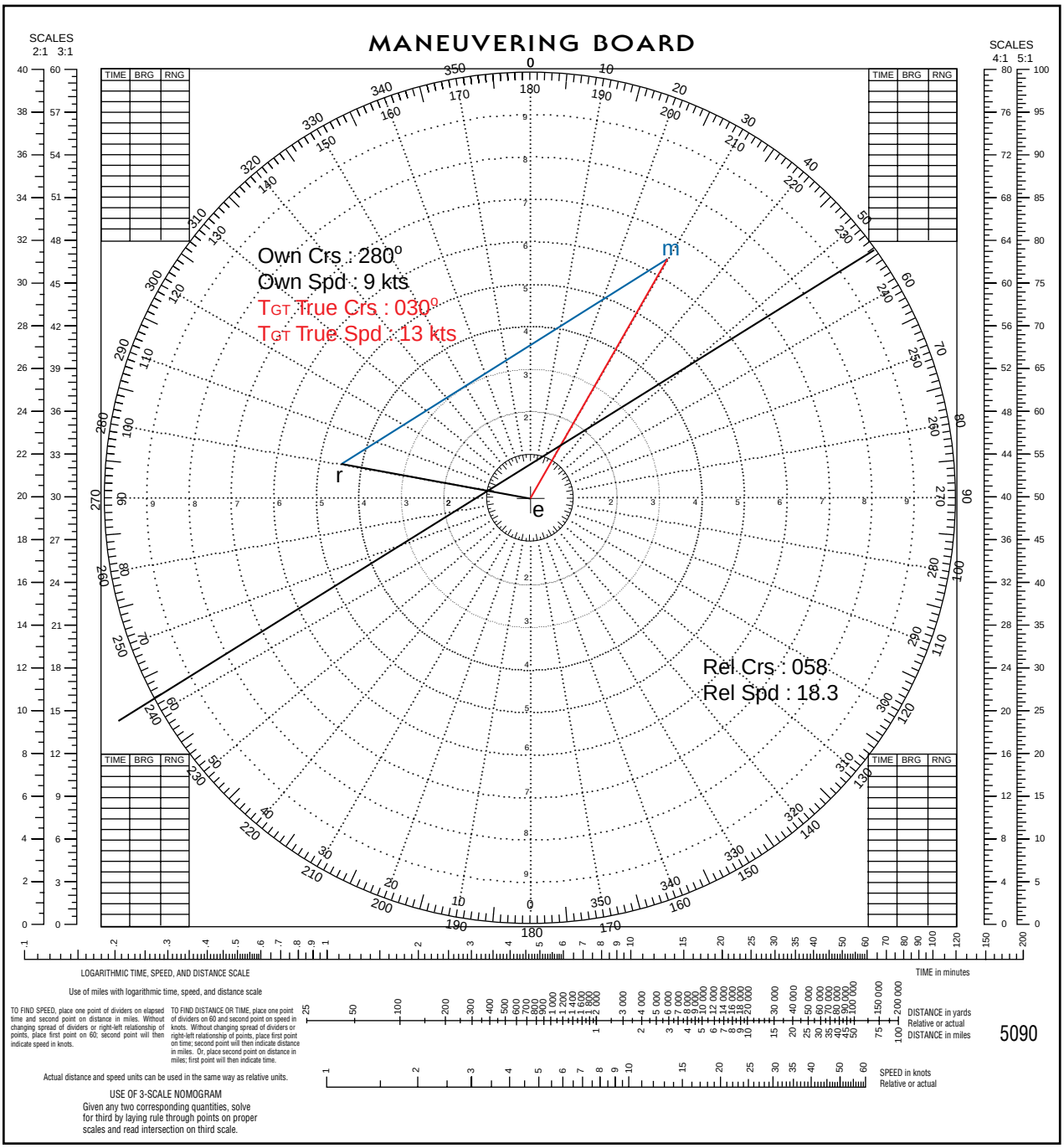
10-3 and 10-4. Solution on page B-46

10-5 and 10-6. Solution on page B-46



Rel Brg 322 = 242T 9.0M

324 =	244	6.5M
327 =	247	4.4M
331 =	251	3.0M


MANEUVERING BOARD
SCALES
2:1 3:1
SCALES
4:1 5:1
TIME BRG RNG
Own Crs : 280°
Own Spd : 9 kts
TGT True Crs : 030°
TGT True Spd : 13 kts
m
r
e
Rel Crs : 058
Rel Spd : 18.3
LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE
Use of miles with logarithmic time, speed, and distance scale
TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.
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Actual distance and speed units can be used in the same way as relative units.
USE OF 3-SCALE NOMOGRAM
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.
TIME in minutes
DISTANCE in yards
Relative or actual
DISTANCE in miles
SPEED in knots
Relative or actual
5090

ANNEX I. The Cruise Problem, Sections I through V

1. c
2. a
3. b
4. b
5. b
6. d
7. d
8. b
9. d
10. d
11. b
12. b
13. d
14. c
15. b
16. b
17. a
18. d
19. b
20. d
21. b
22. c
23. d
24. b
25. a
26. d
27. a
28. b
29. c
30. a
31. a
32. c
33. a
34. c
35. a
36. d
37. d

38. a
39. d
40. a
41. a
42. a
43. c
44. c
45. a
46. c
47. c
48. a
49. b
50. a
51. c
52. b
53. d
54. c

ANNEX I, Section VI

1. d
2. b
3. d
4. d
5. T
6. F
7. F
8. T
9. T
10. T
11. F
12. a
13. b
14. b
15. d
16. T
17. F
18. F
19. T
20. T
21. F
22. T
23. F
24. T
25. T
26. T
27. F
28. T
29. F
30. T
31. T
32. F
33. T
34. T
35. F
36. T
37. F

38. F
39. T
40. F
41. F
42. T
43. F
44. F
45. T
46. T
47. F
48. T
49. c
50. c
51. 0948
52. 5 kts
    295°
53. 178°
54. 074°
55. 3M

APPENDIX D

FORMS

This appendix contains the following blank forms:

4	Sunrise and Sunset Worksheets
4	Height of Tide Worksheets
4	Tidal Current Worksheets
2	Current Diagrams
18	Maneuvering boards
2	Napier Diagrams for Yacht Helena
4	Chart Segments
4	Luminous Diagrams

TIME OF SUNRISE OR SUNSET WORKSHEET

Location: _____
Position latitude: _____ Date: _____
Position longitude: _____

From Table 4 - Nearest date: _____ Nearest latitude: _____
Time of sunrise or sunset at nearest date and latitude: _____

Longitude of time meridian: _____
Position longitude: _____
Difference in longitude: _____

From Table 5- Correction to Local Mean Time for difference in longitude between time meridian and position (local meridian): _____

Time of sunrise or sunset at position: _____

Note: If local meridian is east of standard (time) meridian (longitudinal difference is - in the western hemisphere, + in the eastern), subtract the correction (event occurs earlier). If local meridian is west of standard meridian, add the correction.

Table 5 says to subtract or add corrections to local mean time. Local mean time in each time zone is the time of the standard meridian as given in Table 4; therefore, applying the correction provides the time of the event at the local meridian (position).

For Daylight Savings Time, add one hour to the time.

HEIGHT OF TIDE WORKSHEET

Substation _____ Date _____

Reference Station _____

HW time difference _____ Diff. in height of HW _____

LW time difference _____ Diff. in height of LW _____

Ref. Sta. _____ Sub Sta. _____

LW	_____	_____	_____	_____
HW	_____	_____	_____	_____
LW	_____	_____	_____	_____
HW	_____	_____	_____	_____
LW	_____	_____	_____	_____
HW	_____	_____	_____	_____

Height of tide at any time

Location _____ Time _____ Date _____

Duration of Rise or Fall _____

Time from Nearest Tide _____

Range of Tide _____

Height of Nearest Tide _____

Correction from Table 3 _____

Height of Tide at ____ _____

Depth of water at any time

Charted Depth of Water _____

Height of Tide at _____ _____

Depth of Water at _____ _____

TIDAL CURRENT WORKSHEET

Locality: _____ Date: _____

Reference Station: _____

	Min. before Flood	_____
Time	Flood	_____
Diff.: Min. before Ebb		_____
	Ebb	_____

Speed Flood		_____
Ratio: Ebb		_____
	Flood Direction:	_____
	Ebb Direction:	_____

Ref. Sta: _____		Locality: _____		Locality: _____	
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Velocity of Current at any Time; _____

Interval between slack and desired time	_____	_____
Interval between slack and max. current	_____	_____
Max. current:	_____	_____
Factor, Table 3	_____	_____
Velocity	_____	_____
Direction	_____	_____

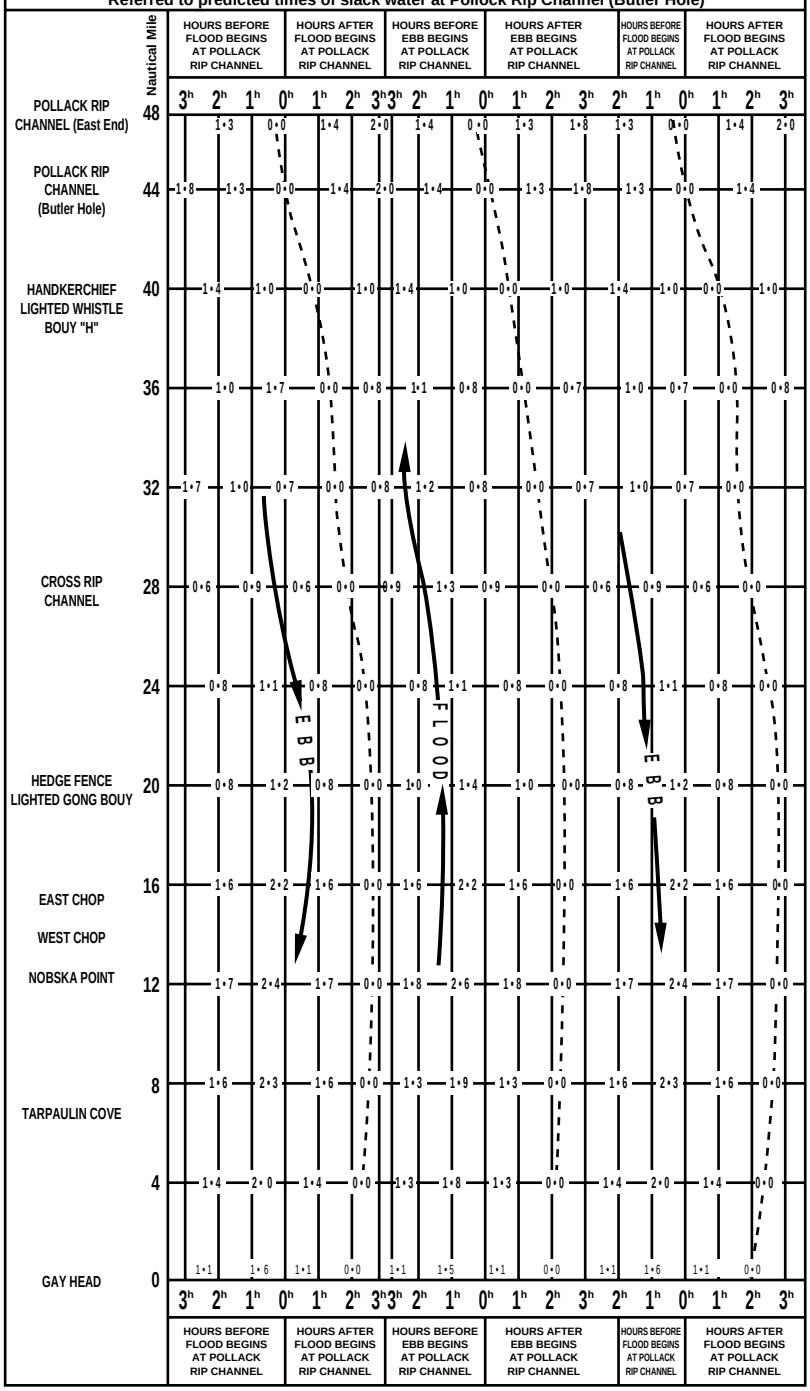
Duration of Slack

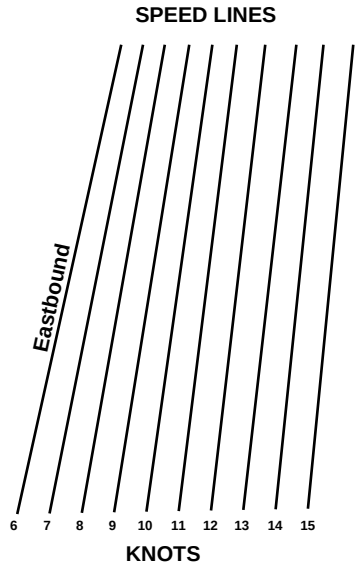
Times of max. current	_____	_____	_____
Max. current	_____	_____	_____
Desired max.	_____	_____	_____
Period - Table 4	_____	_____	_____

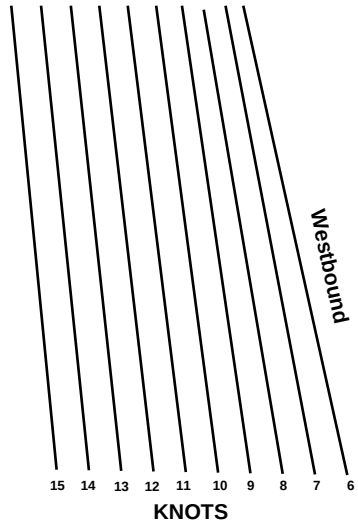
Sum of periods	_____	_____
Average period	_____	_____
Times of slack	_____	_____
Duration of period (+__m)	_____	_____

CURRENT DIAGRAM
VINEYARD AND NANTUCKET SOUNDS

Referred to predicted times of slack water at Pollock Rip Channel (Butler Hole)







