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United States Coast Guard

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Subj: Auxiliary Specialty Course In Navigation (AUXNAV) Student Text

1. PURPOSE. This publication is intended for use as the text for the Auxiliary Specialty Course in Navigation.

2. DISCUSSION. The Auxiliary Specialty Course in Navigation replaces the Auxiliary Specialty Course, Piloting and the ANNEX to the U. S. Coast Guard Auxiliary Boat Crew Manual COMDTINST M16798.12 for the purposes of specialty course material only.

3. ACTION. Area and district commanders shall ensure that this text is used as study material for the Auxiliary Specialty Course in Navigation.

/s/ M. R.
Chief, Office of
Public, and

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Chapter 1

Introduction to Navigation

Navigation Defined

In simple terms, navigation is: "Getting from where you are to where you want to go - safely and efficiently." In more formal terms, it is the "process of directing the movement of a craft from one point to another." It comes from the two Latin words, navis, which means "ship" and agere, which means "to move." The problem of implementing navigation has been around quite a while, since man first tried to get somewhere else from where he was. From earliest times there have been various levels of sophistication involved in the practice of navigation. These days, navigators have a broad array of means to use to a degree of accuracy and precision never before possible, nor with such ease. Knowledge of the practice of navigation and the skills to use it are essential to the Vessel Operators and Coxswains responsible for operation of the small craft in Auxiliary and Coast Guard service and to the skippers navigating small craft for pleasure boating. This chapter is intended to provide you with a firm, broad foundation in those techniques used in the navigation of small craft in the rivers, Great Lakes, coastal and nearshore waters of the United States.

Types of Navigation

Types of navigation are defined according to the craft used, principal tools and aids available and involved in their use. First, there is terrestrial or land navigation - involved with navigation on land surfaces. Then, there is air navigation - navigation of various craft through the atmosphere (air) of our planet. The newest, mentioned only for completeness, is space navigation - navigation of craft beyond our planet's atmosphere. Finally, there is marine navigation - dealing with the navigation of craft on the surface and under the surface of the water. This text deals with marine surface navigation. Within the terms of marine surface navigation (although some of these techniques apply equally well to underwater, submarine navigation) there exist, depending on the tools or aids to navigation (ATON) involved:

Piloting. Navigation involving frequent or continuous reference to landmarks, aids to navigation, and depth soundings.

Dead Reckoning. Determining a position (location) by advancing a previous position using courses and distances.

Celestial Navigation. Using the sun, moon, planets and stars, in other words, the celestial bodies as known, but ever changing, aids to navigation to determine position.

Radio Navigation. Positions are deter- mined using radio waves of known characteristics emitted from known locations. Forms of radio navigation include LORAN-C, OMEGA, and SATELLITE systems. The use of RADIO DIRECTION FINDERS (RDF) and RADAR might be considered forms of radionavigation, but in reality are forms of electronic piloting. INERTIAL NAVIGATION systems, certainly electronic, are really a sophisticated, automatic form of dead reckoning.

In small craft navigation, this volume will be dealing with piloting, including the use of radio direction finders and RADAR, dead reckoning, and radionavigation using radiobeacons and the LORAN C system. The other forms of navigation are beyond the scope of this text.

Discussions of small craft navigation in the pages ahead will cover: the spherical earth and the coordinate system used to locate positions on its surface; direction, and the instruments and principles used to determine it; the nautical chart, the projections used to make it, and the information displayed upon it; navigator's tools, and their uses; dead reckoning and positioning, tides, tidal currents and other currents; determination of sunrise and sunset; radionavigation; and finally, the use of RDF and RADAR, and Loran-C.

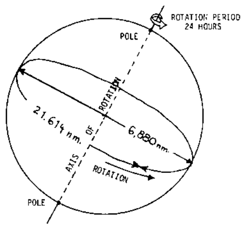
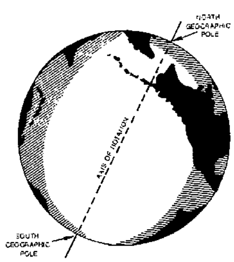


Fig. 1-1 The Earth as a Sphere.

The Earth's Spherical Coordinates

The practice of any form of navigation requires the understanding of the earth's shape and the coordinate system used to define positions on its surface.
The earth is essentially a slightly flattened sphere, slightly wider in its equatorial diameter and somewhat narrower at its polar diameter like an onion. Although these departures from a perfect sphere are important for sophisticated navigation techniques, such as satellite navigation, they are irrelevant for the riverine, lake and coastal navigation covered in this discussion. For our purposes, the earth is a sphere with a mean (average) diameter of 6,880 nautical miles, M (7,918 statute miles, mi.) (1 M equals 6076.1 ft.) and a circumference of 21,614 nautical miles (24,875 statute miles). It rotates at a rate of once in twenty four hours about its axis (of rotation), which passes through its ends, called the poles.

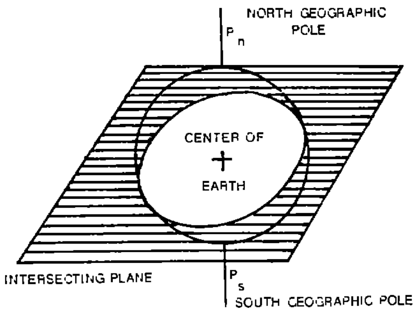
At each end of the earth's axis is a pole -- the NORTH GEOGRAPHIC POLE, or TRUE NORTH POLE, and the SOUTH GEOGRAPHIC POLE, or TRUE SOUTH
POLE.



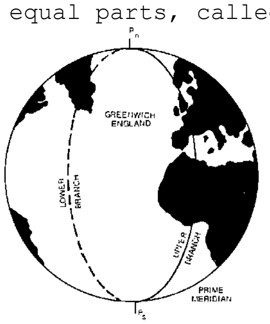
North & South Geographic Poles.

These two points can be used as references for specifying positions on the earth's surface. However, using just these two points is very awkward. An elementary expansion on these points is sufficient to develop a simple two coordinate system which can be used to easily specify, uniquely, any position on the earth's surface.

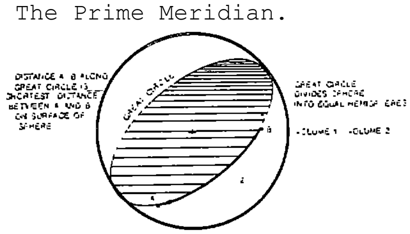
First, pass a plane through the earth in such a way that it passes through the center of the earth. A circle will be formed wherever the plane intersects the earth's surface. This circle is termed a GREAT CIRCLE and has some important features which will be used later. Actually, any plane which goes through the center of the earth will form a great circle at its intersection with the earth's surface.



Great Circle Formed by Intersection of Sphere and Plane Passing Through Center of Sphere. On the surface of the earth the shortest distance between two points lies on this great circle, and the plane, itself, divides the spherical earth into two equal parts, called hemispheres.



The Prime Meridian.

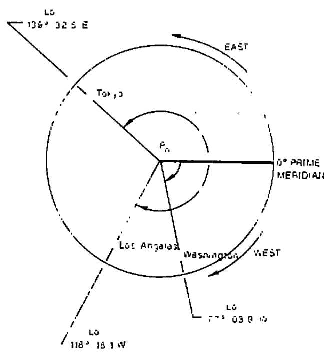


Properties of Great Circles.

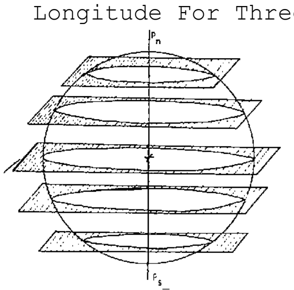
If a plane is passed through the center of the earth, and also through both geographic poles, a great circle is made which begins to form the basis of the spherical surface coordinate system used by navigators to specify position. This kind of great circle, containing the poles of the earth (and, of course, its axis) is termed a MERIDIAN. It has two sides, the one on the observer's side of the earth, which is called the UPPER BRANCH, and one on the other side of the earth, which is called the LOWER BRANCH of the meridian. Now, pass a plane through the poles such that it also passes through a point in GREENWICH, England. This now forms a meridian. By convention, this particular meridian (actually, only its upper branch) is called the PRIME MERIDIAN, and provides the first reference in the spherical coordinate system.

An infinite number of meridians can be developed through the earth's poles, and can be used to partially specify the location of a point on the earth's surface. A particular meridian is specified by its angular distance, in degrees, and fractions of degrees EAST or WEST of the prime meridian.

A circle contains 360 degrees () of arc measure. Each degree is divided into sixty minutes (') (1 = 60'), thus a circle can have 360 x 60 = 21,600' in it. Each minute can be divided into sixty seconds (") (1' = 60"), or in tenths of a minute (more in use) (1' = 10 x .1'). A circle has 360 x 60' x 60 = 1,296,000". The first coordinate in the system is called LONGITUDE, which is abbreviated Lo (sometimes the greek letter lambda, ( ), is used), and is indicated by identifying its angular distance, in degrees, minutes, and tenths of minutes (or in seconds, rather than tenths of minutes) east (E) or west (W) from the prime meridian (0) through 180 . For example, the meridian passing through the Naval Observatory in Washington, D.C. would be identified as Lo = 77 03.9' W (77 degrees, 3 minutes, 9/10 minutes, west of the prime meridian) or 77 03' 54" W (77 degrees, 3 minutes, 54 seconds). The longitude of the Griffith Observatory in Los Angeles, California, is Lo = 118 18.1' W, and that of the Tokyo Astronomical Observatory at Mitaka, Japan, is Lo = 139 32.5' E. Longitude is always specified as east (E) or west W) of the prime meridian.



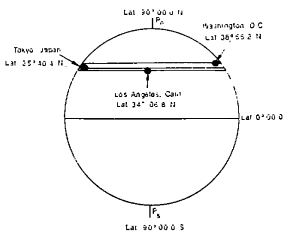
Longitude For Three Locations On The Earth's Surface.



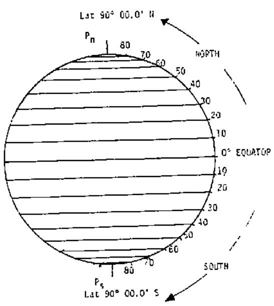
Small Circles Formed By Intersection of Planes Perpendicular to Earth's Axis.

It is not sufficient to identify a position by its longitude, alone, for there are an infinite number of points on any meridian, and an infinite number of places on the earth's surface all have the same longitude, if they lie on the same meridian. Another coordinate is needed to specify a position uniquely. Now, pass a plane through the earth, but perpendicular to its axis. Again, its intersection with the earth's surface produces a circle. However, except when the plane also passes through the center of the earth, this circle is not a great circle. Any plane passing through the earth, but not passing through its center, produces a SMALL CIRCLE at its intersection with the earth's surface. An infinite number of planes can be passed through the earth perpendicular to its axis. In doing so, they form a series of PARALLEL small circles on the earth's surface.

One of these planes, however, passes through the center of the earth and forms a great circle at the earth's circumference. This unique great circle, which is called the EQUATOR because it divides the earth into two equal north and south hemispheres -- half spheres, can be used as another reference to develop a second coordinate for the spherical surface coordinate system. Using the equator as a reference zero, any particular small circle, or more usefully, its parallel, can be identified by its angular distance north (N) or south (S) of the equator, in degrees, minutes and seconds, or tenths of minutes. This coordinate is termed LATITUDE, abbreviated Lat. or simply, L, and is measured from the equator at 0 Lat., north, to the North Geographic Pole at Lat. = 90 00.0' N, or south, to the South Geographic Pole at Lat. = 90 00.0' S. The angular measure is the same system used to specify longitude, 360 in a circle, each degree () has 60 minutes ('), each minute, 60 seconds ("), or tenths of minutes (0.1').

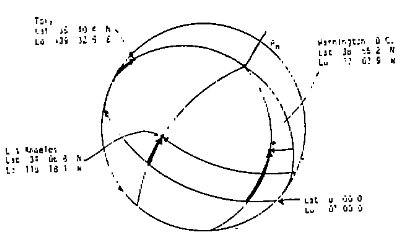


Three Locations on the Earth's Surface.



Latitude Coordinate Defined.

The latitude of the Naval Observatory in Washington, D.C., is Lat. = 38 55.2' N (or 38 55' 12" N). That of the Observatory in Tokyo, Japan, Lat. + 35 40.4' N, and of the Griffith Observatory



Latitude and Longitude Coordinates of Three Positions on the Earth's Surface.

in Los Angeles, California, Lat. = 34 06.8' N.

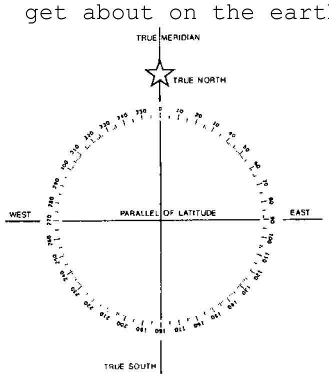
There are now enough coordinates which uniquely specify any position on the surface of the earth, simply by specifying its Latitude (Lat.) and its Longitude, (Lo). Taking the three observatories, their positions can now be uniquely specified as:
Naval Observatory, Washington, D.C. Lat. 38 55.2' N, Lo 77 03.9' W
Griffith Observatory, Los Angeles Lat. 34 06.8' N, Lo 118 18.1' W
Tokyo Astro. Observ., Mitaka, Japan Lat. 35 40.4' N, Lo 139 32.5' E

One very important characteristic of Latitude that will be useful in the near future is the fact that one degree of latitude, measured up and down (north and south) on any meridian, is for all practical purposes equal in surface length, to 60 nautical miles. Thus, one minute of latitude (1 = 60') on a meridian is essentially equal, in surface length, to one nautical mile. Note, however, this relationship does not hold for longitude. Although one minute of longitude, measured along the equator (another great circle) at Lat. 0 00.0', is very nearly one nautical mile in length, as the latitude increases, the distance along any parallel, between two meridians, one minute of longitude apart, continually shrinks until it is zero at the poles (Lat. 90 00.0' N or S).

REMEMBER: Latitude is measured along a meridian (running north and south) in degrees, minutes, and tenths of minutes or seconds, from the Equator, north or south, to the poles (Lat. 90 00.0' N or S).
Longitude is measured along a parallel (running east and west) in degrees, minutes, and tenths of minutes or seconds, from the Prime Meridian (0 00.0') east or west, to the 180 00.0' E or W meridian.

Direction On The Earth's Surface

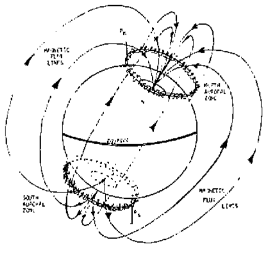
A little thought reveals that simple specification of a particular position on the earth's surface is not quite adequate for getting from here to there. It would also help to incorporate another concept -- that of DIRECTION to help the mariner get about on the earth's surface.



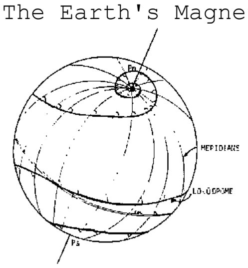
True Rose or Compass Rose.

Directions must be specified relative to something. On the earth's surface, direction, in angular measure, is expressed relative to the local meridian passing through the observer's location on the earth. Since this meridian also passes through the north geographic pole, this direction is also relative to the pole, or to TRUE NORTH. The direction of true north, or northward along the upper branch of the local meridian, is termed zero degrees, and becomes the reference direction. Direction, then, is specified in angular measure (degrees alone are sufficient here, minutes and seconds are rarely used to express direction) in a clockwise manner, using three digits, from zero degrees (000), due north, to 90 (090), due east, to 180 (180), due south, to 270 (270), due west, and back to due north, 360 (360). However, since there are only 360 in a full circle, the direction 360 is the same as 000 , and so, only 000 is usually written. When the complete 360 directional system is developed as a circle with each degree graduated upon it, and with the 000 indicated as true north, the resulting figure is called a TRUE ROSE or COMPASS ROSE. This rose is printed on a map or chart, (a flat representation of the earth's surface). Usually, on a marine chart, the true rose is indicated with a STAR at the true north direction.

When a direction (other than due east or due west) is specified on the surface of the earth, and followed for any distance, so that each subsequent meridian is passed at the same angle relative to the direction of the pole, a line is formed that spirals around the globe, continually edging northward (if the direction is between 270 - 360 or 000 - 090), or southward (if the direction is between 090 - 270), approaching, but never arriving at the pole. This spiral is called a LOXODROME or RHUMB LINE. It is important to note on the surface of a sphere, such as that on the earth, this line is <u>curved</u>.



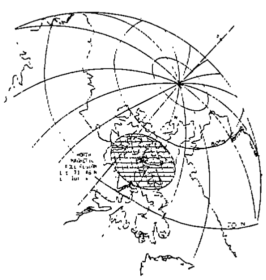
The Earth's Magnetic Field.



The Loxodrome or Rhumb Line,
Intersecting All Meridians At the
Same Angle.

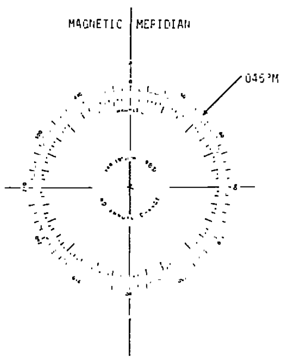
In addition to specifying directions relative to the ends of the earth's axis, the geographic north and south poles, or true north and true south, other physical locations, depending on the mechanism involved, can be used. One of the earliest, and surely the widest used reference for small craft, is the earth's magnetic field.

The earth's magnetic field is thought to be generated by the turbulent flow of the liquid iron alloy core of the planet. This field, often called a dipole field because of its close resemblance, appears like the same magnetic field that would be generated by a large bar magnet located at the center of the earth. The magnetic flux lines flow from the dynamo



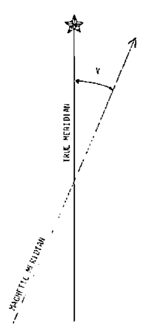
Region of the North Magnetic Pole.

of the core, out, through the auroral zone of the south pole, around the earth, like the ring of a donut, and return through the auroral zone at the north pole. Because of the tremendous size of the earth's core, and its dynamic motion, the "ends of the magnet" are not very precisely defined, and the surface manifestation of the magnet's poles occurs over relatively large areas. In addition, the "bar magnet" is not really aligned with the earth's axis of rotation. As a result, the earth's magnetic poles do not coincide with its geographic or true poles, and are displaced, by several degrees off-axis. Instead of being exact points on the earth's surface, the magnetic poles are relatively large, poorly defined areas - the NORTH MAGNETIC POLE is in the vicinity of Lat. 78.9 N, Lo 103.8 W, and Bathurst, Cornwallis, Melville and Prince of Wales Islands, in Canada's Northwest Territories. The SOUTH MAGNETIC POLE, roughly diametrically opposed on the other side of the earth's surface, is located on the continent of Antartica, about 1530 nautical miles from the true south pole.



The Magnetic Rose.

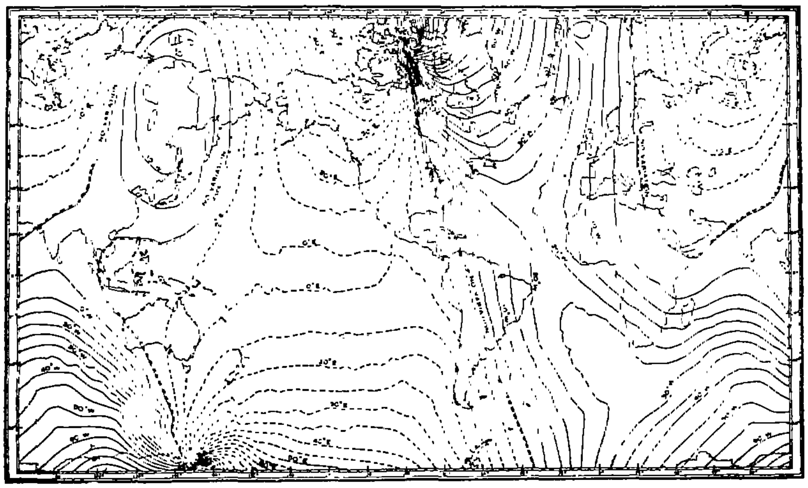
Direction, using angular measurement, degrees, can also be expressed with magnetic north the zero reference direction. The same three digit degree system used to indicate true direction is used, but MAGNETIC DIRECTIONS (M) are indicated, with 000M, specifying magnetic north, 090 M, east, relative to magnetic north; 180M, magnetic south; 270 M, west, relative to magnetic north. Because these directions are relative to the earth's magnetic field, and magnetic north, they are always labeled with an "M", to signify <u>magnetic</u>. A direction



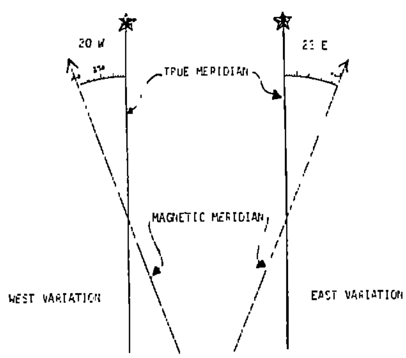
Variation (V) is the Angle
Between True and Magnetic Meridians.

45, clockwise, relative to magnetic north would be expressed as 045 M.
NOTE: True directions, given in three digits need <u>not</u> be labeled to indicate they are true. All other directions relative to references <u>other than</u> true north are labeled accordingly, such as magnetic with the "M".
A system of "meridians" can be developed through the approximate centers of the magnetic poles. These have been termed "meridians" and "great circles" for the purposes of illustration, here. Actually, since the magnetic flux lines vary relative to ferromagnetic deposits, these lines are not true meridians, nor are they great circles. MAGNETIC MERIDIANS, over a large extent of the globe's surface, intersect the true meridians (through the true poles) at an angle. This angle, between the magnetic and the true meridians, varies with location on the earth's surface, and is termed VARIATION (V).

Lines connecting points of <u>equal</u> variation are termed ISOGONIC LINES.
The line connecting points of zero variation - where, to an observer, the magnetic and true poles seem to line up - is termed the AGONIC LINE.



Variation Differs at Different
Locations on the Earth's Surface.



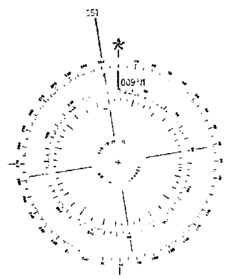
East and West Variation.

Variation is termed westerly, or simply WEST VARIATION when the magnetic meridian angles to the left, counter-clockwise toward the west, of the true meridian. Variation would be easterly, or simply EAST VARIATION if the magnetic meridian angles to the right, clockwise, toward the east.

Looking at Fig. 1-17, variation at different locations on the earth's surface, indicates that the variation in the vicinity of the Chesapeake Bay is about 9 west (9 W). This means in this area the magnetic meridian would intersect the true meridian at an angle, counter clock-wise from true north (toward the west) of 9. In the vicinity of San Diego, California, the variation is 15 east (15E). Here the magnetic meridian intersects the true meridian at an angle, clockwise from true north, of 15 . Near New Orleans, Louisana, the variation is 5E, and along the east coast of the Florida peninsula, where the <u>agonic</u> line passes, the variation is essentially zero (0).

Magnetic directions can be converted to true directions, and vice versa, by simple addition or substraction. This can be illustrated by superimposing a MAGNETIC ROSE on top of a true rose. Depending on location, as shown, the variation will be different. Assuming a location to be on the Chesapeake Bay, variation would be 9W. The true rose would, of course, line up so that its north-south line would align with the true meridian. The magnetic rose would align with the magnetic meridian and be at an angle of 9 counter clockwise to the true rose. The true rose north (000) would correspond to the direction 009 M on the magnetic rose. Likewise, the magnetic rose north (000M) would correspond to 351 on the true rose.

If the direction relative to true north the true direction is termed the CORRECT direction, then the magnetic - less correct - direction of 000M can be converted to its corresponding true direction of 351 by subtracting 009 (V=9W) from 360 (Remember, 360 and 000 are the same direction in angular measure). That is, the magnetic direction with west variation was corrected to its corresponding true direction by



Variation 9W.

substracting the value of the west variation from the magnetic direction to obtain the true direction:

000 M = 360M
360 M - 009W = 351

If the variation were easterly, such as 15E, as observed in San Diego, correction from magnetic to true would be made by adding the east variation to the magnetic direction to obtain the true direction:
000 M + 015E = 015

NOTE: It is a characteristic of angular measure that you can add or subtract 360 to or from any value of direction without changing its value. This is used to keep the direction in question always positive and between 000 and 360.
To convert true direction to magnetic direction the procedure is simply reversed: subtract east variation from true direction to obtain the corresponding magnetic direction, to "uncorrect", and add west variation to true direction to "uncorrect" and obtain the corresponding magnetic direction. If something must be memorized to recall this simple process, it is certainly appropriate. Here is one simple device:

TO CORRECT, ADD EAST variation, subtract WEST variation

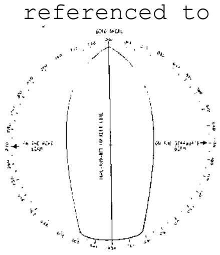
TO UNCORRECT, SUBTRACT EAST variation, add WEST variation

Here are several simple examples to help illustrate the conversion process from true to magnetic and back. The process is fundamental to the practice of piloting using a magnetic compass and should be mastered completely. For the following examples, the values (magnitude and direction) of variation were obtained from Fig. 1-17. (Normally, the navigator would obtain the magnitude and direction of the local variation from the navigation chart of the area of interest. This process will be covered later.) Remember, variation, the angular difference between true and magnetic meridians, varies with location on the earth's surface.

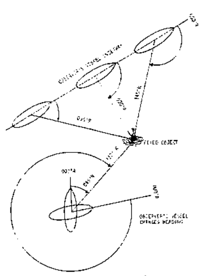
Location: San Diego, California
Variation (V): 15 E
True Direction: 035
Variation (V): 15 E (-) uncorrecting
Magnetic Direction:020M
Magnetic Direction:165 M
Variation (V): 15E (+) correcting
True Direction: 180
Location: Seattle, Washington
Variation (V): 24E
True Direction: 105
Variation (V): 24E (-) uncorrecting
Magnetic Direction: 081 M
Magnetic Direction: 283M
Variation (V): 24 E (+) correcting
True Direction: 307

Relative Directions (Bearings)

It is convenient, from time to time, for mariners to indicate directions referenced to objects other than the true and/or



Relative Bearings.



Relative Bearing of Fixed Object Changes
with Observer's Vessel Heading and Motion.

magnetic meridians. In fact, one of the most used direction systems is that referenced to the fore-and-aft line parallel to or directly over the keel of the observer's vessel.

If a direction "rose" were superimposed over the vessel (plan view) with the 000 line directly forward, at the vessel's bow, 090 on the vessel's starboard beam, 180 directly aft, on the vessel's stern, and 270 on the port beam, the RELATIVE BEARING system is developed. Objects relative to the instant direction of the bow of the boat are indicated in degrees of angular measure, clockwise, just as directions are indicated for the true and magnetic direction systems.
An object 45 off the bow on the starboard side would have a relative bearing of (or would bear) 045R (here the "R" denotes "relative"). If the object were 45 off the bow on the port side, it

would have a relative bearing of: 360 - 045 = 315 R. A vessel dead ahead, directly off the bow, would bear 000R. Note that relative bearings relate to the fore-and-aft or bow direction of the boat and change direction as the boat changes direction (Heading) or position. If the boat is underway, and the object observed is stationary, the relative bearing will change as the boat approaches, passes, and continues on. The relative bearing would also change if the boat is turned, increasing in a clockwise manner as the boat turned counter-clockwise, to port. As is true with magnetic directions, the concept of relative bearings is fundamental in the practice of navigation. The concept should be thoroughly understood. The three direction systems will be linked together in the use of the magnetic compass and the practice of piloting, to be discussed later in this volume.

Chapter 2

Marine Magnetic Compass

Basic Principles

The magnetic compass has been around for a long time, helping caravans cross the deserts of ancient Asia and mariners cross the seas since about the 1400's, as our early forefathers also used the earth's magnetic field for a direction reference. Today's modern compass is not much different from some ancient ones - a needle magnet or an array of needle magnets supported horizontally on a card (graduated in some form of angular measure to indicate direction - See Fig. 2-1) free to rotate on some low friction bearing, so that the magnets may align with a magnetic field.

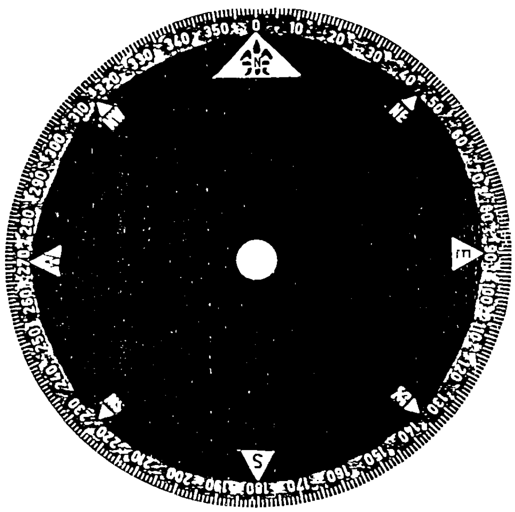
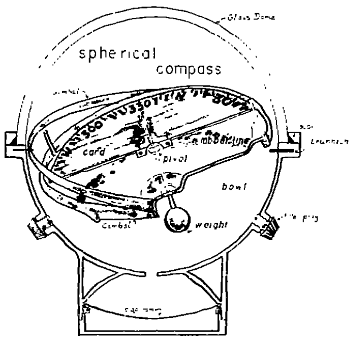


Fig. 2-1 The Compass Card Calibrated In Degrees (360°) and the Cardinal (N,E,S,W) and Intercardinal (NE, NW,SE,SW) Points.

Later, gimbals were added to keep the card and it's support level, and a light set in close proximity to illuminate the card so that it could be read at night. Then the card and its support with needle magnet were placed in a liquid filled, glass topped bowl to damp the excessive motion of an unfettered card. At the advent of the iron ship, with its own magnetic field rivaling that of the earth's, the mariner discovered that life with the compass was not all that simple and added adjusting magnets, huge soft iron "quadrantal spheres," Flinders Bar, and heeling magnets to counteract the permanent and induced magnetism of the iron in the ship being navigated, and enclosed all of this paraphernalia in a binnacle.

The Parts of the Compass

Over the years, the marine magnetic compass has evolved into a functional, relatively easy to read under all lighting conditions, convenient and inexpensive (relatively) navigational tool. The major functional parts of a common type of modern, spherical, marine magnetic, liquid-filled compass are shown in Fig. 2-2. In this compass, the needle (or rod) magnets are attached close to the center, on each side of, and parallel to, the north-south line of the card. The card is graduated in degrees, to conform with the magnetic meridian-referenced direction system (discussed in Chapter 1, Direction on the Earth's Surface) and supported on a jewelled bearing, which turns on a pivot.



Cross Section of a Modern Spherical Marine Magnetic Compass

Older cards were also graduated in the mariner's "point" system. Most compasses also show the cardinal (N,E,W and S) and intercardinal (NE,NW,SE and SW) points. The pivot is mounted on a set of gimbals hung on fore-and-aft and athwartships trunnions to keep the card as level as possible as the vessel rolls, yaws and pitches with the sea. Fastened to one gimbal are one or two whitened, thin pins, called lubber's lines, which serve as reference pointers from which the card graduation can be read to determine the direction of the vessel relative to that of the card. For the compass indicated, a center pin is also attached above the support bearing to assist in this process.
The gimbals, card and magnets are also supported in a hemispherical bowl with a clear, transparent hemispherical glass (or plastic) top, within which the card and gimbals are free to rotate, regardless of the attitude of the spherical container they are held within. This bowl is filled with a non-freezing, non-biologically active liquid (VARSOL) to damp (slow down) the card's excessive motion and reduce its response to a slower, more readable, gentle rotation.