CURRENT DIAGRAM
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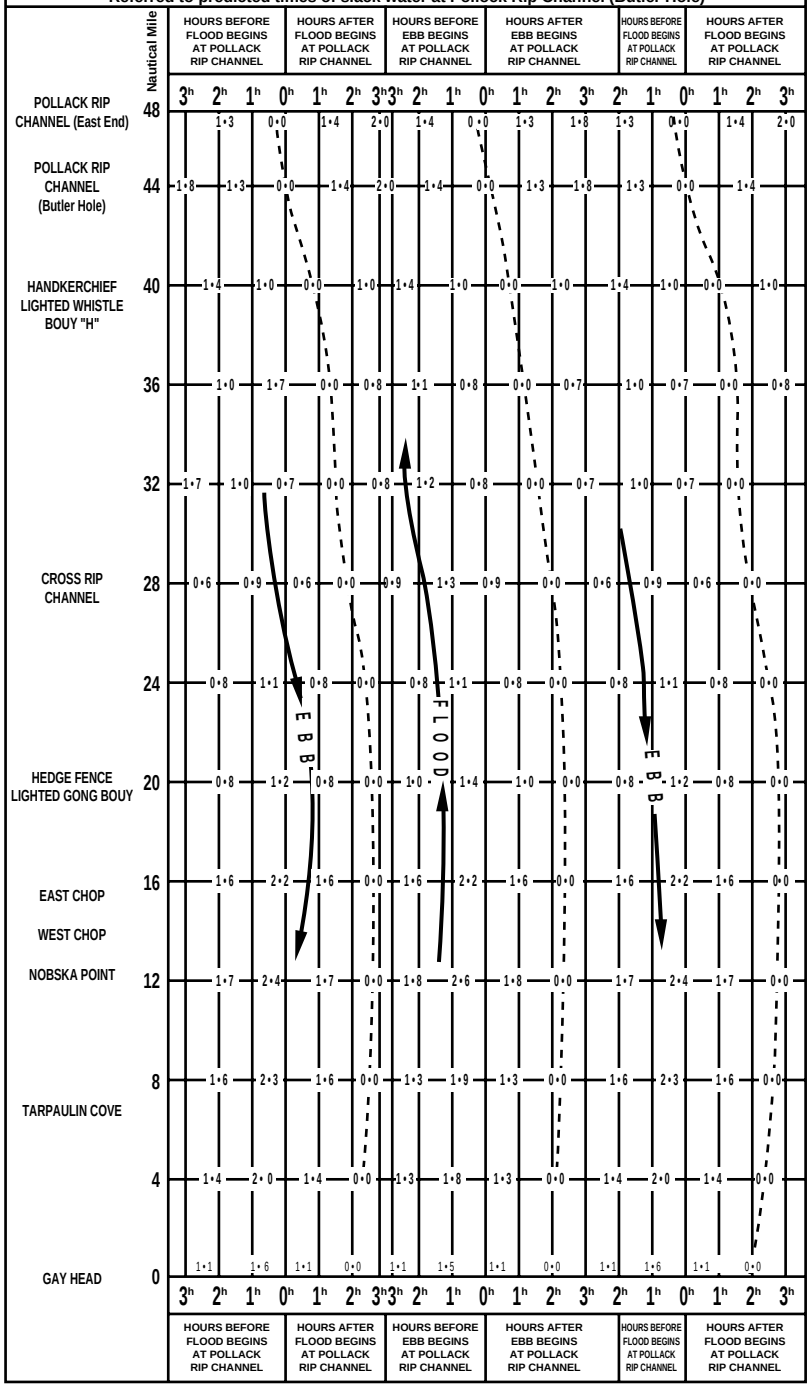
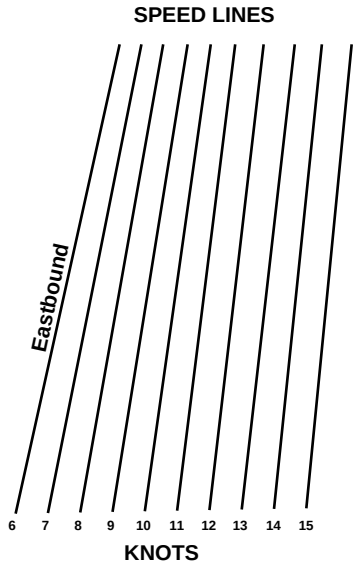
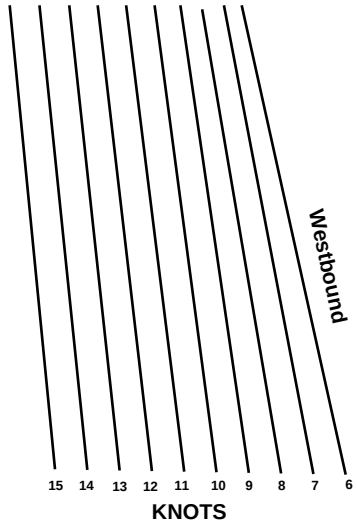
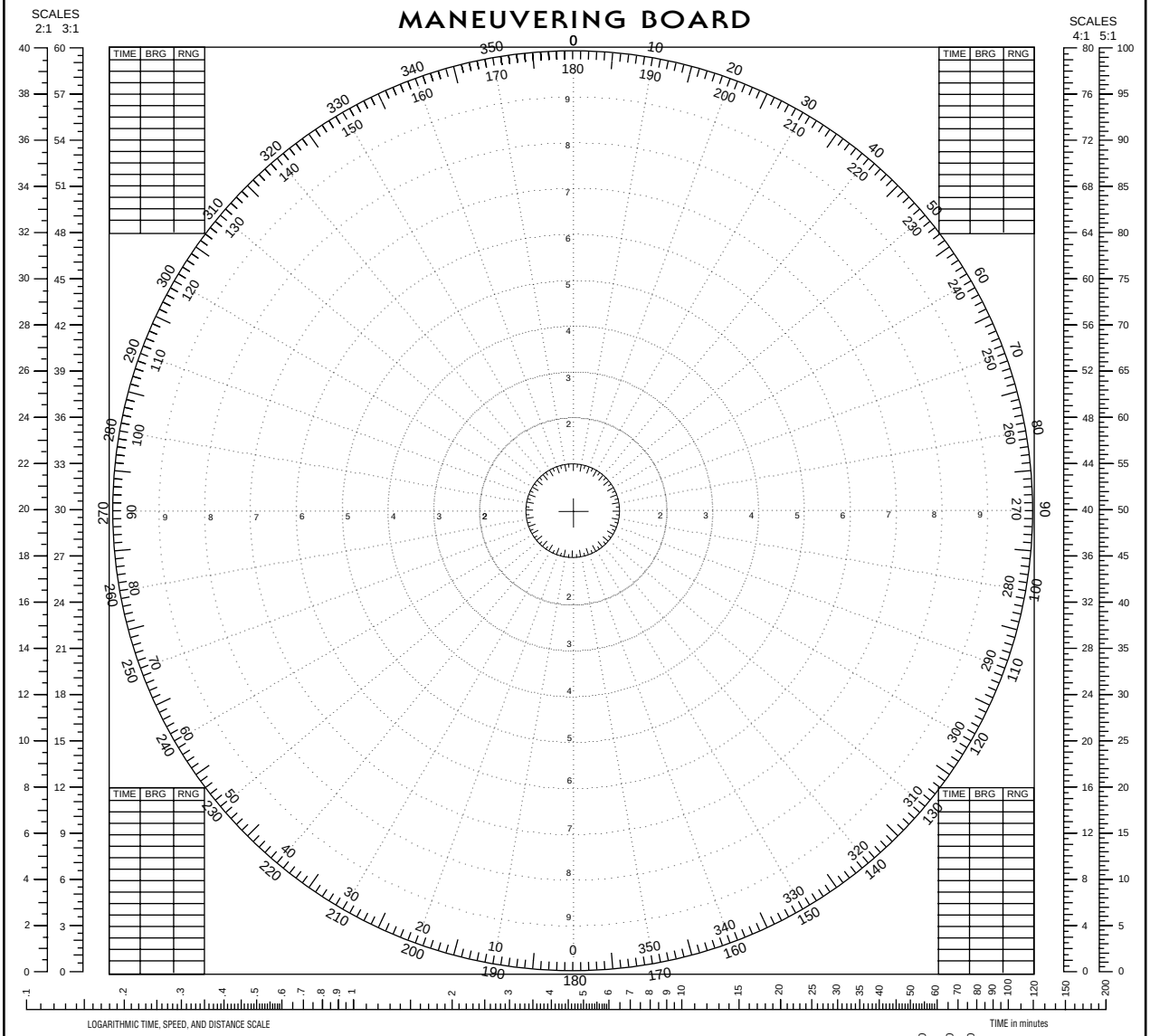






MANEUVERING BOARD



LOGARITHMIC TIME, SPEED, AND DISTANCE SCALE

TIME in minutes

Use of miles with logarithmic time, speed, and distance scale

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DISTANCE in yards
Relative or actual
DISTANCE in miles

5090

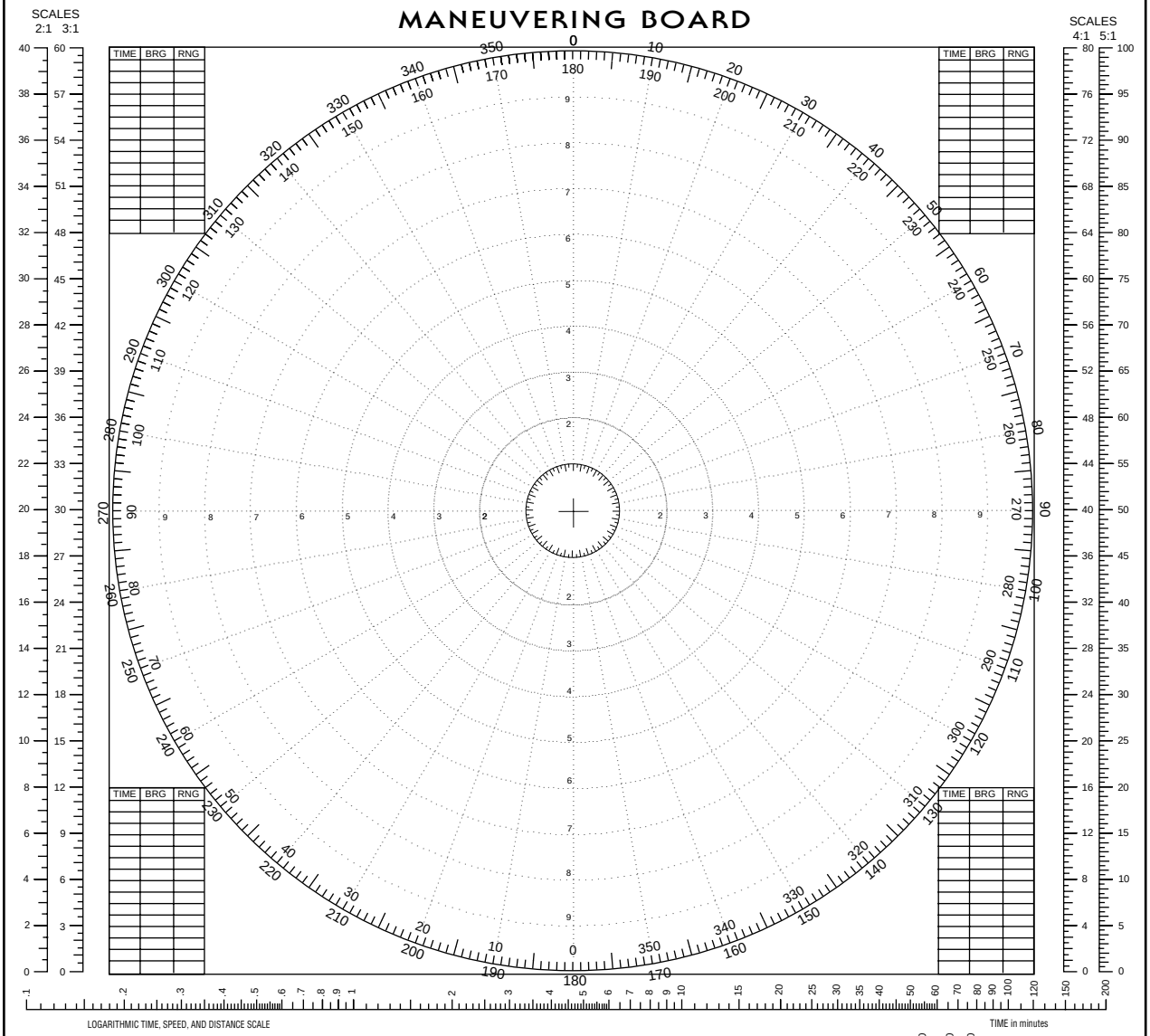
Actual distance and speed units can be used in the same way as relative units.

SPEED in knots
Relative or actual

USE OF 3-SCALE NOMOGRAM

Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.

MANEUVERING BOARD



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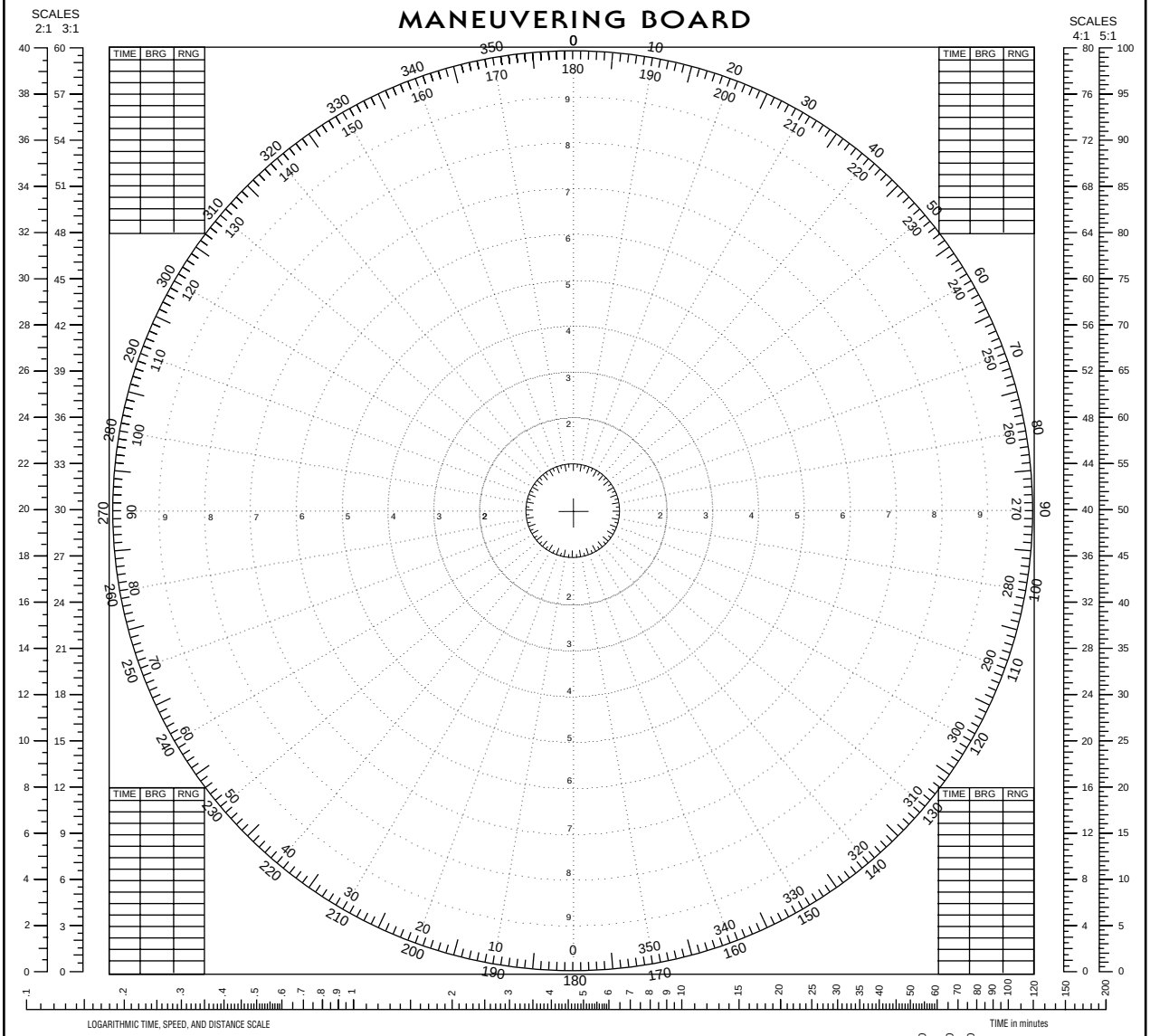