Filler plugs pierce the bowl's sides and a diaphragm is placed at the bottom to allow for thermal expansion of the damping liquid. This bowl is supported in a case, or holder, called a binnacle. A small red light may also be mounted on the binnacle to illuminate the card and lubber's lines, so that the compass may be read in the dark. Small adjusting magnets may also be provided beneath the diaphragm.

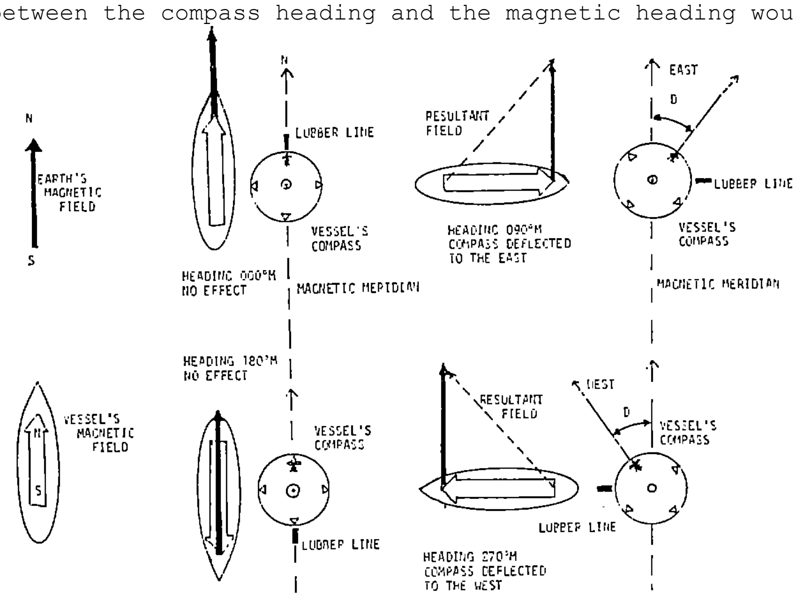
Principles of Operation
The well designed and constructed marine magnetic compass is a sensitive instrument, its card with magnets and bearing are sufficient to allow it to easily align with a weak magnetic field. The principal of the magnetic compass is that its needle or card (really the magnets underneath the card) will align with a magnetic field and thus, indicate directionrelative to that magnetic field. It is very important to note and emphasize that the compass is not particular as to which field it aligns with. It will align with the resultant (combination of) all magnetic fields it senses, regardless of the source.

If there are no other sources of magnetic field than that of the earth's relatively weak magnetic field, then the magnetic compass will align with the local magnetic meridian and will indicate directions in the magnetic direction system.

Unfortunately, with the earth's relatively weak magnetic field, there are many other sources of strong magnetic influence in today's modern world. Magnetic fields are generated about a variety of ferromagnetic and electrical devices. Permanent magnets abound on small craft, contained in such things as: windshield wiper motors, tachometers, electrical meters, radios, radars, sonars, and televisions, just to name a few. Magnetic fields also accompany electrical wires carrying a flowing current. Induced magnetism is also present, being induced by the earth's magnetic field in soft iron fittings, frames, hull plates, engine blocks, etc.

Deviation-Local Magnetic Fields.
The effect of these other magnetic fields on the compass depends on their relative strengths, and their proximity to the compass. Strong magnets held close to the compass may "freeze" the card so that, essentially, it only aligns (points to) with that strong magnetic field and nothing else. Weaker fields, from further sources may simply add or subtract their influence to that of the earth's magnetic field. The resultant combination of these fields will be the field the compass senses and aligns to. Depending on the orientation of the vessel, these local magnetic fields have varying effects on the compass, not necessarily symmetrical nor uniform.

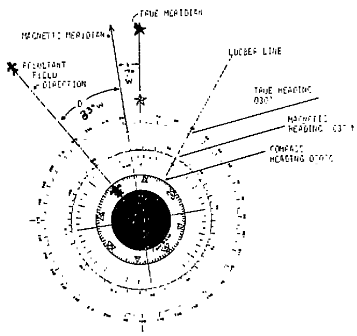
The difference in alignment of the card with the resultant local field and the magnetic meridian is termed DEVIATION. Or, in other terms, DEVIATION is the difference between the direction a compass actually points and the direction that it would point if there were no local magnetic fields aboard the vessel. Its magnitude and direction depend on the orientation or direction of the magnetic materials around the compass relative to the earth's magnetic meridian. (Fig. 2-3). When measured by the compass this fore-and-aft direction is called the vessel's COMPASS HEADING (COMPASS HDG). The vessel's heading relative to the magnetic meridian is termed its MAGNETIC HEADING (MAG HDG), and relative to the true meridian, its TRUE HEADING. (Fig. 2-4). Thus, the angular difference between the compass heading and the magnetic heading would be equal



The Magnetic Compass Points in the Direction of the Resultant Magnetic Field, Here the REsultant is the Earth's Magnetic Field Added to that of the Vessel (Vector Addition).

in magnitude and direction to the deviation at those headings. And, recalling from Chapter 1, Figures 1-16 and 1-18, the angular difference between the magnetic headings and the true heading is equal to the magnitude and direction of the local variation.

If there were no deviation, then the magnetic compass would align with the magnetic meridian and the compass could be used directly for navigation. The simple correction from magnetic directions to true directions would be made for variation and the compass heading would then relate to the true heading. However, except for vessels with few magnetic materials on board, or located far enough away not to have a significant influence on the compass, some correction must be made for deviation. Remember, deviation depends on the combination of the earth's magnetic field with the field produced by the local magnetic materials and is different as this local field interacts according to its direction relative to the magnetic meridian. Thus, deviation depends on the vessel's heading.



Compass, Magnetic and True Headings

Correction for Deviation
On many <u>small</u> craft, deviation is no greater than a few degrees when considering the precision of two or three degrees to which a small marine compass can be read, and the helmsman's ability to hold within a couple of degrees on a compass course, it is not worth the effort to correct. However, on a larger compass, with cards of four inches or more, it is not difficult to read to the nearest degree, and if the deviation is greater than about two degrees, the error must be accounted for. The navigator must then make a correction for deviation.

Correcting the compass heading for deviation to get the corresponding magnetic heading involves the same simple process used to correct magnetic headings for variation to obtain the true heading. When <u>correcting</u>, east deviation is added to the compass heading to obtain the magnetic heading, and west deviation is subtracted. To <u>uncorrect</u> from magnetic to a compass heading, west deviation is added and east deviation is subtracted from the magnetic heading to obtain the corresponding compass heading. Magnetic directions are considered "more correct" than compass directions since compass directions contain two errors, variation and deviation, while magnetic directions contain only one error, variation.

The value for deviation is usually obtained from a deviation table or Napier Diagram (a graphic version of the deviation table), a tabulation of deviations by compass heading and by magnetic heading. This tabulation is worked up by the navigator periodically, usually at least annually, or whenever a change in deviation is expected from the installation, removal, or relocation of any potential source of magnetic interference. The development of this deviation table and the Napier Diagram will be discussed later in this section, along with compass adjustment, to minimize deviation whenever it is excessive.

A <u>sample</u> deviation table for an imaginary compass-vessel combination is provided as

Table 2-1. The table is provided in increments of 15 for compass and magnetic headings to indicate deviation. For example, the compass heading is 045 C, a deviation of 4E is obtained. Remembering that when correcting, add east deviation to compass heading to obtain magnetic heading. Adding 004 E to 045C, and the corresponding magnetic heading is achieved. Looking at Table 2-1, enter on column (a). For the value of 045 C, produces 049M, the corresponding magnetic heading. Similarly, for 270 C the deviation is 3W, and the corresponding magnetic heading is 267 M (270C - 003 W = 267M)
If the magnetic heading is known, then column (c) is entered to provide the deviation for that heading. For a magnetic heading of 285 M, column (c) the deviation is 2W, and the corresponding compass heading would be 287 C (285M + 2 W = 287C). For a magnetic heading of 060 M, the deviation would be 4E, and the corresponding compass heading would be 056 C (060M - 4 E = 056C).

CORRECTING COMPASS TO MAGNETIC		UNCORRECTING MAGNETIC TO COMPASS	
(a) Compass Heading	(b) Deviation	(c) Magnetic Heading	(d) Deviation
000	2 E	000	3°E
015	3 E	015	3 E
030	4°E	030	4 E
045	4°E	045	4°E
060	4°E	060	4 E
075	4°E	075	4°E
090	3 E	090	3 E
105	2 E	105	3°E
120	1 E	120	2 E
135	1°W	135	1 E
150	1°W	150	1 E
165	2 W	165	1°W
180	3°W	180	2 W
195	4°W	195	3 W
210	4°W	210	4°W
225	4°W	225	4 W
240	4°W	240	4 W
255	4°W	255	3 W
270	3°W	270	3°W
285	3°W	285	2°W
300	2°W	300	1°W
315	1 W	315	1 E
330	1°E	330	1 E
345	1 E	345	2°E
360	2°E	360	3°E

A Sample Deviation Table.

When headings fall between the 15 increments, then simple interpolation is required. This may be done by "eyeball" where the deviation is relatively unchanging over a considerable angle such as between 195 C and 255C, where the deviation is a constant 4 W. On the other hand, where the deviation is changing rapidly, such as between 300C (2 W) and 315 (1 W), a simple mathamatical interpolation may be more appropriate. For example, the deviation for a compass heading of 310C is desired. The interpolation is done in this way:

```
300 C)    )      D300 = 2.0W)     )
     ) 10 )                 )  X )
310C)    ) 15  D310 =      )    )1.0W
          )                      )
315 C)    )      D315 = 1.0W     )
```

1. Write down the headings for the known deviations which bracket the desired heading (300 C, 315C).
2. Write down their corresponding deviations and note whether the trend is increasing or decreasing (2.0 W, 1.0W, decreasing).
3. Determine the difference between the base (lowest) bracket heading and the desired heading (310 C - 300C = 10 C).
4. Determine the difference between the bracket headings (315C - 300 C = 15C).
5. Determine the difference between the bracket deviations (2.0 W - 1.0W = 1.0).
6. Let "X" be the unknown deviation.
7. Set up the following proportion:
   10C:15 C = X:1.0
   or

$$\frac{10C}{15C} = \frac{X}{1.0}$$

Solving for "X":

$$X = 1.0 \times \frac{10\ C}{15\ C} = 0.666... = 0.7$$

8. "X" is the <u>increment</u> from D=2.0W, and since the trend is <u>decreasing</u>, "X" should be subtracted from 2.0 W to obtain the deviation corresponding to 310C:
   2.0 W - 0.7 = 1.3 W, rounded off to nearest whole degree, this becomes 1.0W.

Correction for Compass to True Heading

Interchanging from compass to magnetic to true heading and vice versa is a simple process. Its foundations were laid down in the discussions on variation and on deviation. The process is simple:

CORRECTING

(Add East)	**Deviation and**
(Subtract West)	**Variation**

UNCORRECTING

(Subtract East)	**Deviation and**
(Add West)	**Variation**

To illustrate the process, assume a compass heading of 045 C in the Chesapeake Bay (Variation, V=9W) [See Fig. 1-17, or a chart of the Chesapeake Bay]. The corresponding magnetic and true headings are desired. The process is CORRECTING, so ADD EAST and SUBTRACT WEST deviation and variation:

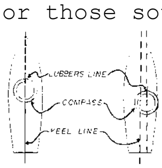
Compass Heading	045 C
Deviation (Table 2-1)	4E (+)
045 C + 4E = 049 M	
Magnetic Heading	049M
Variation	9 W (-)
049M - 9 W = 040	
True Heading	040

Given a true heading of 065, in the same region, determination of the corresponding magnetic and compass headings would be an UNCORRECTING process. Obtaining the variation from Fig. 1-17, and the deviation from Table 2-1, the desired headings would be:

True Heading	065
Variation	9W (+)
065 + 9W = 074 M	
Magnetic Heading	074M
Deviation (Table 2-1)	4 E
074M - 4 E = 070C	
Compass Heading	070 C

Placement of the Magnetic Compass Aboard Small Craft

Correct placement of the marine magnetic compass aboard a small craft is very important. The compass should be mounted so that the helmsman has an unrestricted view of the card and lubber's line under all conditions expected while underway. If the compass is to be used for relative bearings, access should also be unimpeded over as wide an angle as practicable so that bearings may be taken. To minimize deviation error, the compass should be clear of sources of stray magnetism, or those sources should be kept from proximity to the compass as



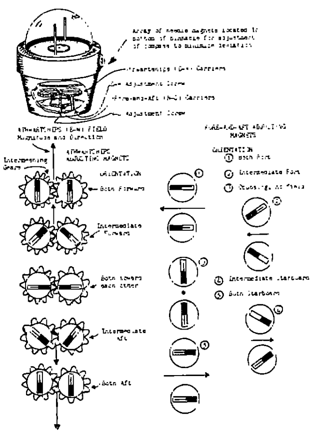
Placement of the Marine Magnetic Compass

Must Be on a Fore-and-Aft Line, Parallel to the Keel.

much as practicable. Most important, when mounting the compass, the lubber's line must line up with a fore-and-aft line parallel to the keel to make sure the vessel's heading and the compass heading are one in the same. Failure to obtain correct alignment of the compass lubber's line with the fore-and-aft line of the vessel will insert a constant error into the compass-to-true correction process which will be difficult to detect.

Compass Adjustment

There are good reasons for adjusting a compass before and after its mounting on board small craft, and good reasons navigators should be familiar with the technique. Modern compasses often come equipped with internal adjusting magnets. These magnets are usually located in the base of the combination compass bowl/binnacle (or case) and are adjusted by means of small screws on the bottom or along side the compass. Although it is intended that new compasses fresh from the factory have these adjusting magnets set in their neutral positions, often times this is not so, and the new compass comes with its own "built in" deviation. Other times, some one has fiddled with these adjustments and left them askew. Thus, there is a need to remove this initial compass error <u>before</u> the compass is brought aboard the vessel.



Internal Adjusting Magnets.

Once aboard the boat, the "proper" deviation influences the compass, there is still good reason to correct this error:

- o It is easier to use the magnetic compass if the deviations are small or are essentially eliminated, and
- o large deviations may cause the compass response to be sluggish and unsteady and affect its operation.

Modern, small craft, marine magnetic compasses are usually equipped with internal adjusting magnets to counteract local "stray" magnetic fields and minimize deviations. These adjusting magnets usually consist of an array of small needle magnets located in the binnacle (or case), directly below the compass expansion diaphragm. (There are several systems used for simple compass adjustment. One such system is discussed here.) (See Fig. 2-6.)

One pair of needles is located equidistant from the compass pivot point on a line athwartships relative to the binnacle. This pair, called the east-west (E-W) adjusting magnets, is placed in two mechanically-coupled, circular carriers which rotate toward each other, arranging the magnets to create a magnetic field oriented fore-and-aft, with intensity which can be varied from a maximum forward, to zero, to a maximum aft.

These E-W magnets only affect the compass card on east-west headings. Since they are coupled to rotate equally, only a fore-and-aft component of the magnetic field is realized (and this affects the compass only on east-west headings). The athwartships component is zero for these magnets since their individual fields oppose or attract equally and thus, cancel each other out.

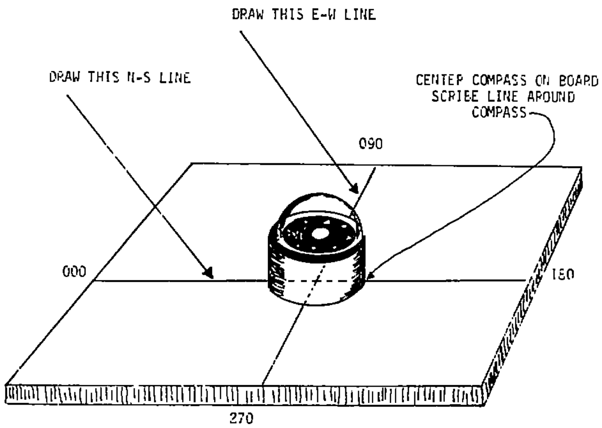
Another pair of adjusting magnets, called the north-south (N-S) adjusting magnets is located just above or below the E-W magnets. This pair is oriented on the fore-and-aft line, in two circular carriers geared to rotate toward each other, equidistant from the compass card pivot point. The magnetic field created by this pair is oriented athwartships and can be varied from a maximum toward the port side, to zero, to a maximum toward the starboard side. Only an athwartships component is realized, since the fore-and- aft field of each magnet balances the other and cancels out that component.

Although these magnets are small, their close proximity to the compass card makes them effective in counteracting stray magnetic fields. Their operation is simple. First the N-S magnets are adjusted to vary their field. They do not affect the E-W headings. Then the E-W magnets are adjusted. They do not affect the N-S headings. Rotation of each pair of adjusting magnets is accomplished by rotating an individual set screw for each pair, usually accessible from a hole or holes in the bottom of the compass binnacle.

Zeroing-in the internal adjusting magnets is done ashore, before the compass is ever brought aboard. Using non-magnetic tools - plastic or brass screwdriver - the adjusting magnets in the base of the binnacle are set to their neutral position. This is not a difficult task.

Take the compass out into an open area, such as a parking lot or field. The idea is to get away from iron pipes and other magnetic materials. Often such materials are buried under the parking lot or field. These must be avoided, but can be easily detected. Using a small, nonadjustable landsman's compass, walk around the area with the compass held close to the ground and observe any deflection caused by the compass passing over magnetic materials. Avoid areas with positive indications of these materials. Your marine magnetic compass can be used for this, too, if the adjusting magnets are not too far out of neutral position. When a suitable area is found, take the marine compass and position it on a level, flat board (free of nails, screws, etc.) on the ground and turn it so that the lubber's line indicates north (000 On the board draw a line around the base with a pencil. This will serve to reposition the compass when adjustments are being made, since the adjusting heads are usually on the bottom, requiring the compass to be picked up, and often turned over, to make the adjustment. Now draw a line on the board coincident with the indicated north-south line of the compass. Reverse the compass so that the lubber's line now points in the opposite direction along the north-south line on the board.

If the card does not read 180 adjustment is necessary. Take the non- magnetic tool and turn the N-S adjusting head to take out 1/2 of the error. Now, place the compass back on the board, and align the compass <u>card</u>, lubber's line and board mark so that they all point south (180 that the lubber's line points north on the board north-south line. If the card now aligns at 000 adjusted. If not, then take out 1/2 of the error, again, and repeat the process, aligning the board, card and lubber's line with north, reversing the compass, and taking out 1/2 of the error, etc., until a satisfactory adjustment of the N-S magnets is obtained. You should be able to remove all of the errors at this time. If you are unable to do so, then someone has probably disassembled the compass and incorrectly replaced the N-S adjusting magnets. If you feel competent enough to try to correct their placement, go ahead. However, if not, then return the compass to the dealer and have it replaced or repaired.



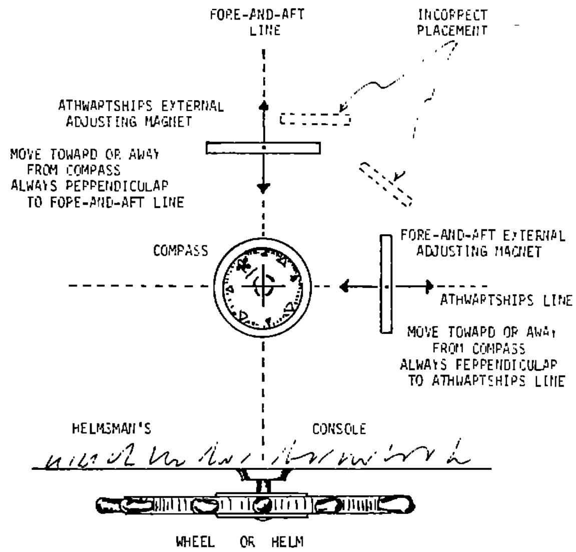
Zeroing-In Configuration for Internal Adjusting Magnets.

Adjustment of the east-west (E-W) adjusting magnets is similar to that of the N-S magnets, only the compass is aligned to an east-west line drawn on the board and the adjustments made in the same manner as for the N-S magnets.
When the compass is zeroed-in, it is ready to be taken aboard and adjusted to minimize deviation.

If the compass has internal adjusting magnets and the zeroing-in procedure outlined above is followed, the compass is ready to be placed aboard. Place the compass in its selected position on the console in front of the helm. Make sure all unnecessary magnetic materials and sources are far removed. On the helmsman's console, mark where the compass is to be set with a pencil line around the compass base making sure the lubber's line aligns with the fore-and-aft line parallel to the keel. Tape the compass down. But remember, you will want to pick it up to make adjustments.

If the compass does not have internal adjusting magnets, obtain a set of external adjusting magnets and use these instead. Mark two lines through the point directly beneath the compass pivot, one fore-and-aft, and the other athwartships. The external adjusting magnets will always be placed perpendicular to these lines with their centers over the line, and their distance varied to the compass to effect adjustment.

Ahead of the compass, place one adjusting magnet athwartships, with its center directly on the fore-and-aft line. This is the ATHWARTSHIPS MAGNET and will be used to minimize deviations on north-south compass headings. It has no effect on east-west headings. On one side of the compass, place the other adjusting magnet with its center across the athwartships line, so that this FORE- AND-AFT MAGNET is parallel to the fore-and-aft line of the boat. This fore-and-aft magnet will be used to minimize



Placement of External Adjusting Magnets.

deviations on east-west headings. It has no effect on north-south headings. These magnets may be taped down temporarily until the adjustments are made, at which time they can be secured permanently.

With these preliminary preparations accomplished, get underway and proceed to an area where the vessel can run, unimpeded for several courses. Bring a good helmsman along to run the vessel while the navigator makes the adjustments. The underway adjustment technique is similar to the zeroing-in procedure done ashore, but now the moving vessel makes it a little more complicated. Instead of picking up the compass and board and turning them around, the boat is run on a series of reciprocal courses as the errors are successively removed in 1/2 error increments. The trick here is simply running reciprocal courses - without a compass. There are two convenient ways to do this: one uses the sun, when the shadows are long, the other a fixed buoy and two disposable ones. Both techniques work quite well.

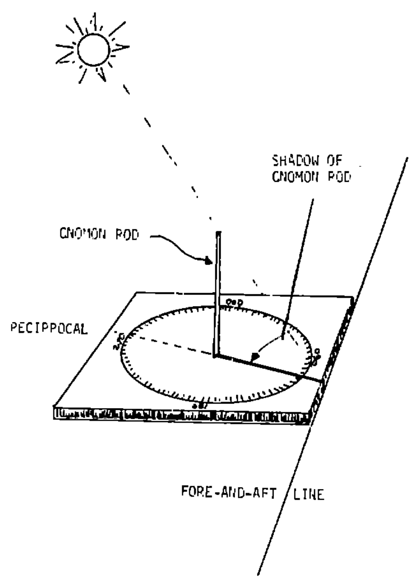
Reciprocal Courses Using The Sun As Reference

You will need another flat board, about one foot square. Fasten a piece of paper on it and draw a compass rose upon it with 360 BOARD sheet, DMAHTC Form No. 2665-10, is excellent for this purpose.) Fasten a long narrow nail vertically, through the center of the rose. This nail will become the GNOMON ROD and will cast its shadow on the board's compass rose. Using this "sun compass" reciprocal courses can be run with ease. The best time to do this is in the early morning or evening, when the sun's shadow is long.

With the boat running on a compass heading of 000 where it will be level and the sun will cast a good shadow from the gnomon rod to the rose. Mark this direction, and then quickly reverse course and align the vessel so that the gnomon's shadow falls on the reciprocal heading on the board. If the compass does not indicate 180 then remove 1/2 of the error on the N-S internal magnets or by moving the athwartships external magnet toward or away from the compass. Always keep the external magnets perpendicular to and centered on the line through the compass pivot.

Now, bring the vessel on a compass shadow, and draw its reciprocal. Come around on the reciprocal sun's heading and note the error in the compass from 270 adjusting the E-W internal magnets or by moving the fore-and-aft external magnet.

With the first two cardinal adjustments made, bring the boat back on a heading such that the gnomon's shadow falls on the same heading indicated at the intial 000 indicate 000 error with the N-S internal magnets, or by moving the athwartships external magnet. Note, if the time for these operations is too long, the sun may have moved too far, and the shadow mark may be off. If this is suspected, establish a new sun line at this point, and continue. (The sun depending on time of day moves about 2 10 minutes in U. S. latitudes.) If the compass is in error less than two degrees, stop. You've done a good job, and it doesn't pay to try to get it any finer. If the error persists and is greater than two degrees, repeat the process until the N-S deviation is acceptable.
Now, head the vessel so that the sun's heading on the gnomon's shadow is along that obtained during the first 090 (The caveat about time and the moving sun line holds here, too.) Again note the error from 090 by adjusting the E-W internal magnets or by moving the fore-and-aft external magnet. Continue the process until you reduce the N-S deviation to 2 You are now ready to SWING SHIP, or to determine the residual deviation remaining on all of the other headings.



Use of Sun Compass - Shadow of Gnomon Rod Establishes
Direction Relative to the Sun.

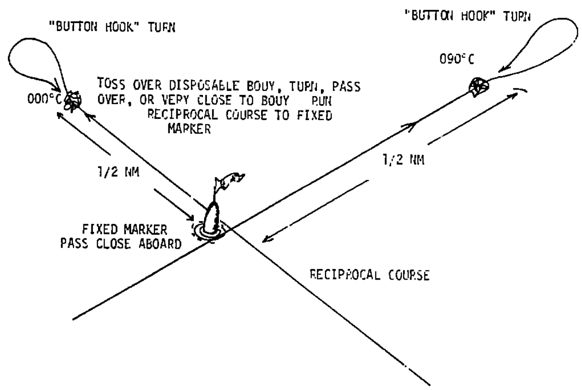
Reciprocal Courses With Fixed and Disposable Buoys
To adjust the compass with this method, choose your adjusting area so that you have a fixed buoy and plenty of sea room free from intruders. Make several

disposable buoys. A piece of newspaper wadded up with a long, thin string and a small weight attached works well. Run to your area and come up on the fixed buoy on a compass course of 000 Passing the buoy close aboard, run for about 1/2 mile (1000 yards) steady on this compass course. When you are ready to come on your reciprocal course, toss one of your buoys in your wake, clear of your screw(s). Run a little further and then execute a "button hook" turn, coming back on the range now formed by your "buoy" and the fixed buoy. You are now running a reciprocal course. If your compass doesn't read 180 of the error by adjusting the N-S internal magnets or by moving the athwartships external magnet toward or away from the compass, along the fore-and-aft line through the compass pivot point.

Run to the fixed buoy, pass close by, and come up on a compass heading of 090 Again, run for about 1/2 mile, toss over your disposable buoy, execute your turn, and settle down on the reciprocal course. Observe the compass heading. If not 270 adjusting the internal E-W magnet or by moving the fore-and-aft external magnet toward or away from the compass.

Continue these maneuvers and adjustments, as indicated above, until the errors are reduced to 2 are now ready to swing ship. After these adjustments are made on the compass cardinal points (heading of 000 180 COMPONENTS of the vessel's permanent magnetic field will be minimized. For small craft constructed of non-ferrous iron in their hulls and superstructure, there is little magnetism induced and little QUADRANTAL deviation requiring correction. This deviation would appear on the intercardinal headings of 045 135

Compass vs. Magnetic Heading



Running Reciprocal Courses Using Fixed and Disposable Buoys.

Deviation is determined by comparing compass headings with magnetic headings. The differences, east or west, are tabulated by compass heading and by magnetic heading to develop a deviation table. Entries can also be made on the Napier Diagram. Usually increments of 15 separate measurements. If time and patience allow, the navigator can go to 10 but if the compass was zeroed-in properly, and deviations minimized sufficiently, the extra precision gained by the additional measurements is usually not worth the effort on small craft with small compasses. There are several different techniques in use to determine deviation. The differences do not lie in the comparison of headings, but in the determination of the magnetic heading. The compass heading is simply read from the lubber's line on the card.

Determining Magnetic Heading
There are three techniques in common use, today. The first, used by professional adjusters and professional navigators, uses the sun's azimuth for the determination of magnetic heading and is very practical for large ships. This technique utilizes H.O. Publication No. 250, Azimuths of the Sun and Other Celestial Bodies of Declination 0 commonly called the "Red Azimuth Tables." (Although this publication is now out of print, it may be obtained from a local library, or a second-hand book store, or an old navigator friend. The cover of the book is red.)

Requiring an accurate time piece, a means of taking relative bearings of the sun (a pelorus equipped with a sun shade or a gnomon rod), and the latitude of the vessel to the nearest degree, the technique is remarkably straightforward, simple and well within the accuracy and precision of most small craft compasses. The description of this process, and the necessary tables, are relatively lengthy and beyond the scope of this text. It is very well described in DMAHTC 250, and interested Coast Guard Auxiliarists and other boaters are encouraged to obtain a copy of the tables and use the method. (With the advent of the small, programmable hand calculator, or microcomputer, programs have been written to replace the need for calculators, and preprogramed "chips" are available on the commercial market.)

Magnetic heading requires the use of a distant, charted object, or a known range and nearby fixed buoy or other marker, and the use of a simple relative bearings indicator - a pelorus easily constructed out of readily obtainable materials.

Construction Of a Simple Pelorus
A simple, adequate pelorus may be constructed using a flat board, about one foot square, a large protractor or maneuvering board sheet to graduate the scale, and a pointer arm with a bolt pivot and two sighting vanes constructed of light sheet metal, plastic, a nail or cardboard.

1. Center the protractor or maneuvering board sheet on the base board, with the north or zero mark toward the center of one edge and fasten with glue or other

2. Make the sighting arm the same length as the diameter of the rose. Scribe a line, lengthwise, down its center, and drill a bolt hole in its exact center, length and width wise. Also drill such a hole in the center of the base board.

3. Make sighting vanes from sheet metal, plastic, cardboard, or simply, two nails. For the eye-piece vane, scribe a centerline on the vane and drill a hole in it about 1/8 inch in diameter, at a convenient height on the sighting vane above where it would attach to the sighting arm (about 2 inches). For the objective vane, a simple nail will do, or a clear plastic vane can be made with a centerline, the sighting line, scribed vertically on its center.

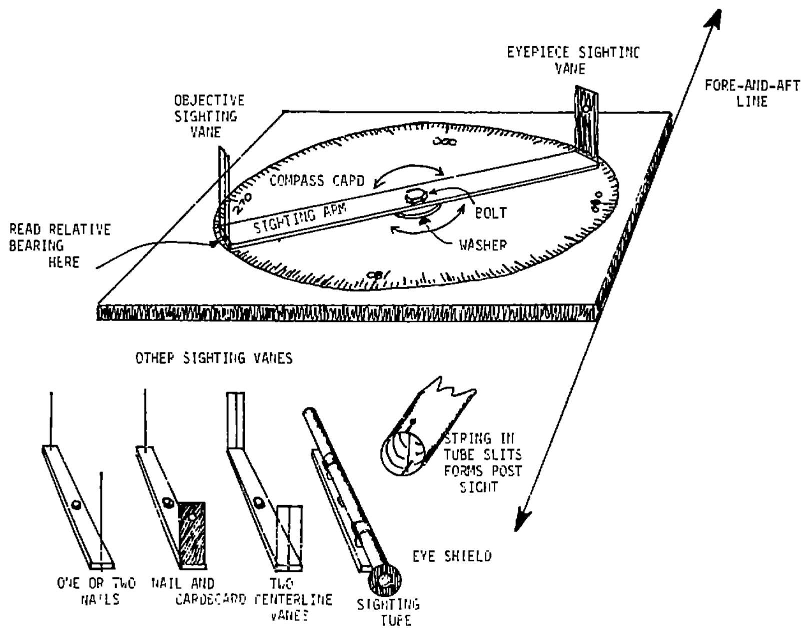
4. Fasten the eye-piece sighting vane on the sighting arm at one end so that the centerlines align.

5. Fasten the nail or plastic objective sighting vane at the other end of the sighting arm so that the nail or the sighting line of the vane are aligned with the centerline scribed on the sighting arm.

6. Secure the sighting arm on the base board using a bolt, nut and two wide washers. It should be secure enough not to rock or wiggle, but free enough to turn easily.