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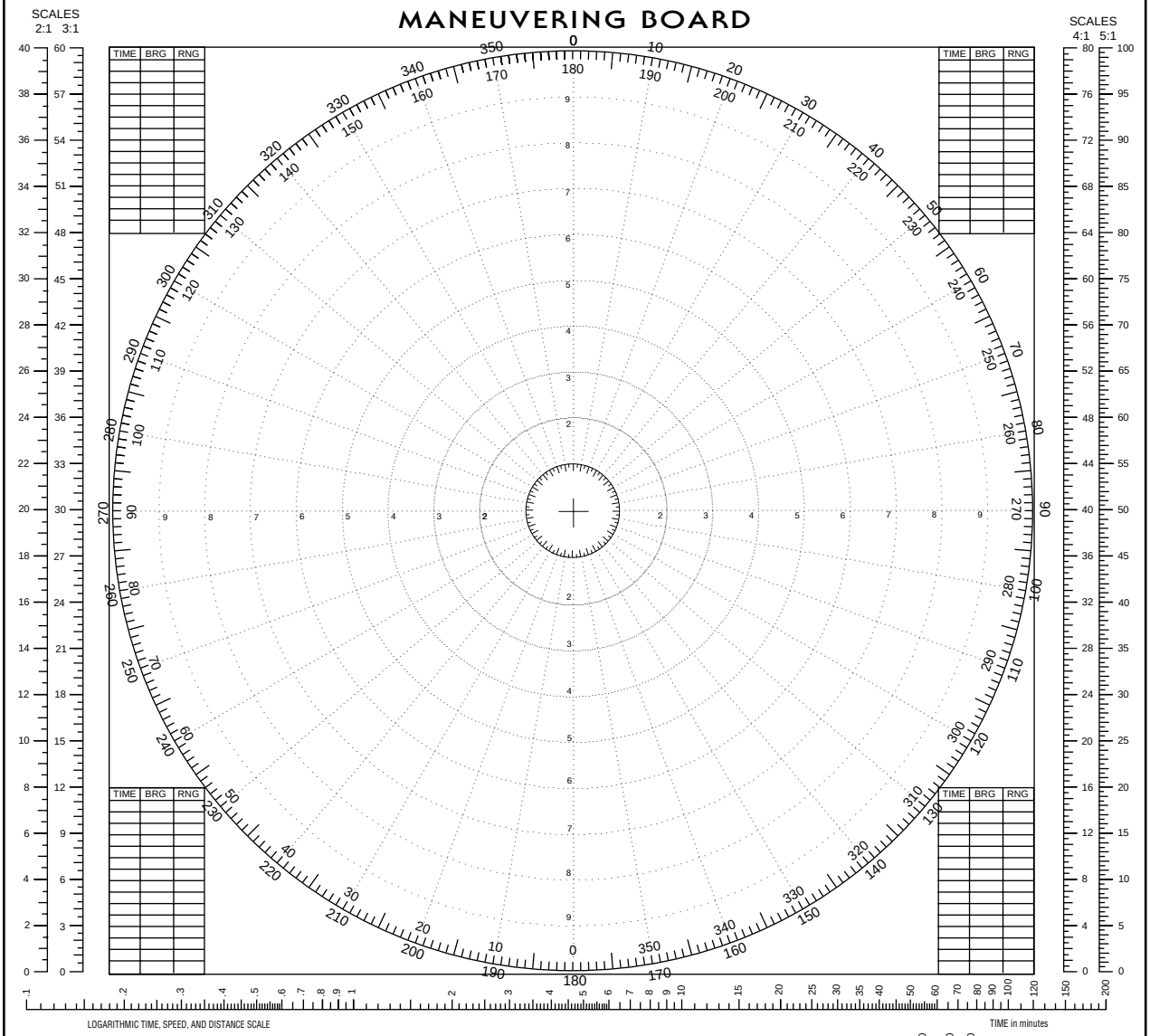

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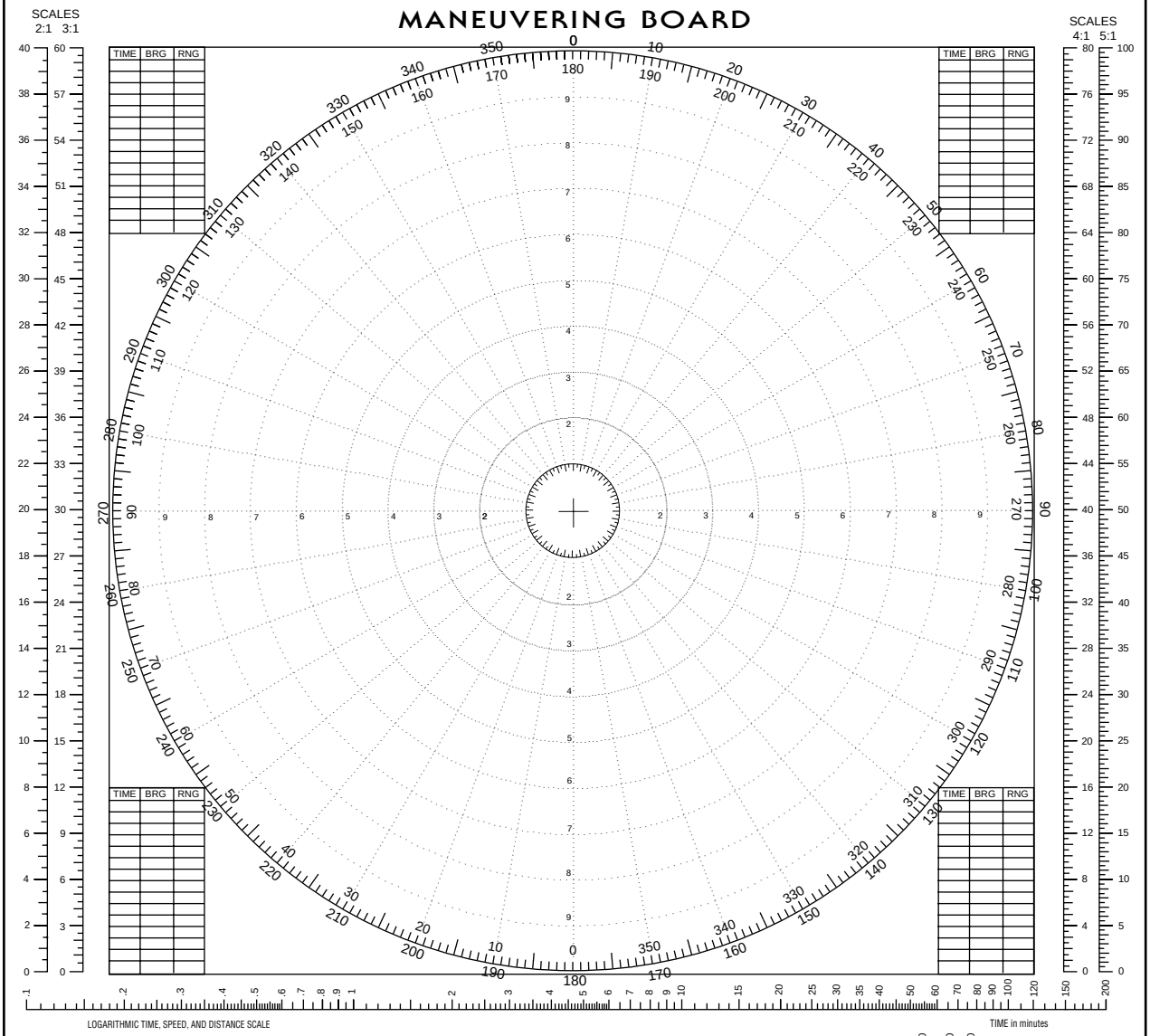

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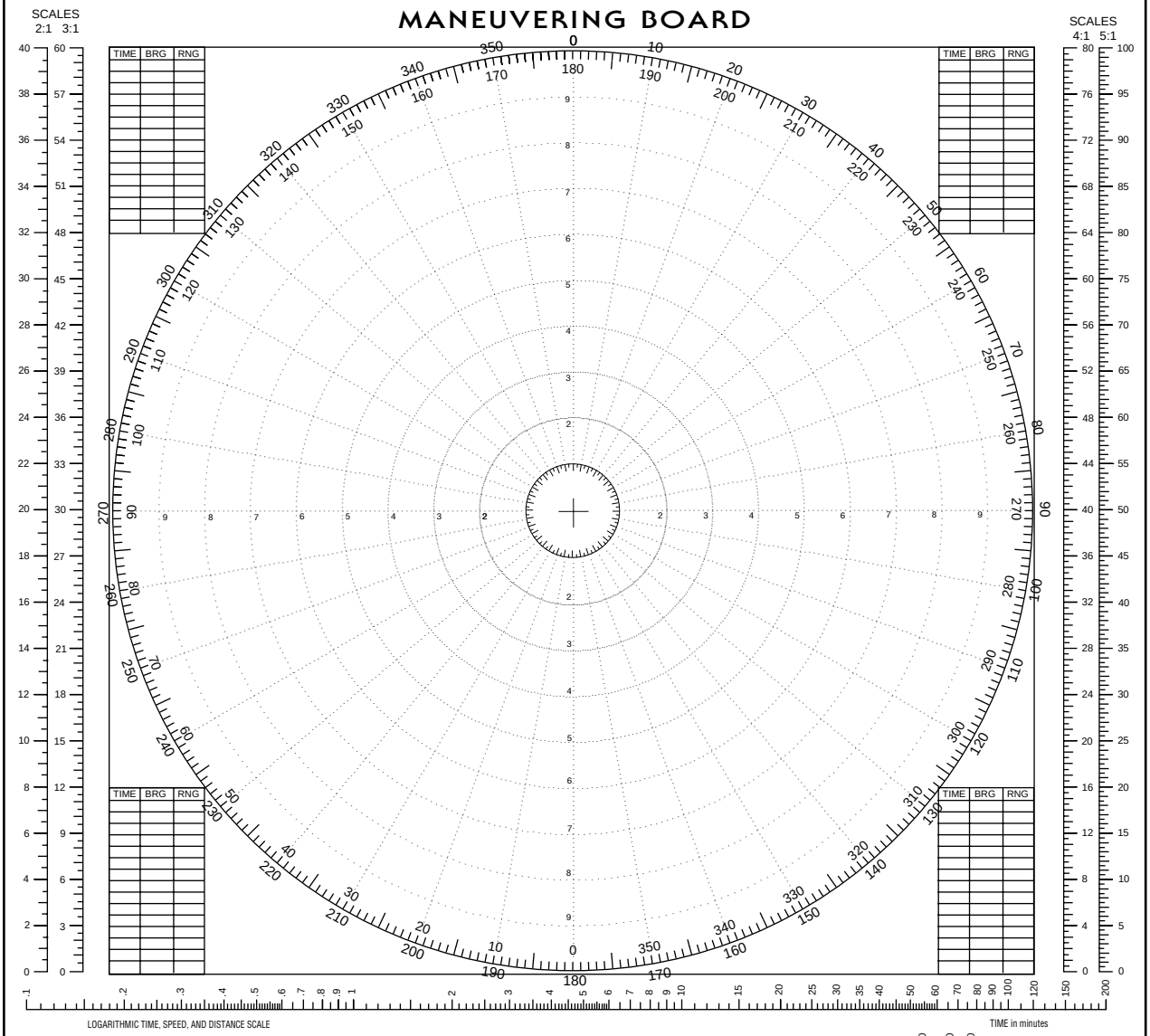

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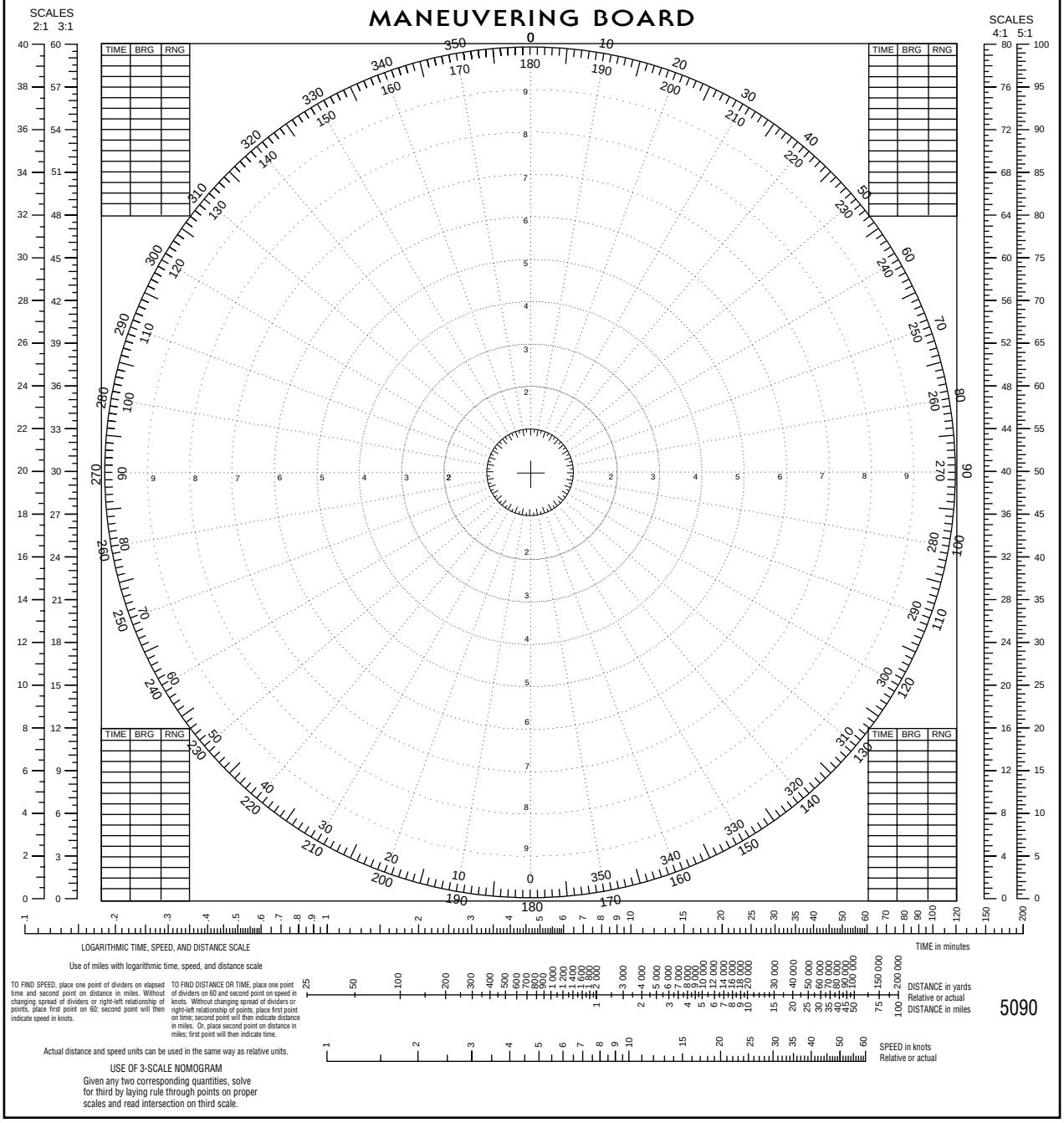

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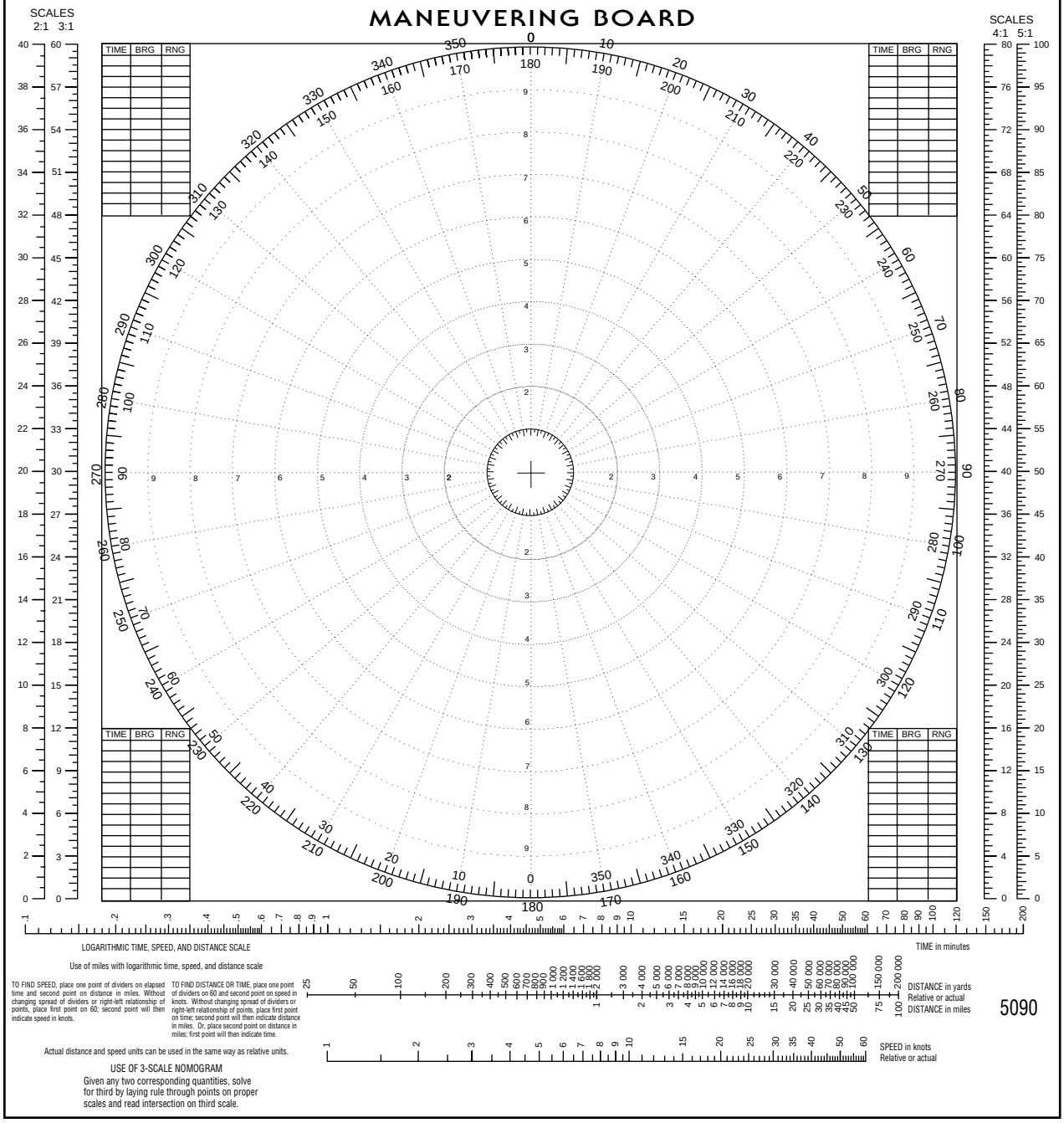

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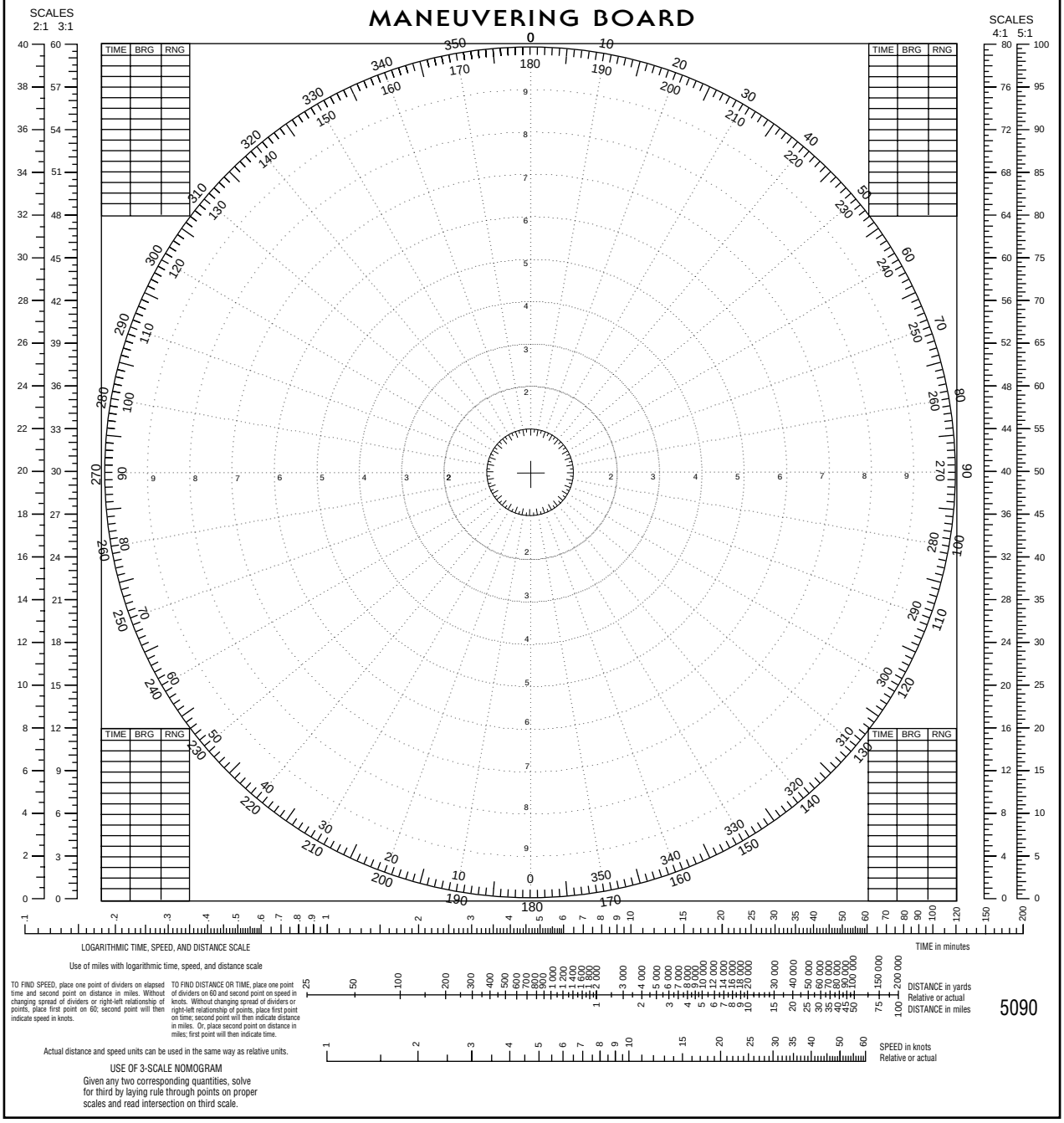

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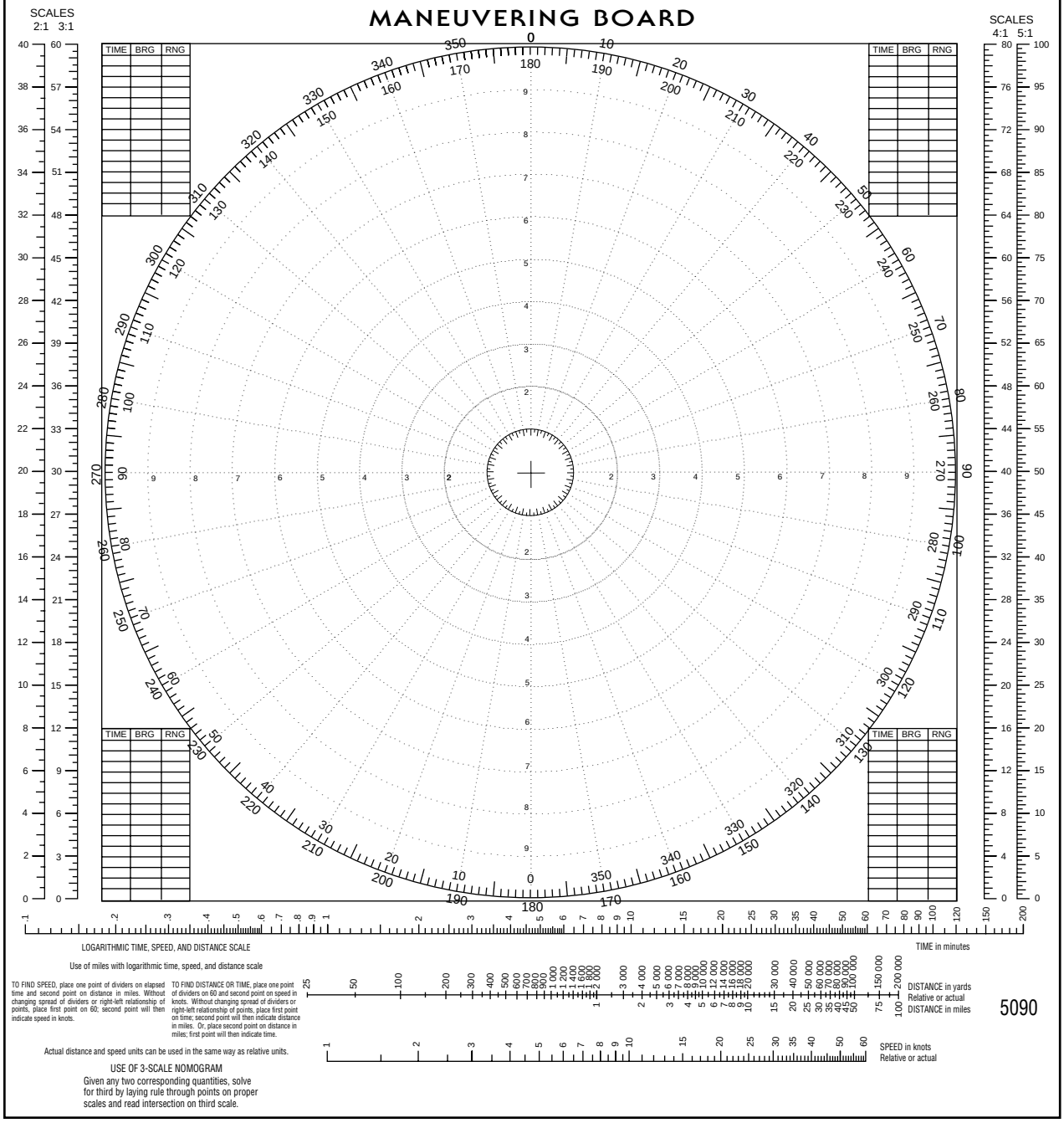
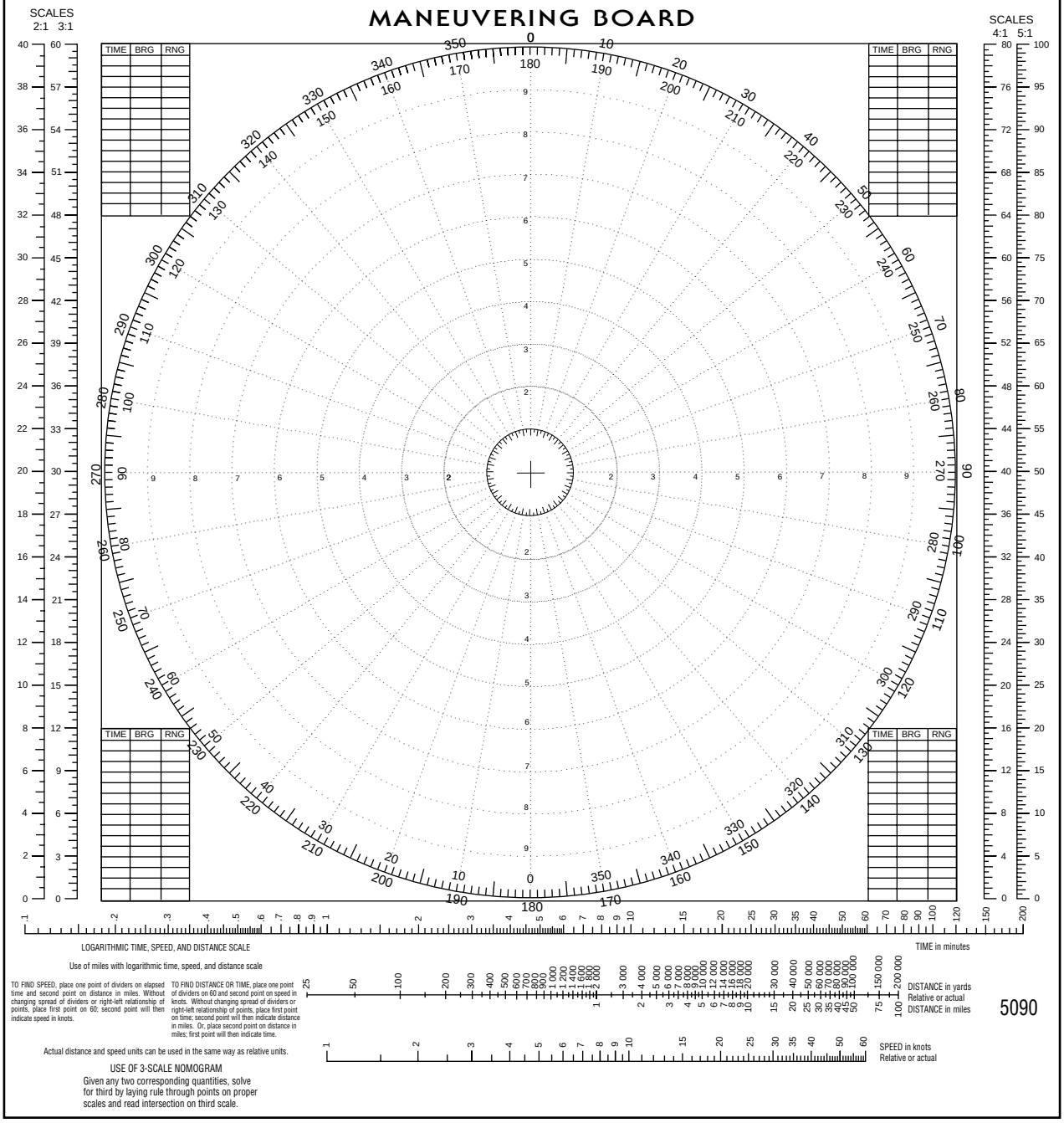