7. The pelorus is now completed. It can be mounted at any convenient location on board the vessel, making sure the N-S, 000 the fore-and-aft line of the vessel. This can be checked by pointing the bow of the vessel at a distant object - several miles - and sighting the object through the pelorus. The relative bearing should be 000 the pelorus in place for the time required to swing ship. The object is sighted through the vanes and its relative bearing read off the scale directly beneath the center line scribed on the sighting arm. More elaborate peloruses may be constructed, depending on the maker's skill, but are not required for this task.

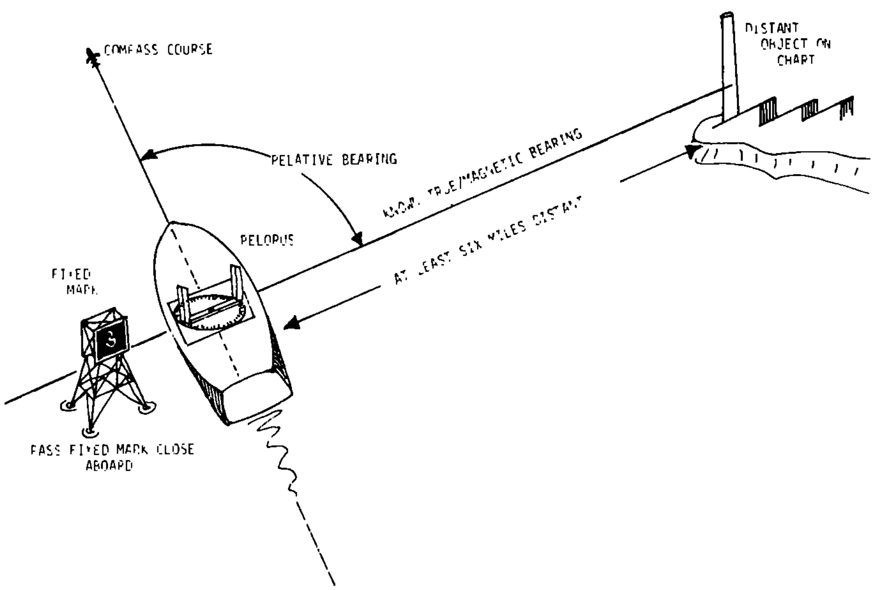
Magnetic Heading by Bearings on a Distant Object
To determine deviation, use will be made of the pelorus, above. Locate on a local chart an area of open water that has least six nautical miles away) and a



A Simple Pelorus or Relative Bearing Indicator.

close-in reference (base) object, such as a pile or daymark, in which to swing ship. Draw a line from the buoy or other base object (day marker, pile shown on the chart, etc.) to the distant object and determine its true bearing. (Obtaining directions on the chart will be covered in a later portion of this chapter.) Convert this true bearing to a magnetic bearing. Go out to the area, and, staying close to the base mark, run compass courses at 15 line. Using the pelorus, take bearings of the distant object when you cross the line close to the base object. Record the bearing together with the compass headings. The pelorus bearings are relative bearings and must be converted to your magnetic heading in order to make the comparison with the compass heading to determine the deviation for that specific compass heading. This process is illustrated in Fig. 2-12.

For example, the magnetic bearing of the distant object from the base buoy is 075 relative bearing of 115 First, since the relative bearing is greater than the magnetic bearing, add 360 keep the result of the next operation within the range of 000 The magnetic bearing is now 435 + 360 relative bearing of 115 magnetic bearing to obtain the magnetic bearing.
Compare this magnetic heading of 320 with the observed compass heading of 330 magnetic to compass heading is observed. Remembering how to convert from magnetic to compass headings (add west errors when uncorrecting), this difference, which is the deviation for the compass heading of 330



Determination of Magnetic Heading Using Fixed Mark and Distant Object.

Enter this in your tabulation and proceed with the next compass heading until all twenty four increments have been measured. The resulting tabulation will be your deviation table for that compass for that configuration of local magnetic materials.

If electronic gear or other electric apparatus are located nearby, the deviation should be checked with these devices in operation to assure it does not change. If a different deviation is observed, then another deviation table should be developed for use when those devices are being used, (i.e. windshield wipers - on and off; depth sounder - on and off; radar - on and off; etc.).

Determination of Magnetic Heading from a Range
This method is a little simpler than the "distant object" technique. Here, the area for swinging ship should be chosen in the vicinity of a range. The magnetic bearing of this range should be obtained from the chart. (Obtaining directions from the chart will be discussed in the subsection on piloting.) The boat is taken to the area selected and the various compass headings are run across the range line. As the line is crossed, its relative bearing, and the instant compass heading are recorded.

The relative bearing is converted into a magnetic heading as discussed above, and the deviation is determined by comparing the magnetic heading with the compass heading. The compass headings, magnetic headings and corresponding deviations are tabulated to develop the deviation table (see Fig. 2-13). Another variation of this technique is to select several ranges, with different bearings. Run the vessel into and away from each range, noting the compass and magnetic headings for each range. Plot or tabulate the difference - deviation - for the various compass and magnetic headings.

The Napier Diagram
Some navigators find a curve of deviations constructed on the Napier Diagram more convenient than a deviation table especially if they wish to detect fine structure in the compass's deviation. Such a construction is easily accomplished using the tabulation of magnetic and compass headings and deviations obtained above. An example of the Napier Diagram (blank) is provided in Fig. 2-14. An example of the diagram with a curve of deviations plotted is provided as Fig. 2-15.

The headings, numbered in five degree increments, but indicated for each degree constitute the vertical coordinate of the diagram. Diagonally to this vertical are placed at an angle of 60 equilateral triangle - with sides of equal length) a solid line to represent the deviation observed for a magnetic heading (remember: solid is more correct.), and a dotted line for the deviation observed for a compass heading (remember: dotted is less correct.). If the deviation is east, it is entered to the right of the vertical line. If the deviation is west, it is entered to the left of the vertical line.

The tabulated values of deviations obtained above are plotted for their respective magnetic and compass headings on the dotted or solid lines using a pair of dividers to measure the deviation, using the vertical line for a scale. They are read off in the same manner in which they are plotted.
As an example, using the deviations indicated in Table 2-1, for a compass heading of 045 observed. On the vertical scale of the Napier Diagram locate the point corresponding to 045 dividers and at that point measure on the vertical scale, 4 point). Swing the dividers to the right (the deviation is east) and mark with an "X" the deviation on the dotted line,

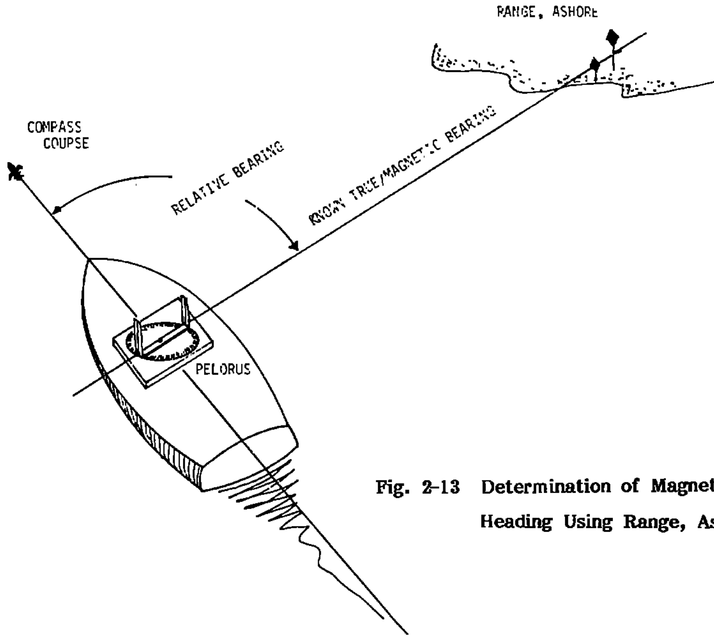


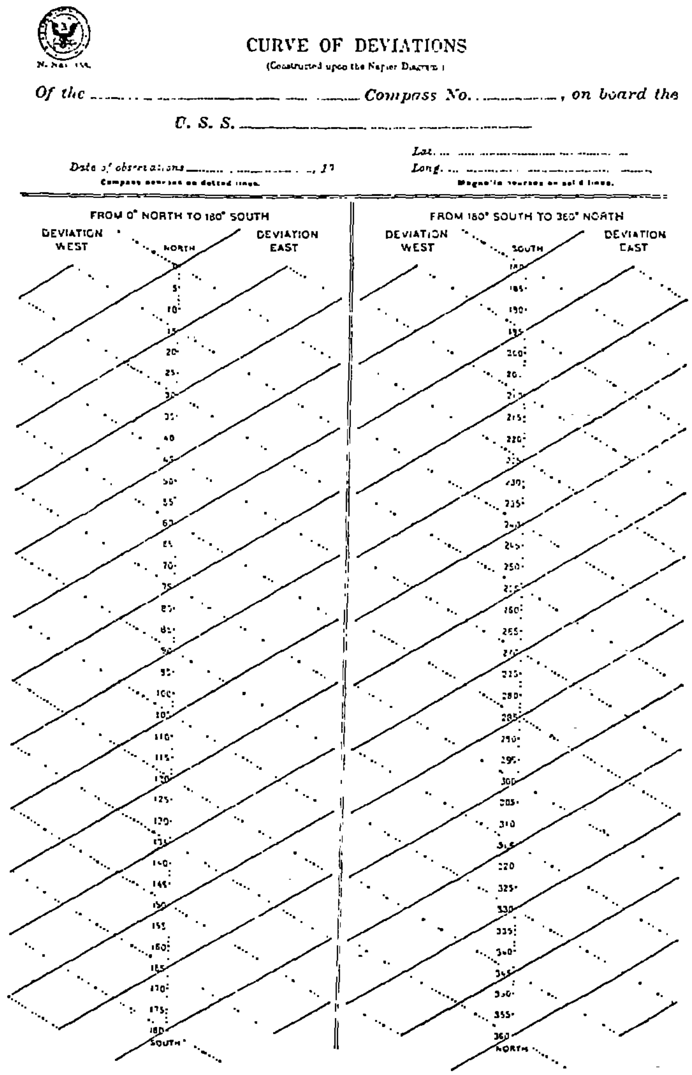
Fig. 2-13 Determination of Magnetic Heading Using Range, Ashore.

Determination of Magnetic Heading Using Range, Ashore.

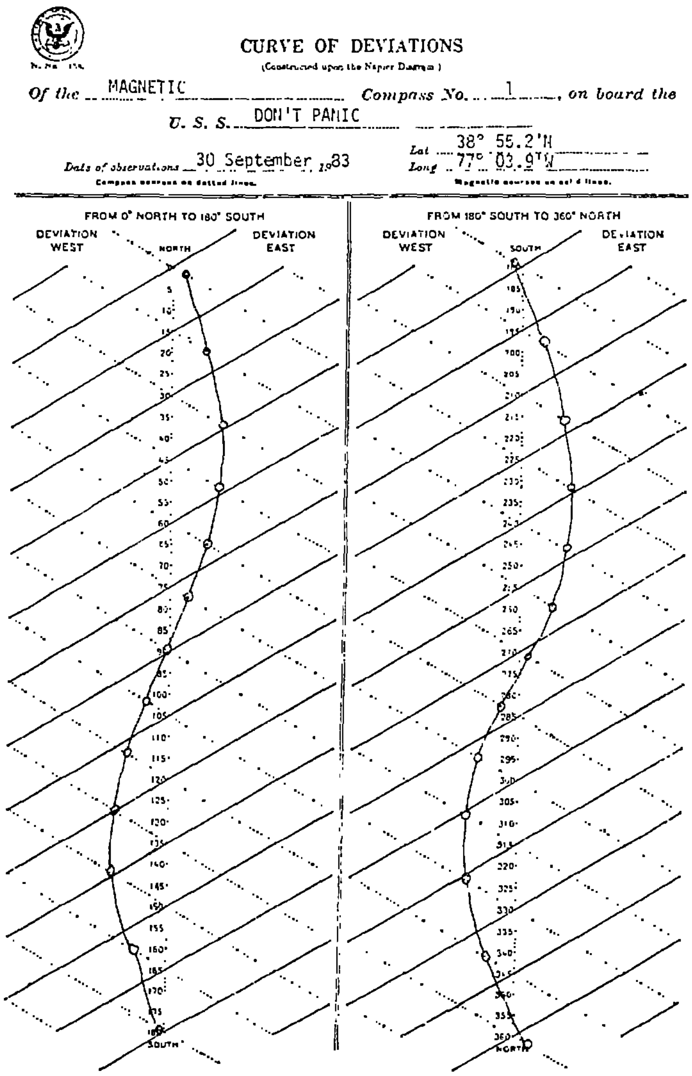
because the deviation was observed for a compass heading. Continue to plot all of the deviations for their respective compass headings, measuring on the vertical scale and plotting on the dotted (compass) line, on the right side for east deviation and on the left side for west deviation. If no dotted line exists, draw one in parallel to the other dotted lines through the heading desired. Connect all of the plotted deviations with a line to develop the CURVE OF DEVIATIONS.

Reading the Napier Diagram is a simple matter. Whether you enter with a compass or magnetic heading, go to the desired degree value on the vertical scale. If you know the compass heading, measure to the curve from the vertical along the dotted line if the line does not pass through the value. The width of the dividers is the deviation and can be measured by simply swinging the dividers back to the vertical scale. However, it is even easier to directly read off the corresponding magnetic heading. Simply come down, on the vertical scale to the compass heading (say, 330 With a straight edge, or by eyeball, parallel to or along the dotted line, go to the curve (Point Y) from the intersection of the straightedge (dotted line) and the curve, swing back to the vertical, parallel to a solid (magnetic heading) line. The value observed on the vertical line, 331 corresponding magnetic heading (331 for that compass heading (330

To obtain the corresponding compass course for a known magnetic heading, follow the same procedure, only go out on, or parallel to the solid line (magnetic heading) and return on, or parallel to the dotted line (compass heading).



Napier Diagram, Blank.



Napier Diagram With Curve of Deviations Plotted Where Semicircular Deviation Has Been Reasonably Corrected (i.e. Less Than 2

CHAPTER 3

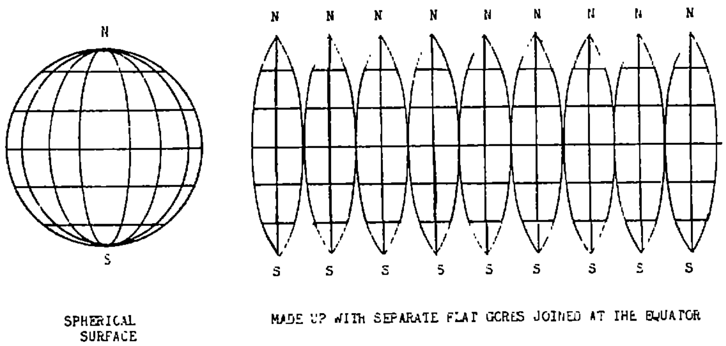
The Nautical Chart

Marine Chart-Nautical Road Map Defined

The landsman's raod map provides the information needed to navigate a car from one point to another, indicating which road to take, alternatives, the type of road important landmarks and other necessary information. The marine chart provides the same kind of information to the mariner. It is a map - for navigational use - a storehouse of information necessary for the safe navigation of craft on the water.

A Source of Vital Information

The marine chart provides distance, direction, locations of aids to navigation, geographical features, depth of water (soundings), vertical and horizontal clearances under bridges, heights of other structures, information on hazards, restricted areas, services and many other types of essential navigation information.



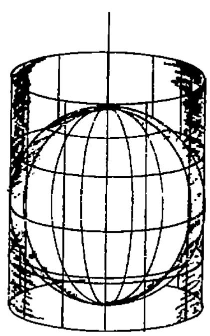
The Student Globe Disassembled Into Its Separate Gores.