MANEUVERING BOARD



Use of miles with logarithmic time, speed, and distance scale

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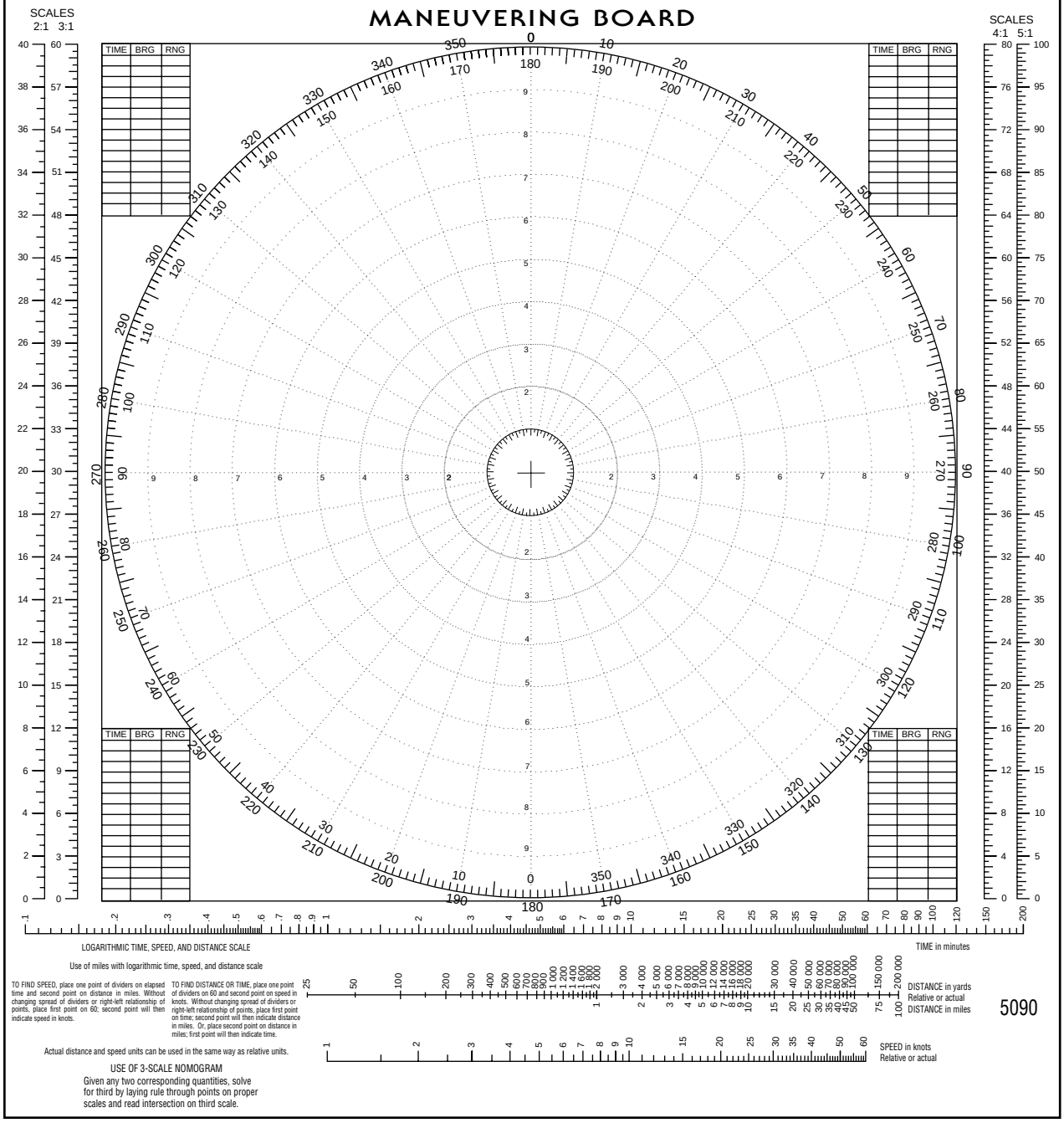
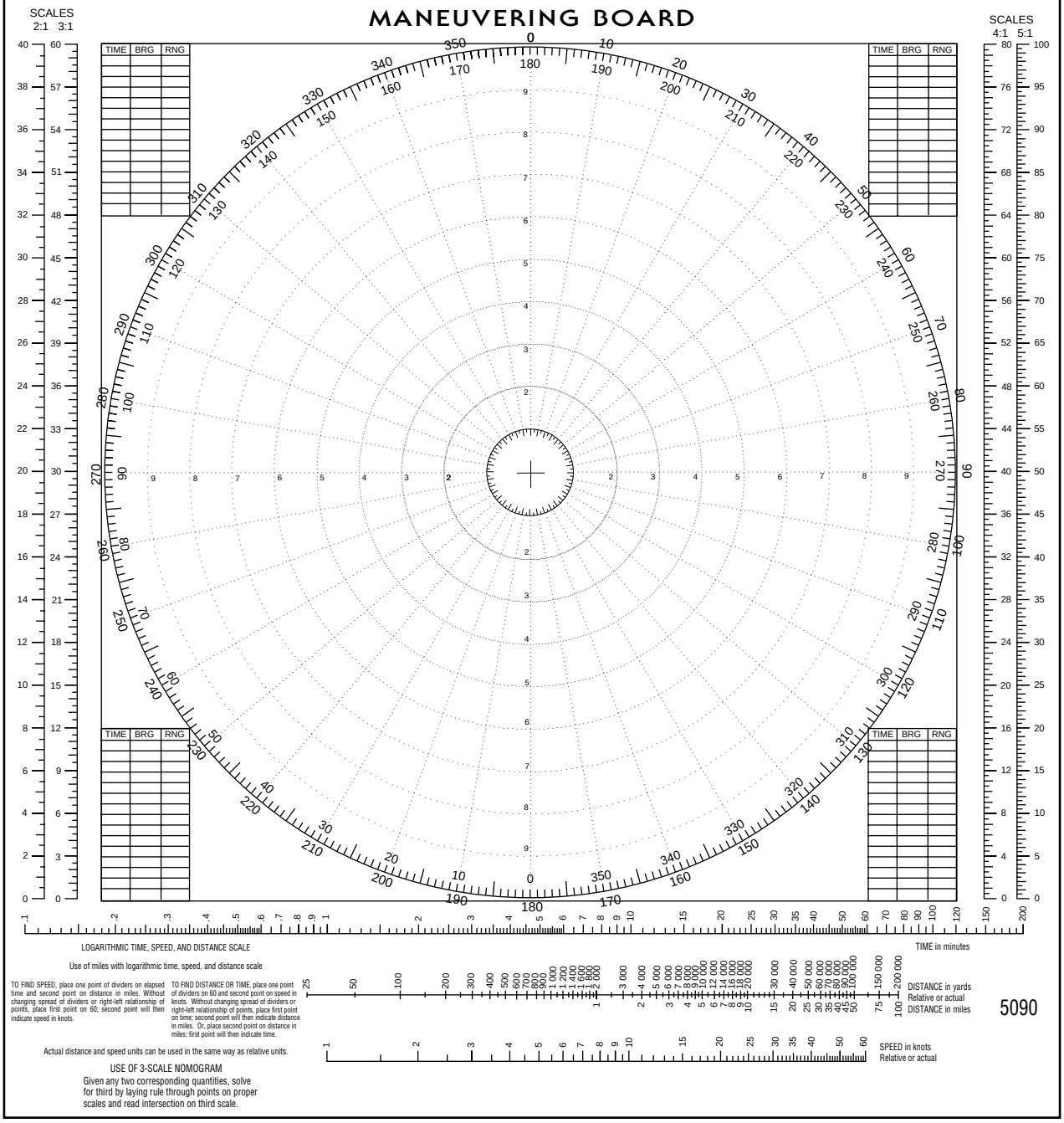


MANEUVERING BOARD



Use of miles with logarithmic time, speed, and distance scale

TO FIND SPEED, place one point of dividers on elapsed time and second point on distance in miles. Without changing spread of dividers or right-left relationship of points, place first point on 60; second point will then indicate speed in knots.

TO FIND DISTANCE OR TIME, place one point of dividers on 60 and second point on speed in knots. Without changing spread of dividers or right-left relationship of points, place first point on time; second point will then indicate distance in miles. Or, place second point on distance in miles; first point will then indicate time.

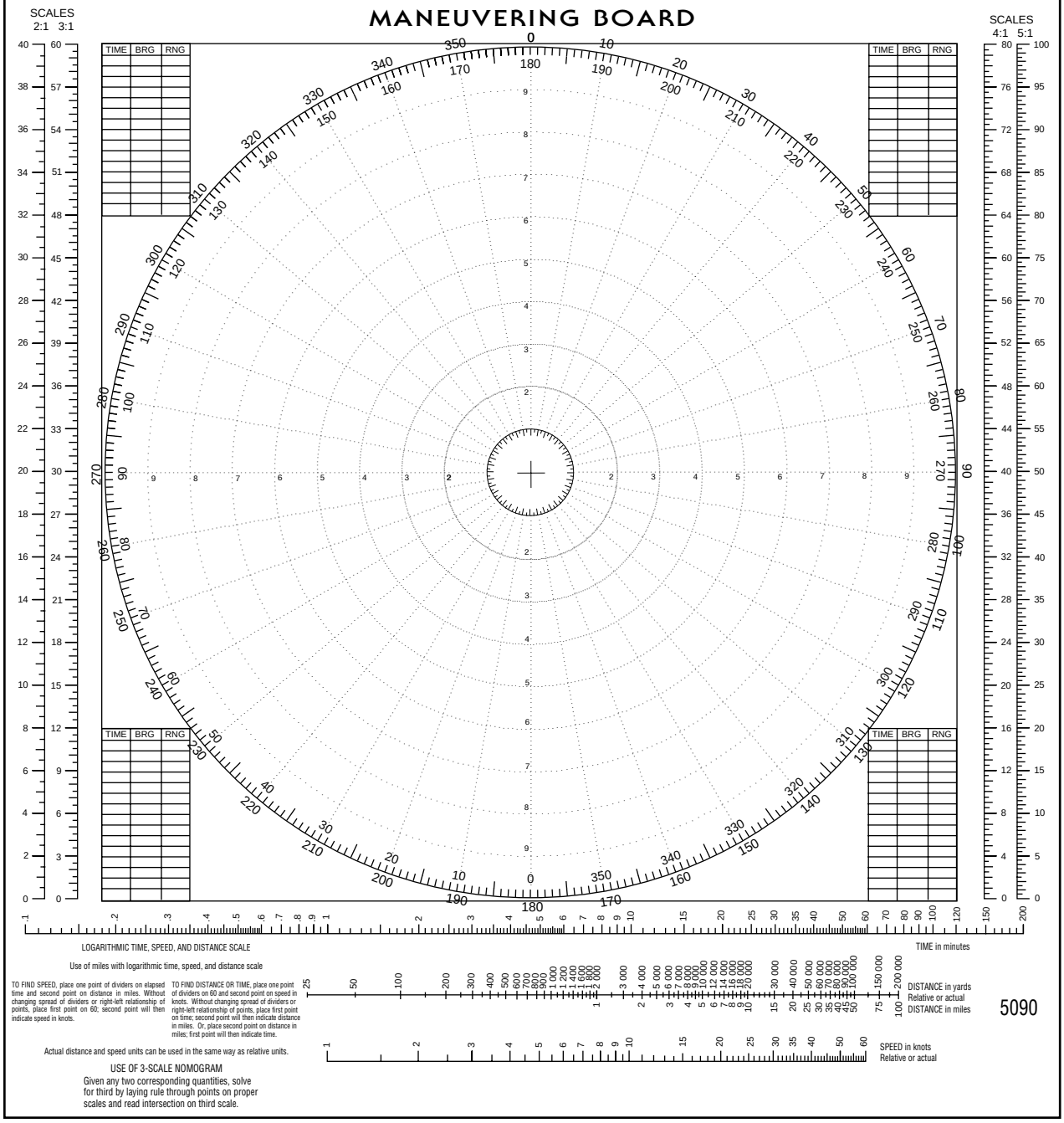
Actual distance and speed units can be used in the same way as relative units.

USE OF 3-SCALE NOMOGRAM

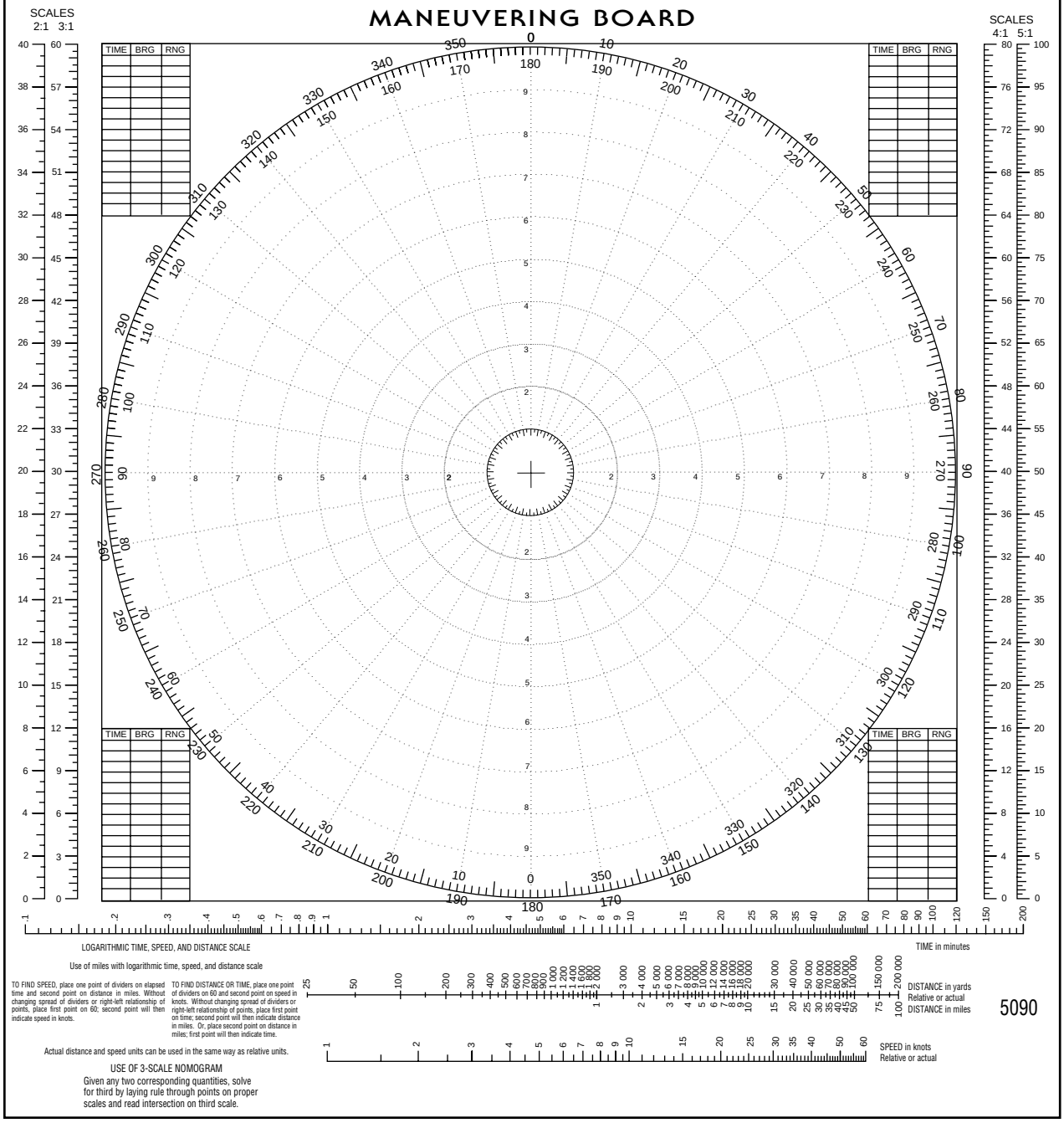
Given any two corresponding quantities, solve for third by laying rule through points on proper scales and read intersection on third scale.

5090

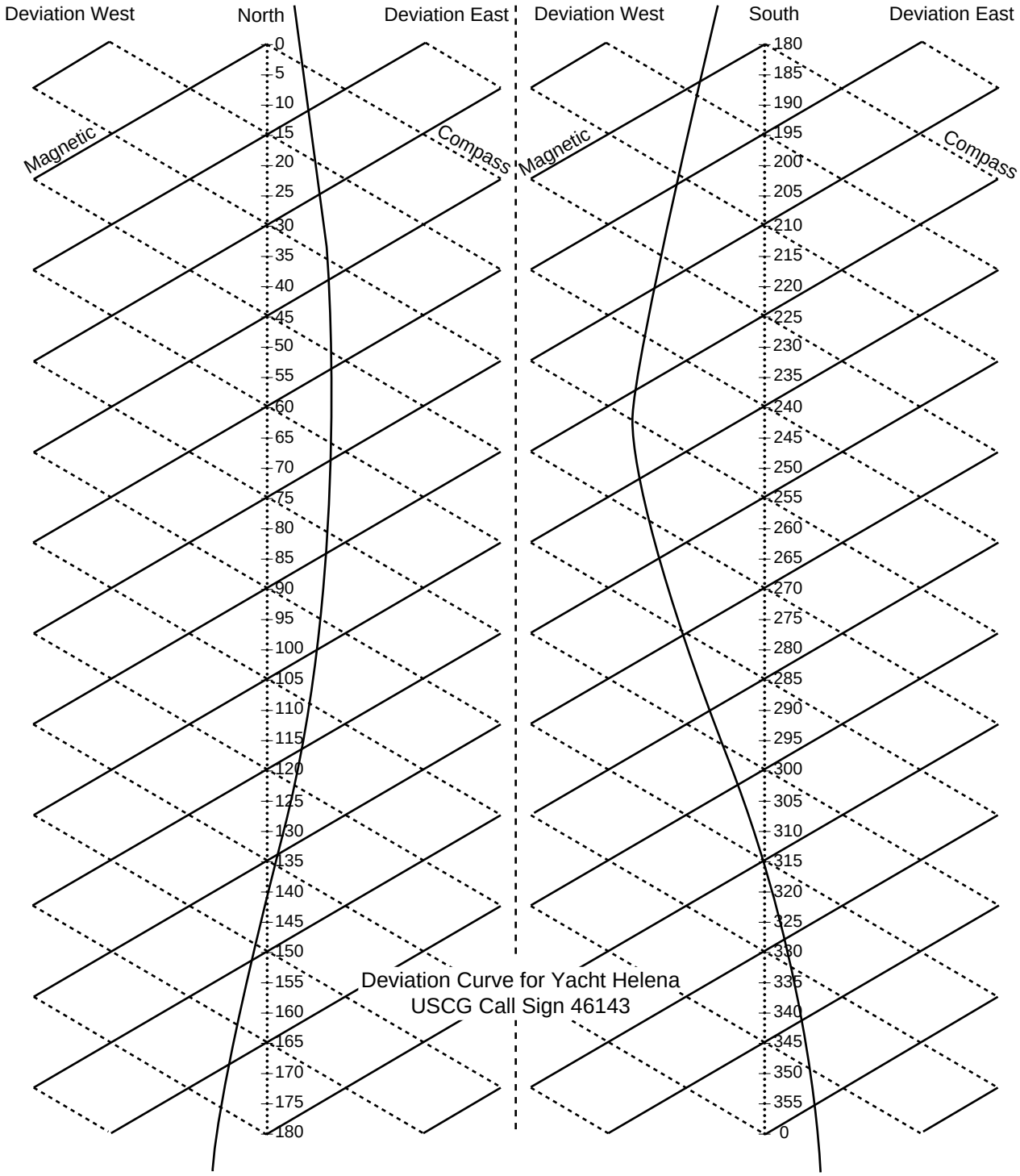
MANEUVERING BOARD



MANEUVERING BOARD



Compass Course on Dotted Lines — Magnetic Course on Solid Lines



Deviation Curve for Yacht Helena
USCG Call Sign 46143

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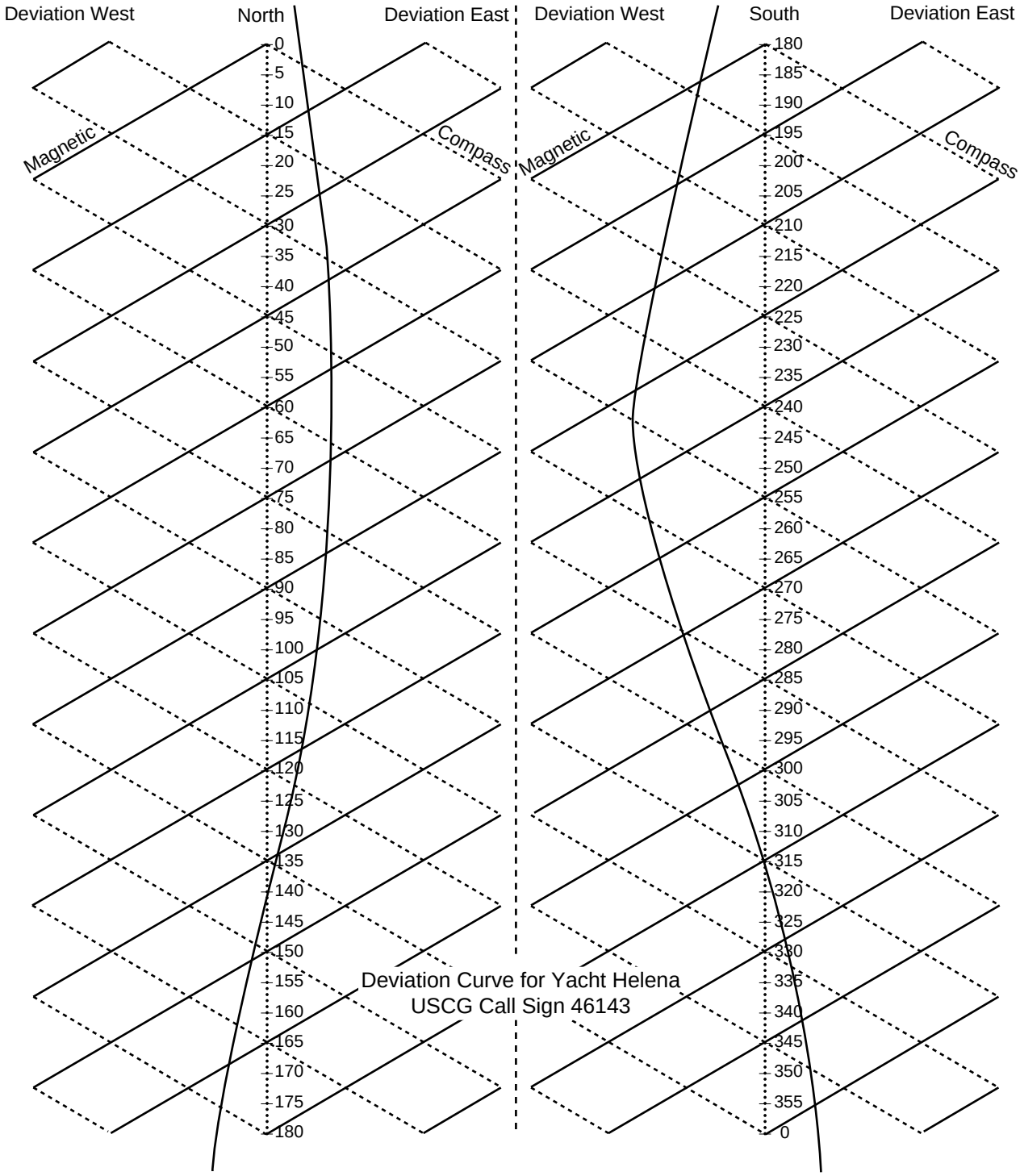