Upon reflection, the amount of, complexity of and timeliness of the navigation information presented on the marine chart is incredible. To accomplish this communication of information to the navigator, the most useful projection is used, together with the choice of appropriate scale, chart symbols, abbreviations, lettering styles, colors, paper, photometric and printing techniques, and charting technology, to produce the present day, high quality, marine chart.
Charts for riverine waters are produced in the same manner, and, with the exception of the specific riverine data presented on them, are essentially no different from marine charts. For this reason, the discussion will be based on the marine chart, but when differences are important, they will be specifically treated for the riverine chart.

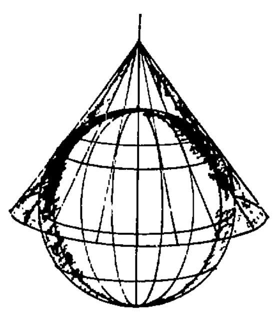
Representation of a Spherical Surface Upon a Plane or Flat Surface
The student of navigation quickly realizes that it is impossible to represent a large spherical surface upon a flat surface without some distortion, in distance, direction, shape and area. Even the school reference globe made out of paper or plastic printed on flat or rotary presses is made up of GORES of essentially flat surfaces <u>cut</u> to <u>bend</u> and <u>fit</u> upon a spherical SURFACE. If the globe were disassembled, and its separate pieces laid out, one would have a flat surface where areas would be "correct," but there would be huge gaps between the gores, and direction, shape and distances would have no meaning in the spaces between, nor continuity from one gore to another, except at the equator, where all gores are joined. (See Fig. 3-1.)

Chart Projection
Throughout the history of navigation there have been attempts to fit a round surface onto a flat one. Some have been remarkably successful under certain conditions, but <u>all</u> such PROJECTIONS suffer severe limitations to the area for which distortion is small. The goal of the various projections is to carefully balance and minimize the distortions to produce a representation that preserves, as best possible, direction, distance, shape, area and correct angular relationships. A projection which preserves correct angular relationships is termed CONFORMAL. This property, or a close approximation to it, is essential if the chart is to be used for navigation. No projection is fully adequate over a large area, but several are sufficiently so to be useful to the small craft navigator. For navigation charts the spherical surface of the earth has been projected on a cylinder and also on a series of coaxial, tangent (touching the earth's surface at one point or along one line) cones to provide the MERCATOR and the POLYCONIC PROJECTIONS respectively. Each of these projections has its particular utility and each has severe limitations. A particular projection is chosen dependent upon the intended use.

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



SPHERICAL SURFACE
DEVELOPED ON A
CYLINDER
CYLINDRICAL PROJECTION



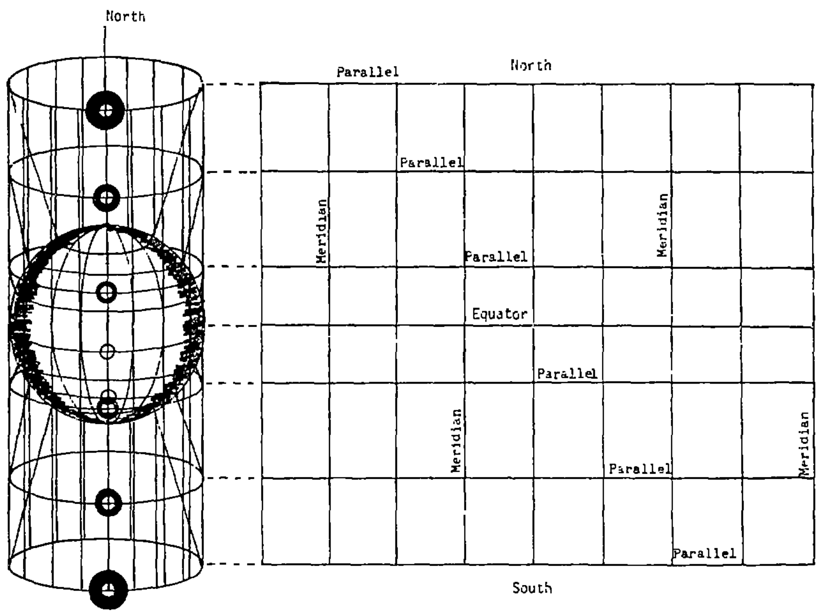
SPHERICAL SURFACE
DEVELOPED ON A
CONE
CONIC PROJECTION

The Earth's Spherical Surface Developed on Two Geometric Surfaces
Which Can Be Made Into Flat Sheets: The Cylinder and the Cone.

The Mercator Projection

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

This projection is <u>conformal</u>, but distance and area relationships are distorted. Both the meridians and the parallels are expanded at the same ratio with increasing latitude. The expansion is equal to the secant of the latitude (secant 0 = 1/cos 0), with a small correction for the ellipticity of the earth. The projection does not include the poles,



Mercator's Conformal Projection.

or usually, not even the uppermost 15 of latitude, because the value of the secant at these angles is too large, being infinity at Lat. 90 (N or S). Since the expansion is the same for all directions and angular relationships are correctly indicated, the projection is conformal and compass directions (rhumb lines or loxodromes) are shown as straight lines - of tremendous value to the mariner.

Distances can be measured directly, but not by a simple distance scale for the whole chart or for large areas. Instead, the <u>latitude</u> scale is used <u>along</u> any meridian. (Remember, 1 Lat. = 60 M, 1' Lat. = 1 M) Great circles appear as <u>curved</u> lines on the Mercator Projection except for the meridians and the equator, which appear as straight lines. Note: The Mercator Projection may also be made as an oblique projection (at an angle to the equator or meridian), using any great circle, rather than the equator, for the base line. Such a projection is termed an OBLIQUE MERCATOR PROJECTION, and is used for special navigational circumstances.

Coordinates for the Mercator Projection

The format for the Mercator Projection is a rectangle. Latitude and longitude are the coordinates used for the Mercator Projection. The parallels of latitude usually appear as horizontal, straight lines, running from the right to the left, with the projections oriented such that North is at the top of the chart and South, at the bottom, East at the right margin, and West at the left. (There are some Mercator Projections where, for various reasons, North does not appear at the top of the page.)

The meridians appear as straight, parallel lines running from the bottom of the chart to its top. The values for the meridians (longitude scale) are indicated on the top and bottom margins of the chart. The values for the parallels (latitude scale) are provided on the right and left hand margins, and are used for distance measurement, as well. Compass roses, indicating <u>true</u> and <u>magnetic</u> directions are placed at convenient locations about the chart.

Establishing a Position on the Mercator Projection

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

1. Using the Latitude scale at the right or left margins (these scales are <u>along</u> meridians.) simply take the latitude value and draw a <u>light</u> pencil line from this point across the chart <u>parallel</u> to the top, bottom and other parallels on the chart. Every point on this line has that same latitude.

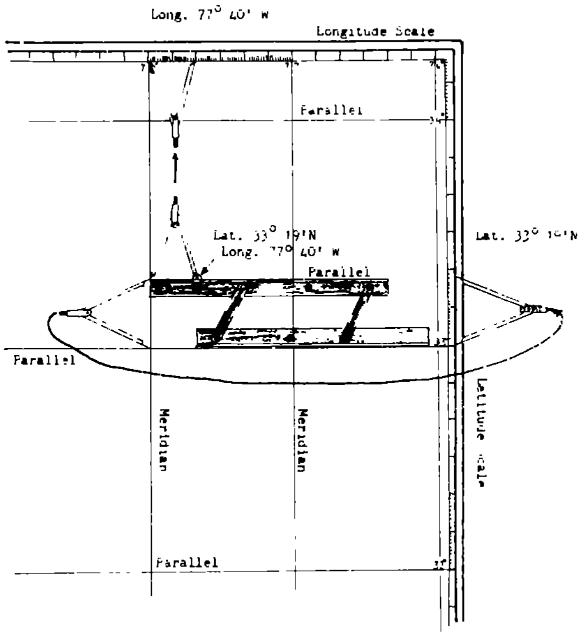
2. To specify the position uniquely, now using the <u>longitude</u> scale at the top or the bottom of the chart (these scales are <u>along parallels</u>.), locate the desired longitude value and strike another <u>light</u>, pencil line up or down, parallel to the meridians, and the sides of the chart. All points on this line (itself, a meridian) are of the same longitude. Where the two light, pencil lines intersect, the position is uniquely specified. Only this one point has both the particular latitude and the particular longitude specified above.

Use of Parallel Rulers and Dividers to Establish a Position on the Mercator Projection

A good navigator keeps his chart clean and free of unnecessary marks, lines, etc. In keeping with this good practice, the parallel rulers and the dividers are used to minimize marks on the chart while plotting a position. The technique is simple and is illustrated in Fig. 3-4:

1. Place the parallel rulers - which are two straight edges constrained to remain parallel as they are "walked" or "opened and closed" - with one edge along a parallel of latitude shown on the chart. Holding the base ruler along the parallel, swing the other ruler to the desired value on the latitude scale. A light, pencil line is drawn only in the vicinity of the approximate longitude, which is "eyeballed" or estimated downward or upward from the longitude scale.

2. After the latitude line has been drawn, take the dividers and set their points so that one point falls on the nearest meridian, and the other at the value of longitude desired. Now, bring the set dividers, carefully so as not to disturb the setting, down, along the meridian until the desired latitude line (parallel) is encountered. If the line crosses the meridian, simply measure along the latitude line (parallel) with the dividers from the meridian. Where the other point of the dividers falls is the desired longitude. The two coordinates now specify the position, uniquely. If the latitude line (parallel) does not cross the meridian, simply swing the parallel rulers



Plotting a Position On the Mercator Projection Using Latitude and Longitude Coordinates.

(keeping the base ruler along the parallel) so that the other ruler falls along the desired parallel and crosses the meridian, as well. Then, as above, measure the increment of longitude from the meridian along the parallel ruler, to the position.

3. The process can also be used with the meridian first, and the dividers set off of the parallel and the latitude scale. In addition, the dividers may be used directly, without the parallel rulers, to locate the position. In this case, the dividers are maintained "parallel" to the meridian or parallel by eye - relatively easy to the practiced navigator - as the position is struck.

Taking a Position Off of the Mercator Projection

Taking (reading) a position off the Mercator Projection is a very simple process, similar to plotting one, as shown above:

1. At the desired position, swing the parallel rulers from a parallel of latitude. Measure the latitude increment <u>along</u> a nearby meridian with the dividers.

2. Taking the dividers over to the latitude scale at the right or left margin of the chart, determine the value of latitude by measuring the set on the

dividers from the parallel up or down along the scale.

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

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

Direction on the Mercator Projection

A marine chart developed on the Mercator Projection usually has several compass roses (true and magnetic) placed at convenient locations about the chart. Directions are taken from these roses using the parallel rulers or other parallel producing navigation tool. The process is very simple and is illustrated in Fig. 3-5:

1. Place the parallel rulers along the course or bearing line to be measured.

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

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

It is important to realize that all directions indicated on and used to develop the marine chart are TRUE directions. Although the magnetic rose is provided within the true rose, the student is encouraged to take directions only from the true rose and not from the magnetic rose.

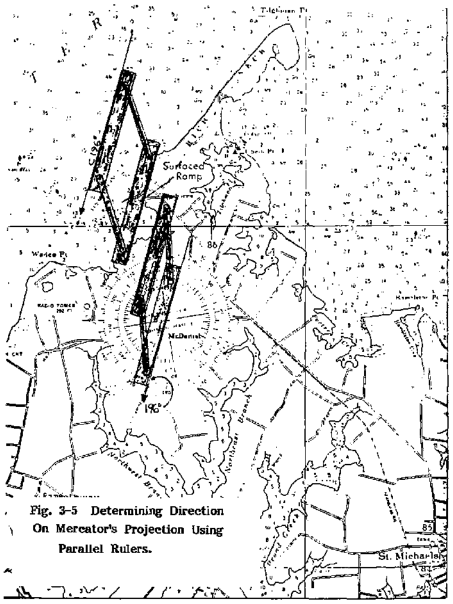
Uncorrection from true to magnetic and then to compass direc- tions should be performed by calculation, using current values for variation (which can change with time) and deviation. Taking directions off of the magnetic rose may, at first, seem to be an obvious short cut, but the reader is cautioned this can be very deceiving and disarming.

Most Aid to Navigation (ATON) information publications indicate only true directions. Under the bad habit of using the magnetic rose directly when utilizing such ATON information the less cautious navigator may fall into the trap of plotting true directions as magnetic ones without thinking. Such errors, caused by complacency and bad habits are completely avoidable if directions on the chart are kept true, and questionable short cuts avoided.

Measuring Distance on the Mercator Projection

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

Remember, however, that Mercator's Projection expands the scale as latitude increases. So, it is important where on the scale the distance is measured. Distance is taken using the navigator's dividers. Fig. 3-6 illustrates the technique for three lines: one short diagonal, one long diagonal, and one parallel, of essentially equal latitude. To minimize error caused by change in scale as latitude increases (especially on a small scale chart covering a large geographic area) the dividers are set for a distance increment about the latitude of the middle of the line to be measured. This is called the MID LATITUDE. For line AB, the mid latitude is 3350'N. For line CD, it is 32 N and for line EF, which is of constant latitude, it would be that latitude, 3030'N. The process is as follows:



Determining Direction On Mercator's Projection Using
Parallel Rulers.

1. Set the dividers on the latitude scale (along the meridian at the margin of the chart) to some convenient incremental value.

2. Take the set dividers, carefully, to avoid changing the setting, and place one end at an end of the line to be measured.

3. "Walk" the dividers, carefully, to avoid changing the setting, along the line, point to point, until the other end of the line is reached, or overrun.

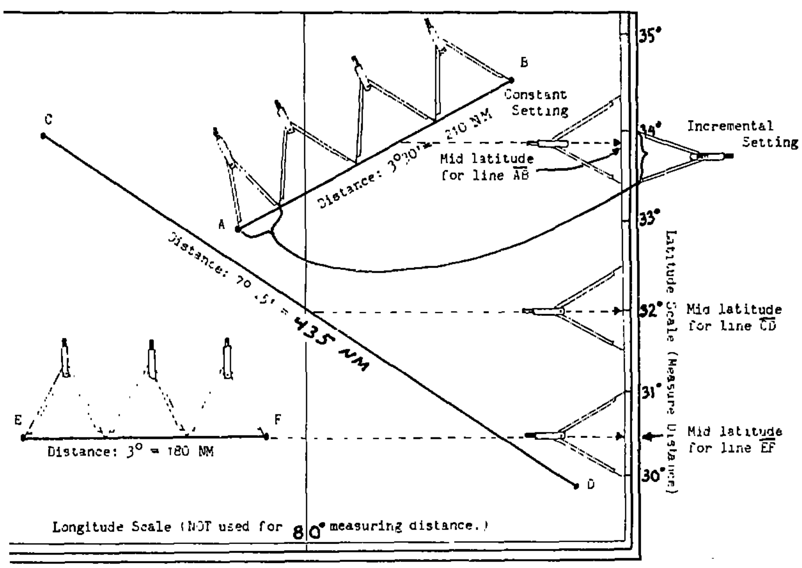
4. Count each complete "walking step" and multiply this sum by the distance increment setting. This is the base distance.

5. For the rest of the line remaining after the walking of the dividers at constant setting, keep one end of the dividers set on the line where the last complete "walking step" ended, and collapse the dividers to bring the other point to the end of the line.

6. Without changing the new setting, measure this distance along the latitude scale. Add this increment to the base distance to obtain the full length of the line. Remember, use only the latitude scale along the meridians forming the right or left margins of the chart for measuring distance on the Mercator Projection. Do not use the longitude scales at the top or bottom of the chart. Except at the equator, the longitude scales are constantly changing their value and are useless for distance measurement, no matter how "good" they look.

7. On large scale charts (scale is covered later) a graphic bar scale is also provided. The dividers can be used on this bar scale rather than on the latitude scale with similar technique and results. On such charts the latitude scale is divided into minutes and seconds, not minutes and tenths.

The Plotting Sheet, a Useful Approximation of Mercator's Projection
There are times when a navigator needs to construct a simple Mercator Projection - the printed chart has too small a



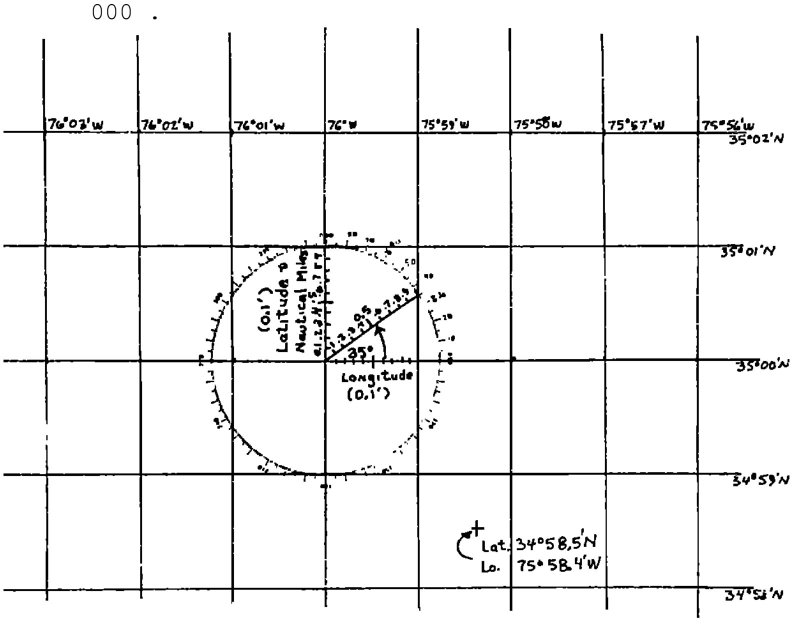
Measurement Of Distance On Mercator's Projection Using Navigator's Dividers and Latitude Scales.

scale, it isn't desirable to place additional markings on the printed chart, or when land, visual aids to navigation and depth of water are unimportant and when plotting radio bearings.

The position PLOTTING SHEET is an excellent, easy to construct, temporary substitute (but not replacement) for the printed Mercator chart under these conditions. It is designed primarily for plotting dead reckoning and lines of position obtained from celestial or satellite observations or from radio aids to navigation. Because its scale can be chosen in degrees, minutes, or other subdivision of the minute (multiple powers of 10) it offers a very rapid and simple way to construct a very large scale, local chart having all of the desirable features of Mercator's Projection.

The plotting sheet is based on a graphical solution of the secant of the latitude, which approximates Mercator's expansion, but does not correct for ellipticity of the earth. Preprinted Universal Plotting Sheets are available in pads at establishments which sell marine charts. Using a protractor, drafting compass, dividers, and parallel rulers, the plotting sheet can be made in the following manner (illustrated in Fig. 3-7), and if desired, reproduced on an electrostatic copier for convenience:

1. On a sheet of paper, draw a circle, and using a protractor, mark and label the circle with 000 at the top to 090 if directions are necessary or continue to 359 if directions are desired. Once the sheet has been marked, begin at the 090 mark, label degree marks in a counter clockwise direction from 090 to 000 .



Construction Of the Plotting Sheet.

This will then be used to select the mid
latitude of the sheet.

2. Through 000, the center of the rose, and 180 , draw a vertical line from the top of the sheet to the bottom.

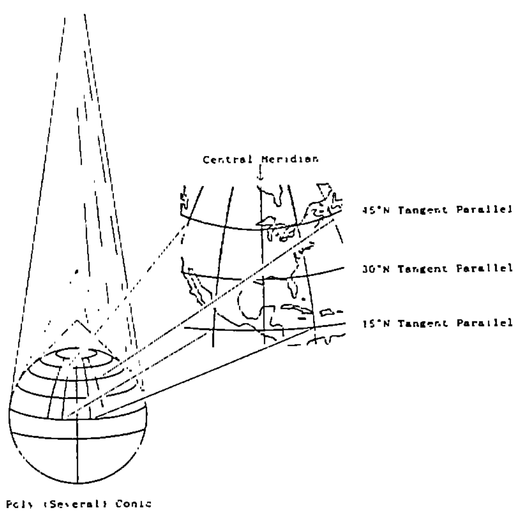
3. Horizontally, draw a line from the left margin to the right margin through 270, the center of the rose, and 090 .

4. Parallel to the horizontal (270-090) line draw lines tangent to the top and bottom of the circle and parallel to these lines at distances equal to the radius of the circle. These will be parallels of latitude. They may be one degree apart or one minute apart, depending on the desired scale. (Remember, 1 Lat. = 60 M, 1' Lat. = 1 M)

5. For the desired mid latitude, say Lat. 35 N, draw an oblique line from the center of the circle at an angle (counter clockwise) to the horizontal line of 35 on the upper right hand quadrant of the circle. (If the desired mid latitude was 35 S, the same procedure would be followed.)

6. Draw in and label the meridians. The first is the vertical line through the center of the circle, and can be labeled with any desired longitude. The second is a vertical drawn through the intersection of the oblique line drawn in step 5, above. Subsequent meridians are drawn parallel to, and at the same distance apart as the first two meridians. Use your dividers to strike off the distances.

7. Graduate the oblique line into conven- ient units. If one minute of latitude is the scale chosen, then this scale serves as both the latitude scale and the nautical mile scale. Longitude can also be taken by measuring horizontally from a meridian rather than obliquely, along the line, using the dividers and parallel rulers.



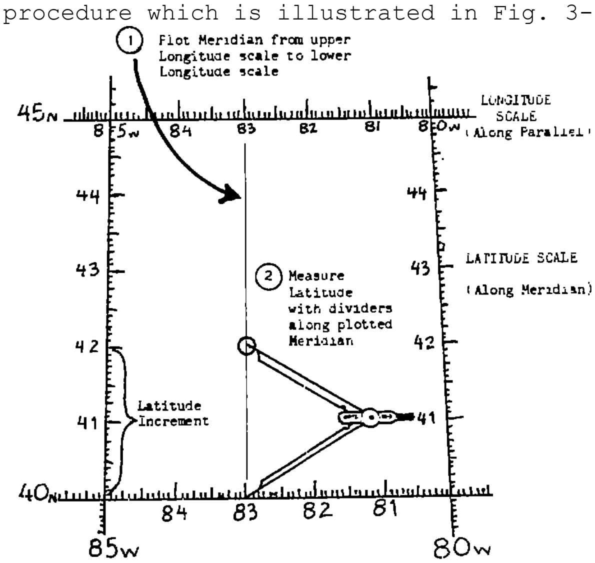
The Polyconic Projection.

The Polyconic Projection

Nearly all marine navigation charts for the Great Lakes are based on a POLYCONIC projection - a series of cones concentric with the earth's axis, and tangent to the sphere at different parallels of latitude. The earth's surface features are projected on the resulting surface, outward from the center of the earth. When a plane portion is taken from the polyconic surface, as shown in Fig. 3-8, the meridians appear almost as straight lines, very slightly curved converging northward beyond the top of the chart, toward the apexes of the cones. Great circles appear as essentially straight lines and parallels of latitude appear as slightly curved, almost parallel lines intersecting the meridians at 90 angles and diverging as they approach the edges of the chart. Distortion is least along the CENTRAL MERIDIAN and increases toward the sides of the chart, as the distance between parallels of latitude increases. Although the polyconic chart is not conformal, great circles do appear as essentially straight lines, and radio signals (following great circles) can be plotted as straight lines on this projection.

Latitude and Longitude Scales on the Polyconic Chart

Because the parallels of latitude appear as curved lines diverging toward the sides of the chart, and the meridians, although nearly straight lines, obviously converge to an imaginary spot off the top of the chart, it would do no good to have latitude and longitude scales on the squared margins of the chart such as found on Mercator's Projection. Rather, the latitude and longitude scales appear on the meridians and the parallels at intervals which depend on the scale used. Positions are plotted on the polyconic projection using the following procedure which is illustrated in Fig. 3-9:



Position Plotting On the Polyconic Chart.

1. Using an AIRCRAFT NAVIGATIONAL PLOTTER (a rule with a protractor mounted on its side), or other similar tool as a straight edge (However, for this particular procedure a simple straight edge will do. The plotter will be useful for other measurements on the polyconic chart.) draw a light, pencil line from the longitude scale on the upper parallel to the longitude scale on the lower parallel nearest the position.

2. Because the parallels of latitude are curved, and divergent on this projection it is not possible to use the straight edge on the latitude scales. Instead, the latitude is taken on the nearest meridian with latitude scales using the dividers, or a length measurement with one of the scales on the Aircraft Navigational Plotter, and transferred to the longitude meridian just drawn using 1., above.

Distance on the Polyconic Chart for Great Lakes Region
Distances on Great Lakes charts are indicated in statute miles (mi.) and notin nautical miles (M). Large scale Great Lakes charts may also indicate distances in meters (m), yards (yd.) and feet (ft.). Bar graphs are provided for measuring distances.

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

The Aircraft Navigational Plotter is a very convenient tool to measure direction on the polyconic (and Mercator chart, for that matter) chart. This process is illustrated in Fig. 3-10. Simply place the straight edge (or one of the several parallel scales) of the rule portion of the plotter on the line for which the direction is to be measured. Then slide the rule parallel to the line until the center of the attached protractor intersects the nearest meridian. Read the true direction of the line of the protractor scale. If the direction is between 000 and 180 , read the outer scale. If the direction is between 180 and 360 , read the inner scale. The Aircraft Navigational Plotter is partic- ularly useful for determining directions in the higher latitudes, where the meridians converge rapidly and rhumb lines are significantly curved.

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

The scale on the nautical chart is expressed as a ratio of the units, such as one inch on the chart is equivalent to 2,500 inches on the earth's surface, or 1: 2,500. There are several scales in use,

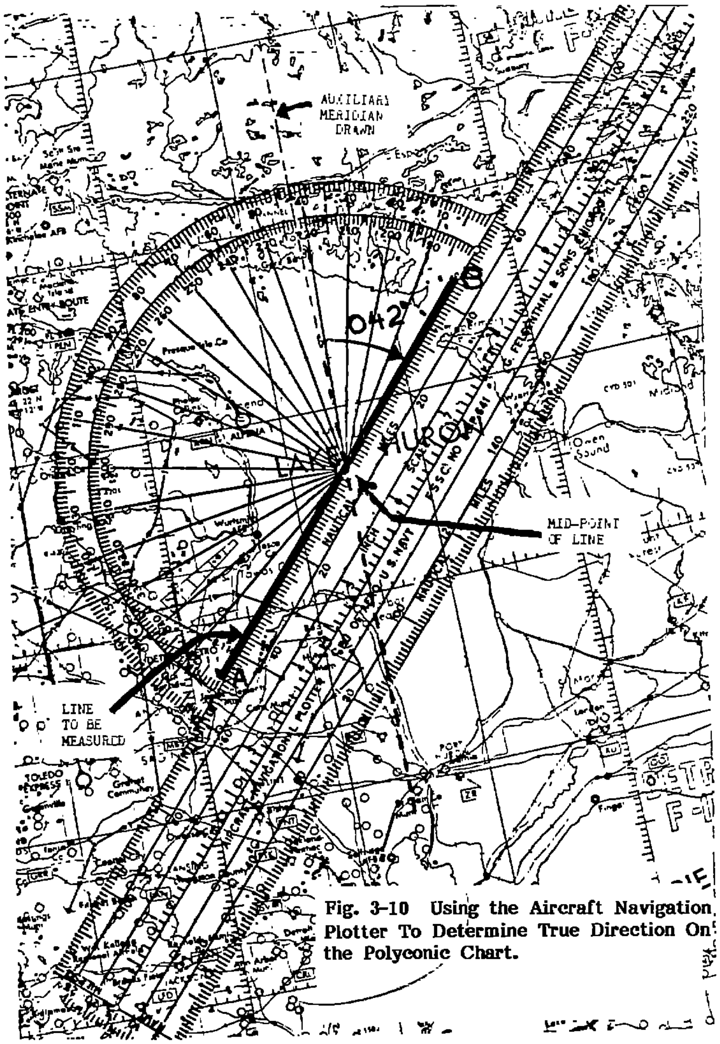


Fig. 3-10 Using the Aircraft Navigation Plotter To Determine True Direction On the Polyconic Chart.

Using the Aircraft Navigation Plotter To Determine True Direction On the Polyconic Chart.

depending on the area being charted and the detail to be revealed. Relative size of the scale (large or small scale) is determined by the relative size of the ratio expressed as a simple fraction. The larger the <u>value</u> of the fraction, the larger the scale. A scale of 1:5,000,000 would be considered a SMALL SCALE chart. A <u>large</u> scale chart covers a small area. A <u>small</u> scale chart covers a large area. Always use the largest scale chart available for navigation to show the maximum detail.

1:2,500 expressed as a fraction, 1/2,500 has a much <u>larger</u> value than the scale of 1:5,000,000 where the fraction has a value of 1/5,000,000. Thus, a chart with a scale of 1:2,500 would be considered a LARGE SCALE chart, and a chart with a

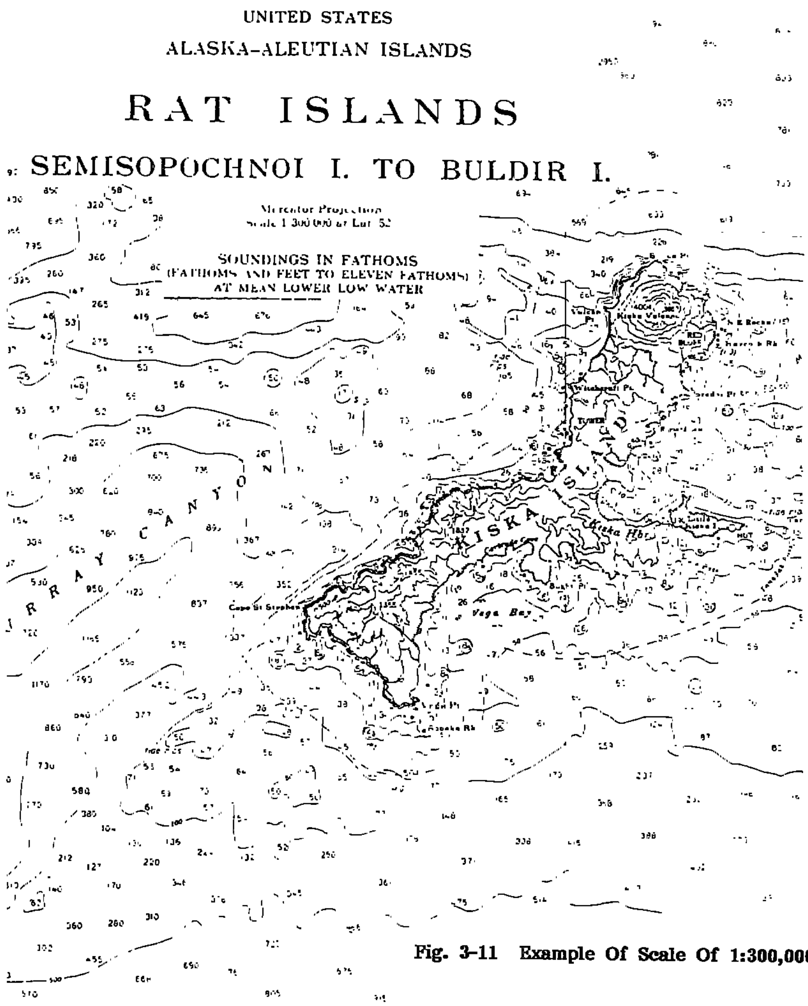


Fig. 3-11 Example Of Scale Of 1:300,000.

Types of Marine Charts
There are several types of marine charts. In general, these are differentiated by their scale and their intended use. These types, and their principal uses are:

<u>SAILING CHARTS</u>. Scales of 1:600,000 and smaller. Used in navigating offshore, outside of coastal areas, or for sailing between distant coastal ports. The shoreline and topography are generalized. Offshore soundings, principal lights, outer buoys, and landmarks visible at considerable distances are shown. Detail needed for close-in navigation is lacking. Charts of this series are useful for plotting the track of major tropical storms.

<u>GENERAL CHARTS</u>. Scales between 1:150,000 and 1:600,000. Used for offshore, but within coastal zones of navigation outside of outlying reefs and shoals when the vessel is generally within sight of land or aids to navigation and its course can be directed by coastal piloting techniques. (See Fig. 3-11.)