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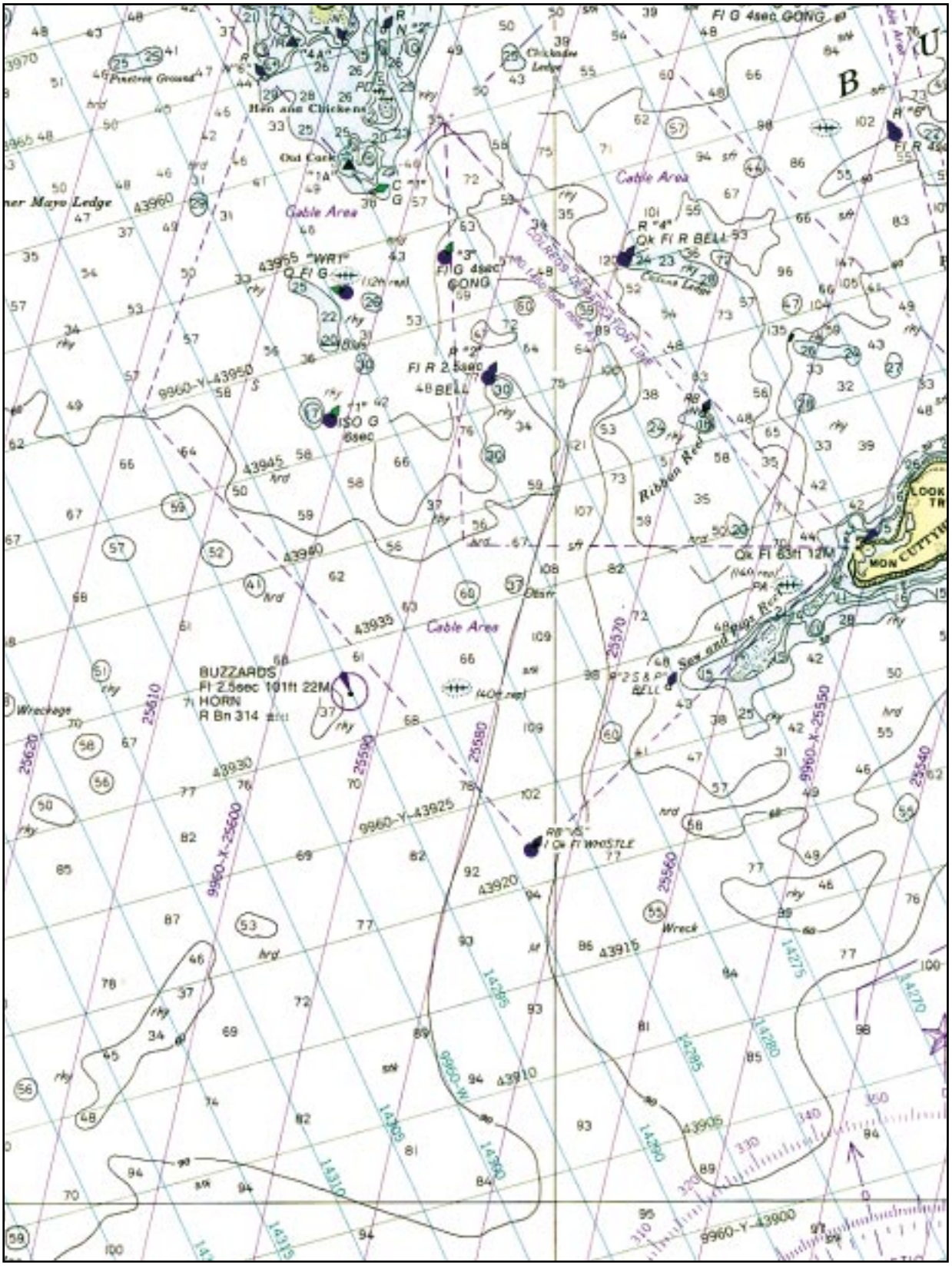
Fl G 4sec GONG
Prairie Ground
Hen and Chickens
Chickadee Ledge
Old Cork
Cable Area
Cable Area
Cable Area
Q Fl G
Fl G 4sec GONG
Fl R 2.5sec 48 BELL
ISO G 6sec
Qk Fl R BELL
Ribbon Reef
Qk Fl 6.5ft 12M
MON CUTTYH
Sex and Pugs Reef
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Qk Fl WHISTLE
Wreckage
Wreck
9960-Y-43950
9960-Y-43925
9960-Y-43900
9960-X-25600
9960-X-25550
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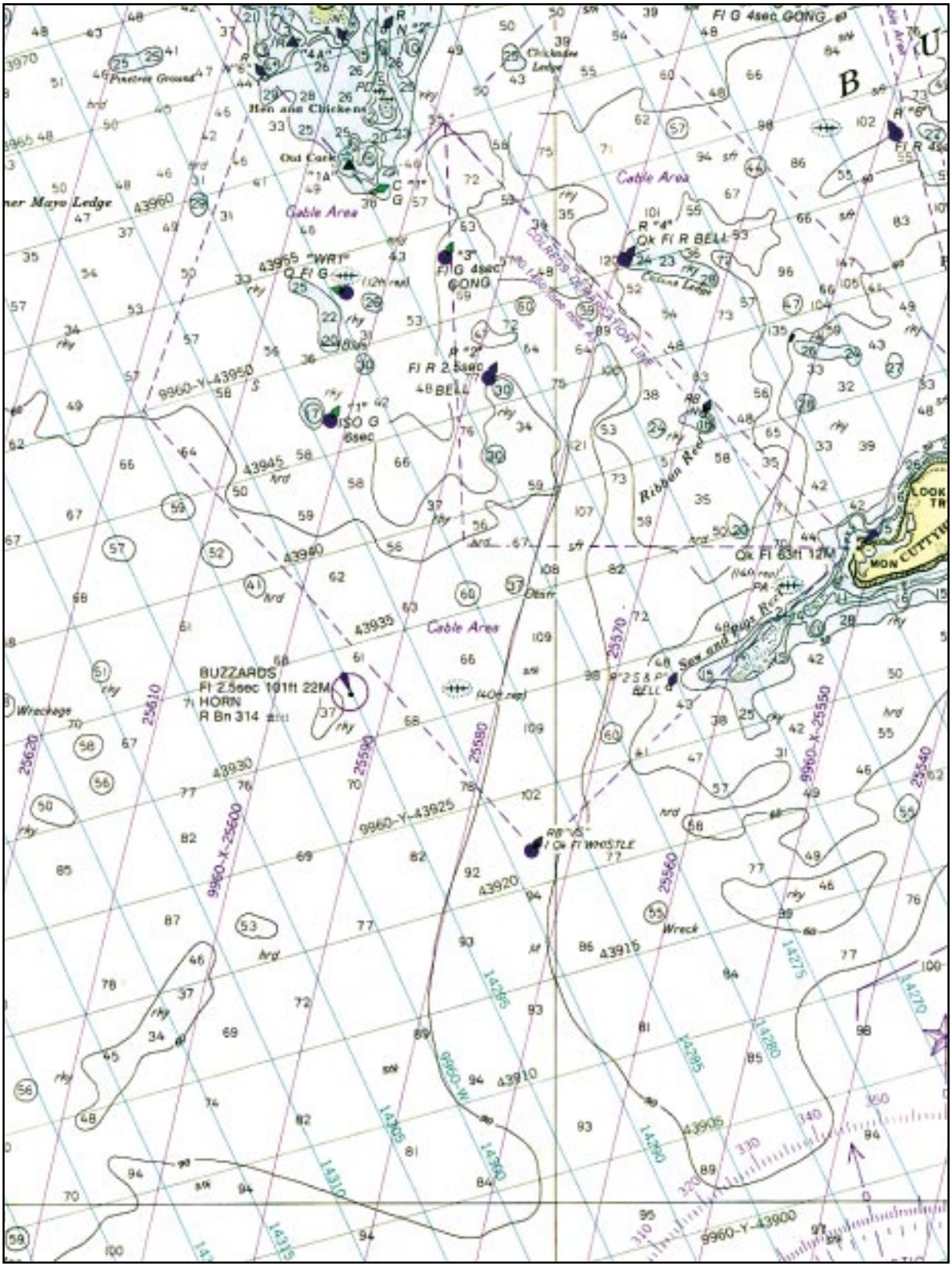
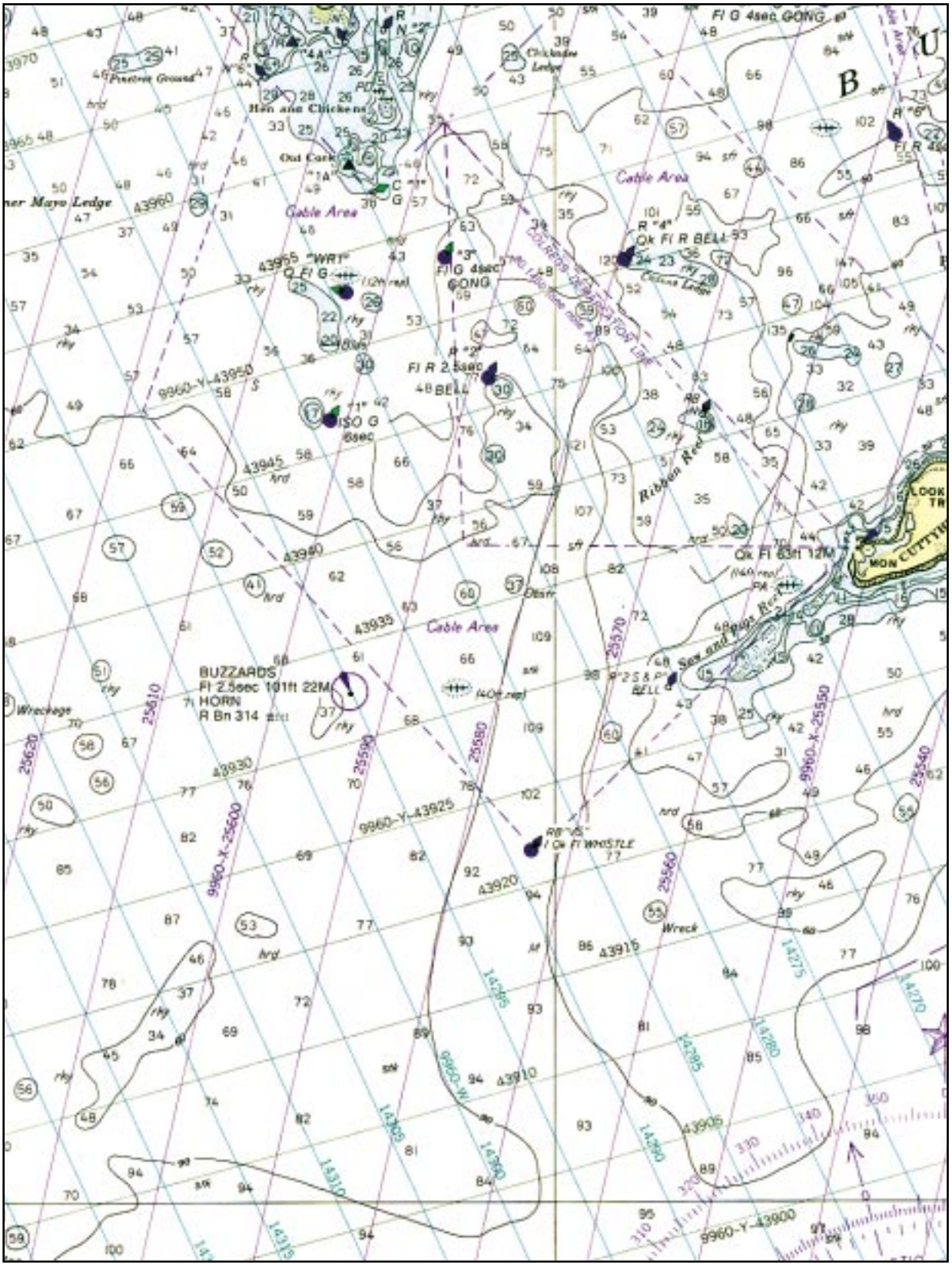

Fl G 4sec GONG
Pinetree Ground
Hen and Chickens
Chickadee Ledge
Out Cork
Cable Area
Cable Area
Cable Area
Fl G 4sec GONG
Fl R 2.5sec
BELL
ISO G
6sec
Ribbon Reef
Sea and Bass Rock
BUZZARDS
Fl 2.5sec 101ft 22M
HORN
R Bn 314
Wreckage
Wreck
Fl R 4sec
B
U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9960-Y-43900
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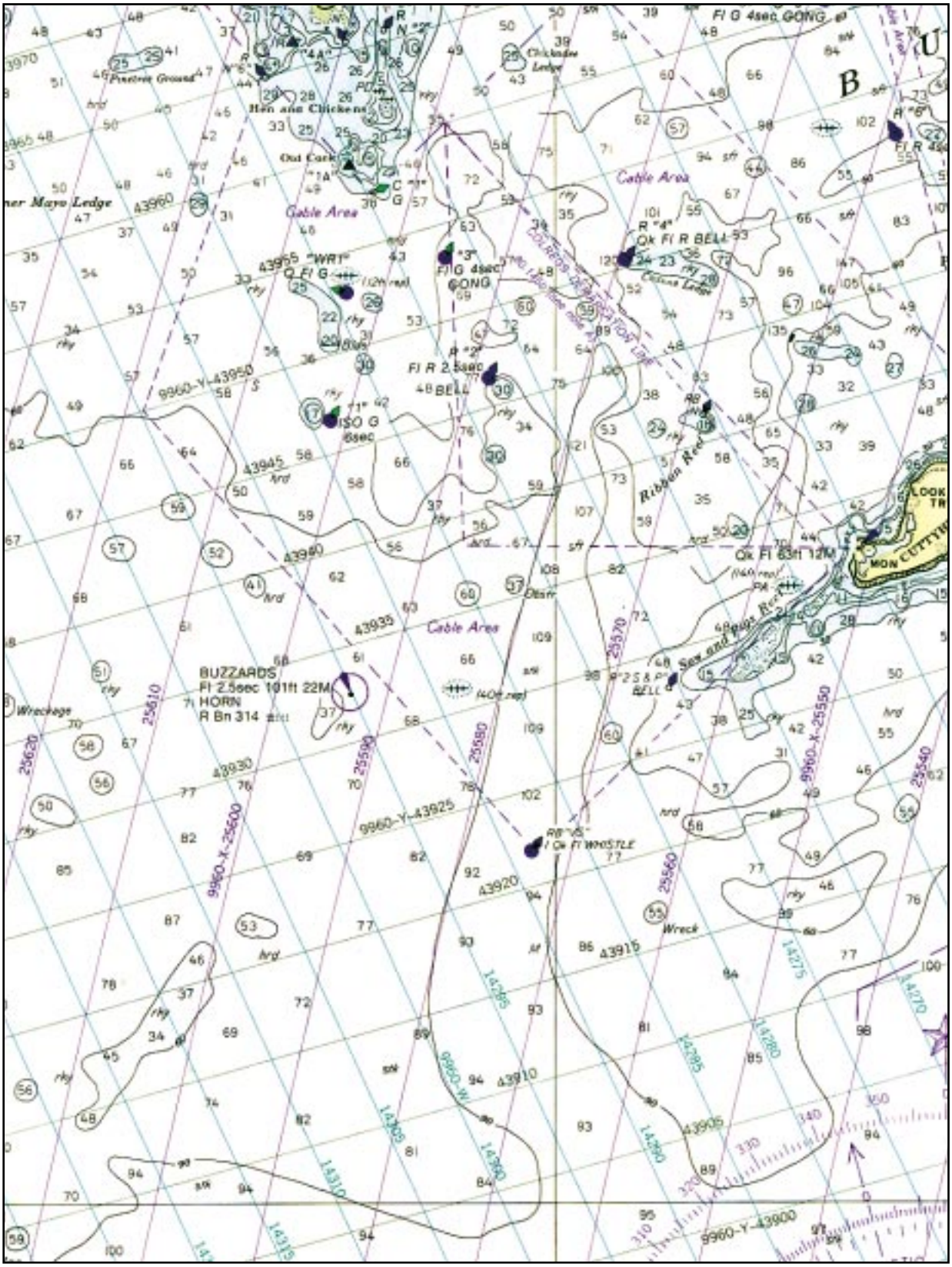
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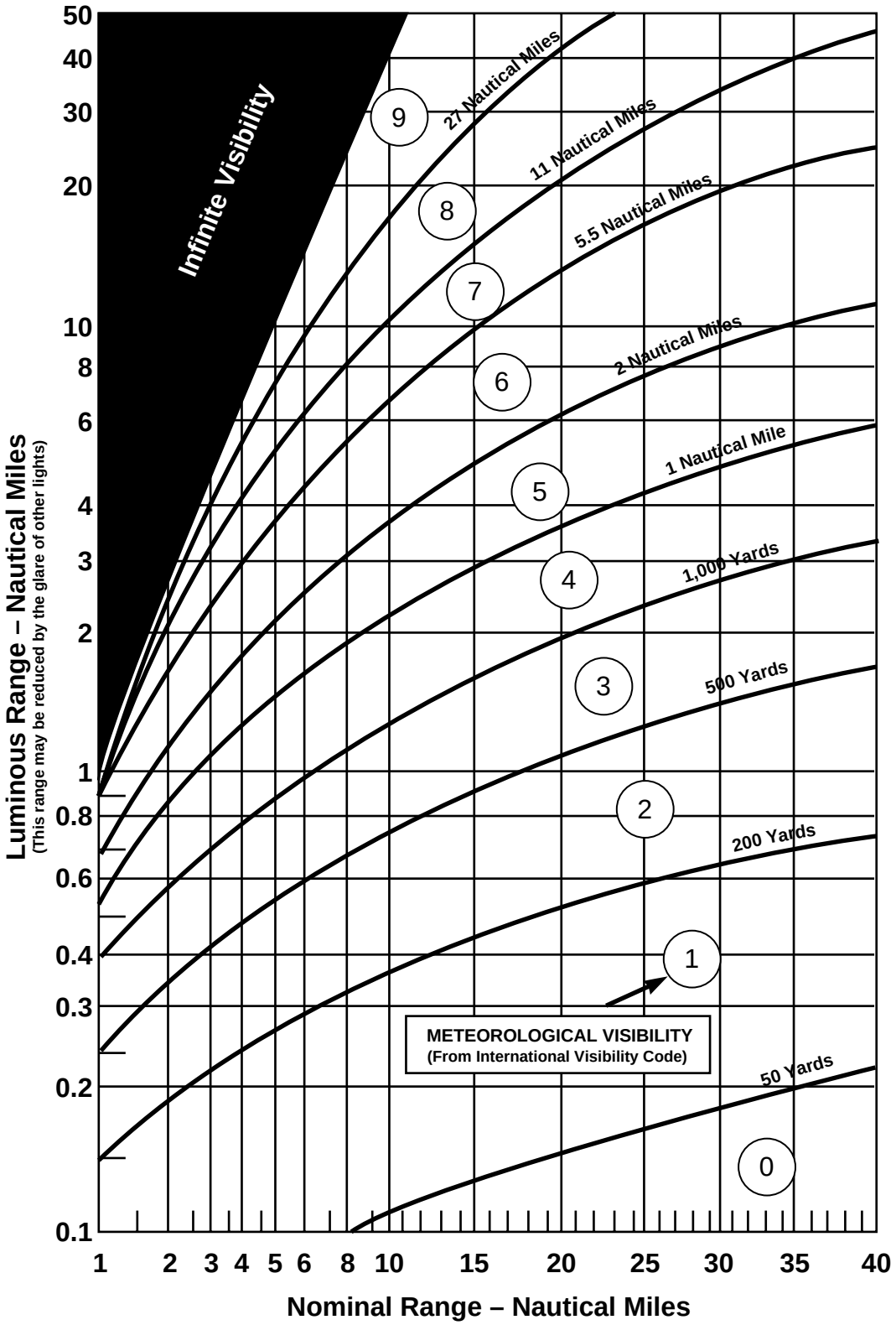
Infinite Visibility
27 Nautical Miles
11 Nautical Miles
5.5 Nautical Miles
2 Nautical Miles
1 Nautical Mile
1,000 Yards
500 Yards
200 Yards
50 Yards
9
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METEOROLOGICAL VISIBILITY
(From International Visibility Code)
Luminous Range – Nautical Miles
(This range may be reduced by the glare of other lights)
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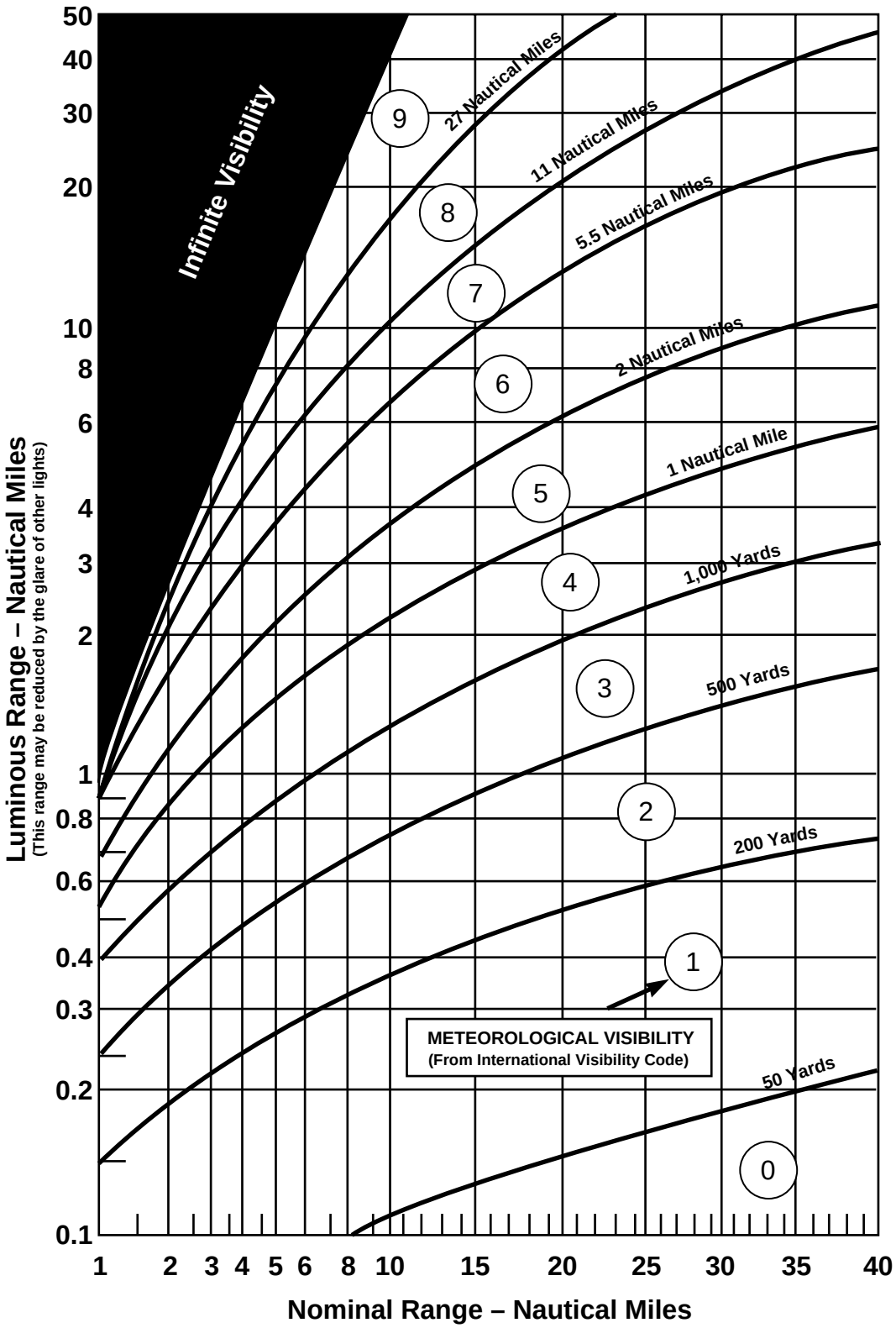
Nominal Range – Nautical Miles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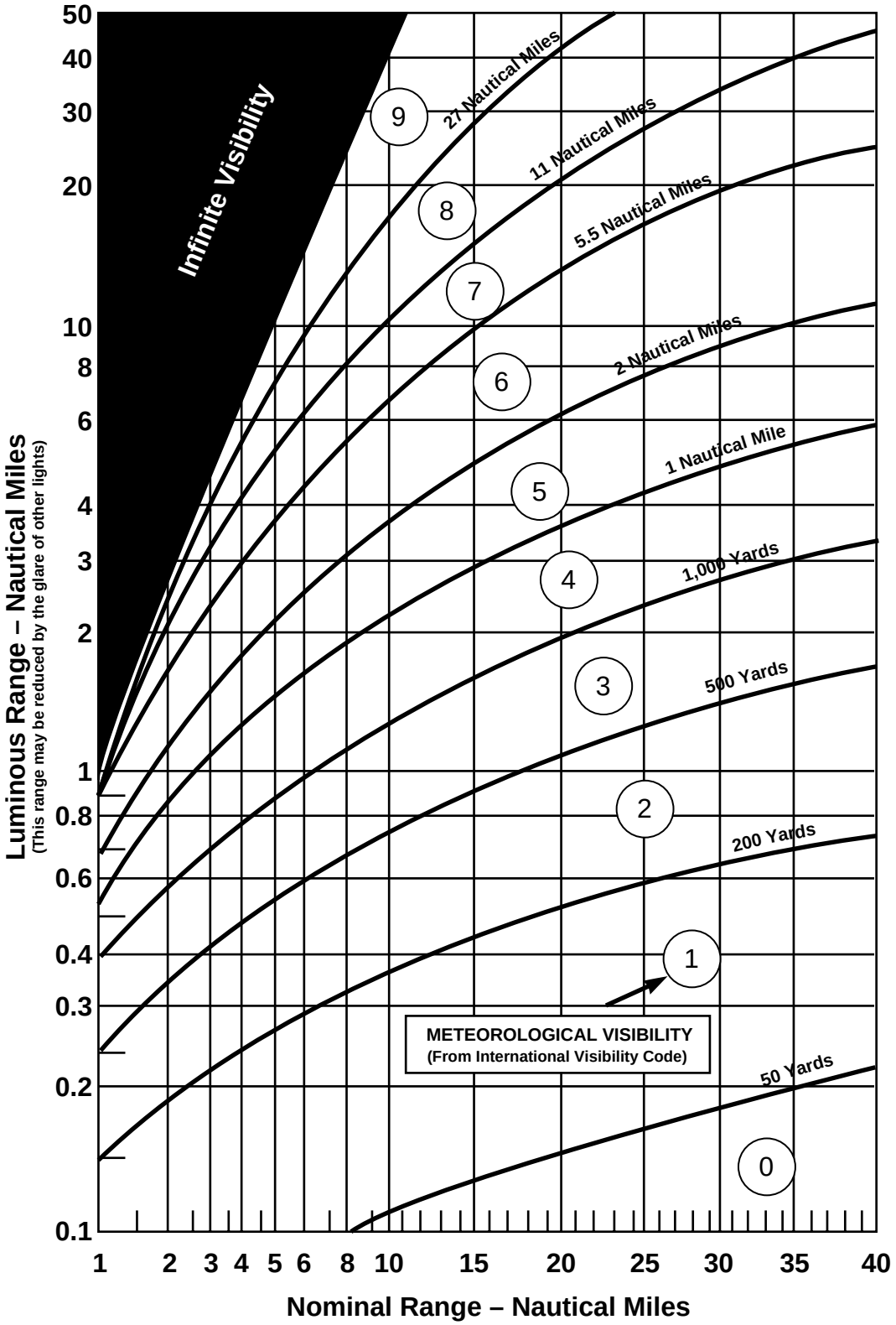
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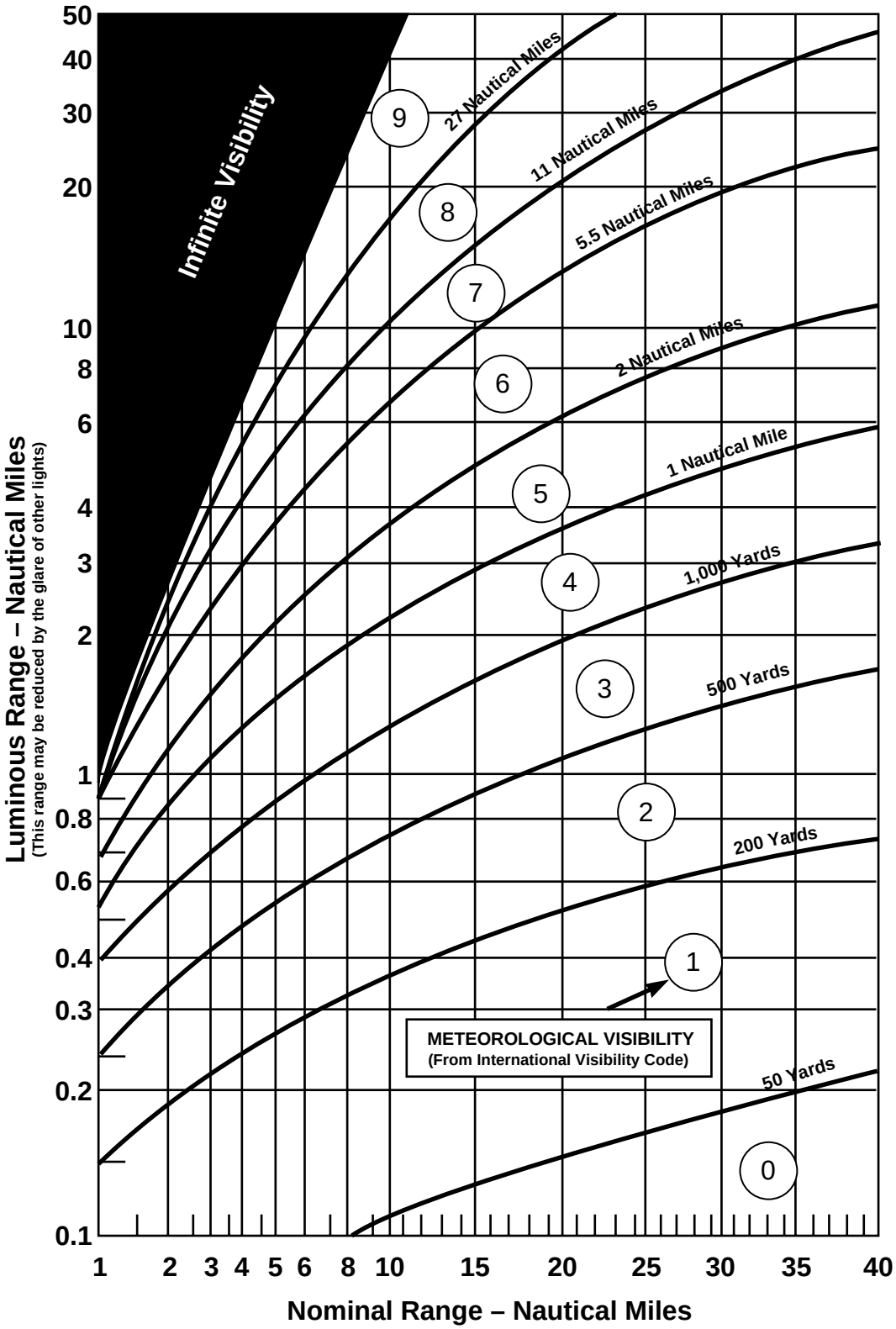
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