<u>COAST CHARTS</u>. Scales between 1:50,000 and 1:150,000. Used for inshore navigation of bays and harbors of considerable width and for large inland waterways and coastal passages.

<u>HARBOR CHARTS</u>. Scales larger than 1:50,000. Used in navigating harbors, anchorage areas and small waterways.

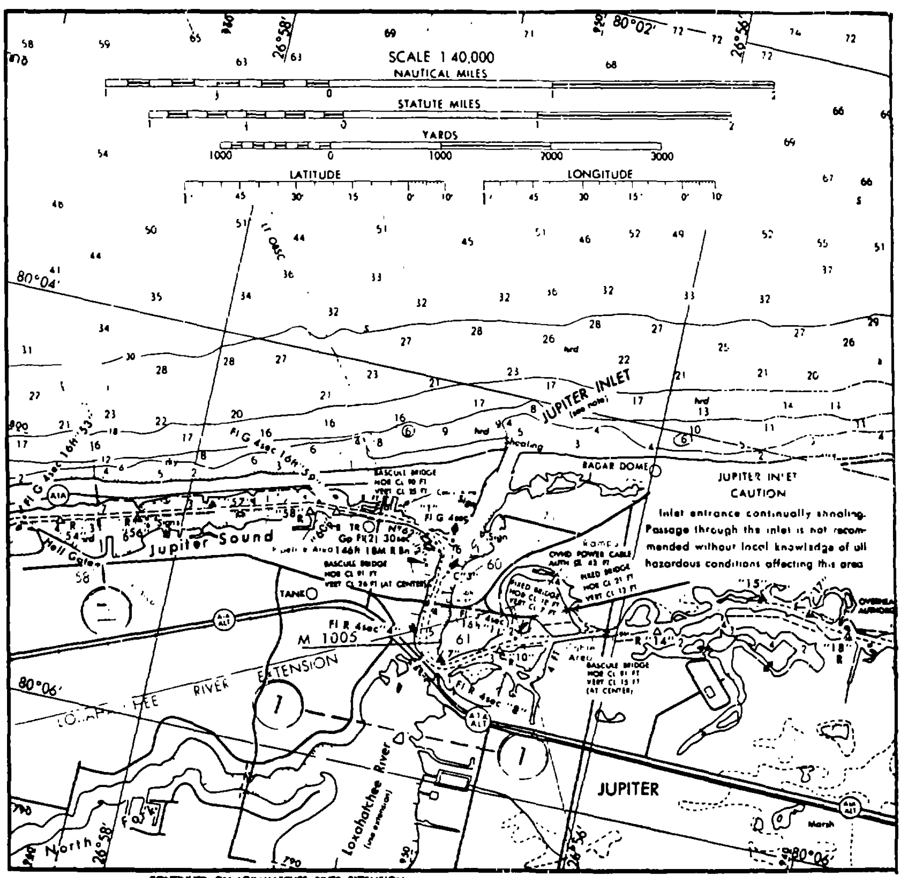
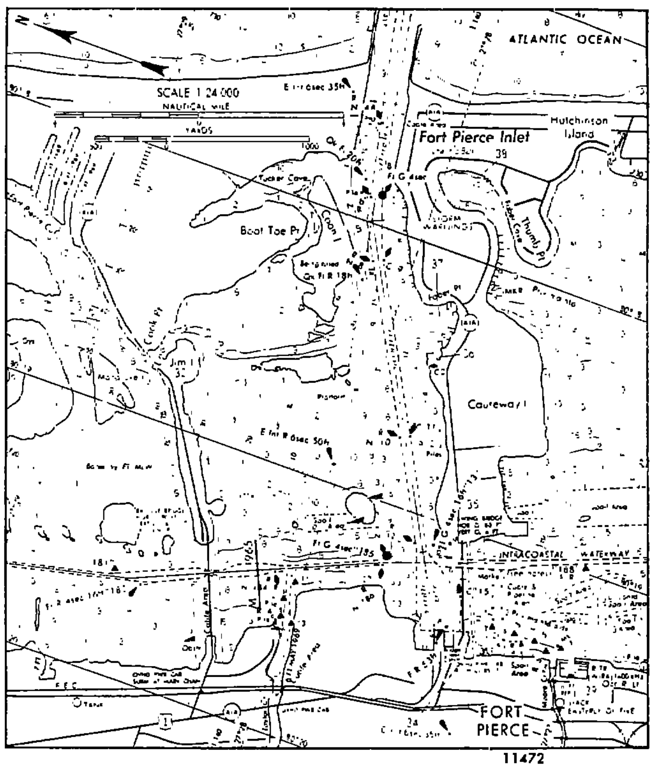


Fig. 3-12 Example Of Scale of 1:40,000.

Example of Scale of 1:40,000

Shows considerable detail, even to individual piers and slips. (See Fig. 3-12.)

SMALL CRAFT CHARTS. Scales of 1:40,000 and larger (although some are at smaller scales). These are special, composite type charts of inland waters, including the intracoastal waterways. The mercator projection is used on these charts, but it may be skewed - north does not necessarily appear at the top - to fit the expanse of water on to the chart. A river, for example, would run lengthwise on the chart, and north would be toward the side. (See Fig. 3-13.) Small Craft Charts are printed on lighter weight paper and folded. These charts contain additional information of interest to small craft operators, such as data on marinas, tide predictions and weather broadcast information. They are designed for use in open boats and runabouts. Prior to 1974, these charts were numbered with an "SC" designator. Some charts may still be found with this number. The latest of these charts conforms with the current National Ocean Service/Defense Mapping Agency Hydrographic, Topographic Center (NOS/DMAHTC) numbering system.



Example of Scale of 1:24,000.

Soundings
One of the most critical types of information shown on a chart is depth of water and bottom characteristics. This is accomplished through the use of a combination of numbers, color codes, underwater contour lines and a system of standardized symbols and abbreviations.

The soundings on the chart normally represent the water depth from a specified datum. Datum refers to the base line from which a chart's depth measurements are made. On the east coast the tidal datum is mean low water (the average low tide). The tidal cycle on the east and Gulf coasts produces tides whose change is approximately equal in height and depth. Since the least water is under the keel during low water, the mean low water is used as the datum. A number of low tides are average to determine mean low water. Realize, however, for this reason, the actual low tide may be lower than the mean low water.

On the Pacific coast and Gulf of Mexico datum is the mean lower low water mark. The reason for this is the Pacific and Gulf Coasts experience two different high tides and low tides each day. These tides may differ by several feet and one low tide may be much lower than the other. In the interest of vessel safety, the mean or average of the lowest daily tides in the tidal cycle, (a month) is used as the basis for establishing sounding datum.

Contour lines connect points of equal depth and profile the bottom shape. These lines are either numbered or coded according to depth using particular combinations of dots and dashes.

Charted depth of water may be in feet, fathoms (a fathom equals six feet) or meters (a meter equals about 3.3 feet). The chart legend will indicate which unit (feet, fathoms or meters) is used. Sometimes both fathoms and feet are used. This is clearly indicated on the chart.
Clearance of bridges and heights of landmarks are given in feet above mean high water. Analogous to using mean low water for soundings, indicating clearances above mean high water is also conservative and allows more room for safe passage of your boats's superstructure and mast. However, some high tides are higher than the mean and vertical clearances will then be less than charted.

Although the datum for depth and height is conservative, it must be realized that the datum is based on average values of low or high tides. Thus, by definition, these mean or average values result from tides which are higher or lower than the resulting mean value used as the datum.
Lower or higher tides are indeed possible and must be expected.

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

General Information Block (See Fig. 3-14) contains the following items:
1. The chart title, which is usually the name of the prominent navigable body of water within the area covered in the chart.
2. A statement of the type of projection and the scale.
3. The unit of depth measurement (feet, fathoms or meters) and datum plane.

Notes. All notes should be read carefully because they contain information that cannot be presented graphically such as:
1. The meaning of special abbreviations used on the chart.
2. Special notes of caution regarding danger, prohibited areas, dumping areas, safety areas, firing areas, vessel traffic zones, etc.

3. Tidal information.
4. Reference to anchorage areas.

Edition Number. The edition and/or revision numbers of the chart indicate the currency of the chart.

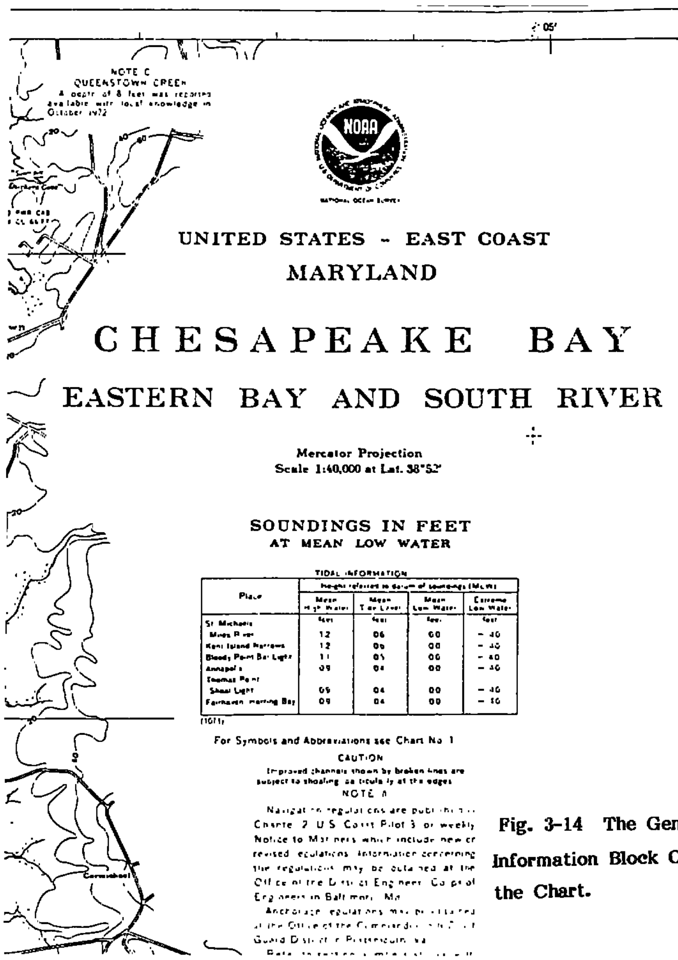


Fig. 3-14 The General Information Block On the Chart.

The General Information Block On the Chart

1. The edition number and date of the chart are located in the margin of the lower left hand corner.

2. In addition, hand written notations may be placed on a chart incorporating corrections occurring after the date of issue which were published in the Notice to Mariners or Local Notices to Mariners. Corrections occurring after the date of issue and published in this manner must be entered by hand on the chart. This is the chart owner's responsibility. Failure to use the latest navigational information could be the cause of a serious mishap.

Chart Symbols and Abbreviations. A vast array of symbols and abbreviations are used on charts to indicate the physical characteristics of the charted area and details of the available aids to navigation. Standardized chart symbols and abbreviations are shown in "Chart No. 1, Nautical Chart Symbols and Abbreviations" published jointly by the Defense Mapping Agency and the National Ocean Service.

Accuracy of Charts

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

1. The source and date of the chart are generally given in the title along with the changes that have taken place since the date of the survey. Earlier surveys often were made under circumstances that precluded great accuracy of detail. A chart based on such a survey should be regarded with caution. Except in well-frequented waters, few surveys have been so thorough as to make certain that all dangers to navigation have been found and charted.

2. The scope of sounding data is another clue to estimating the completeness of a survey. Most charts seldom show all soundings that were obtained. However, if soundings are sparse or unevenly distributed in charted piloting waters, the prudent navigator exercises care. Proceed with caution.

3. Large or irregular blank spaces among soundings may mean that no soundings were obtained in those areas. Where the nearby soundings are "deep", it may logically be assumed that in the blanks the water is also deep. However, when surrounding water is "shallow", or if it can be seen from the rest of the chart that reefs are present in the area, such blanks should be regarded with great caution. This is especially true in areas with coral reefs and off rocky coasts. Give such areas a wide berth.

4. Everyone responsible for the safe navigation of a vessel must have a thorough working knowledge of the nautical chart. Select a chart you commonly use in navigating, and with this in hand, reread the preceding parts on charts!

Chapter 4

The Navigator's Tools

Introduction
In addition to the magnetic compass, charts, parallel rulers, dividers, aircraft navigational plotter and pelorus described in the foregoing subsections, the navigator of a small craft uses several other tools upon occasion. Most of these tools are relatively inexpensive for the aid obtained by their use. Accuracy depends on good quality and technique in the tool's use.

A navigator is encouraged to obtain the best tools for the money and projected use. The most expensive tools, however, are not necessarily the best, nor are the least expensive, a bargain.

But, just as a mechanic and a carpenter knows, good tools cost good money - and quickly prove their worth. Novices rapidly find, to their dismay, the inexpensive, student drafting compass and dividers, made of plated, stamped steel, quickly fall apart, or rust in the marine environment, while the moderately priced German silver or heavily chrome-plated, marine brass, well-constructed navigator's divider's and compass are rugged by design as well as materials, and prove by their long and dependable service, to be the better bargain, by far. Remember, the marine environment, salt or fresh water, is a harsh taskmaster, and only good tools survive its test. These other tools, which the navigator may find useful, are described below:

Plotters
There are plotting devices other than parallel rulers in common use by small craft operators. Among such tools are the "paraglide" or "paraline"-type plotter (a graduated rule, with protractors and parallel lines, attached to a roller, constrained to roll such that the rules always remain parallel). With this tool, the user has the option of rolling the gliding rule from the course line over to a convenient compass rose and taking the reading from the appropriate side of the rose, along the edge of the rule; or simply gliding the rule from the course line over to a meridian or parallel and reading the direction using one of the protractors inscribed on the face of the rule. Both methods are suitable and easy to accomplish on small craft, if the user is familiar with the tool. There are several plotting devices which are essentially like the "paraline"-type plotter, without the roller, but with many parallel lines scored lengthwise. These are used in the same manner as the rolling type only rather than roll, the parallelism is maintained by "eyeball" relative to the many parallel lines. Another "tool" consists of two identical drafting triangles - 30 - 60 - 90 - (used, hypotenuse to hypotenuse, or long side to long side as to form a parallelogram, which is expanded by sliding the triangles together until the compass rose center is touched). See Fig. 4-1. Such devices have their followers, with just cause. And, there are many other novel devices for plotting. The ones which are most suitable for the individual navigator are the ones which are found to be useful in rough seas on the small craft. Not all are satisfactory all of the time and in all conditions.

Individuals are encouraged to inquire of their shipmates as to their experience with such devices, and try as many as possible before choosing their favorite(s). The navigator should be comfortable with the tools chosen.

Drafting Compass
The drafting compass is an instrument similar to your dividers, however one leg has a pencil lead attached. This tool is used for swinging arcs and drawing circles.

Wrist Watch (or other accurate time piece).
Time is one of the basic dimensions of piloting. A reliable time piece is essential. Without a means of telling time, dead reckoning navigation, running a search pattern or identifying the proper characteristic of an aid to navigation are

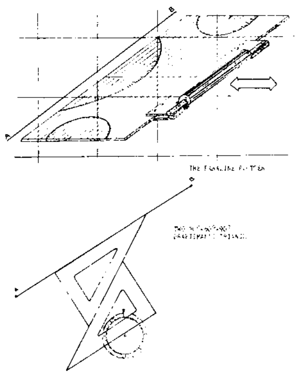


Fig. 4-1 The "Paraglide" or "Paraline" Type Plotters and the Draftsman's Triangles Used To Determine Direction.

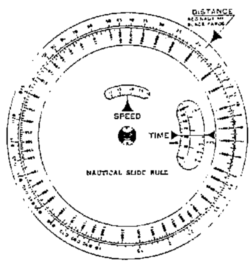
all impossible. Every crew member should get in the habit of always wearing a wrist watch when under way. The wrist watch should be waterproof and have means of indicating hours, minutes and seconds. Experience has shown that digital, quartz controlled, electronic watches with chronograph (stop watch) features are usually both accurate and precise enough for piloting and navigation work.

Pencils
It is important to use a correct type of pencil for plotting. The pencil should leave a line which is easy to see, does not smudge and yet, is easy to erase completely, and does not leave a permanent mark on the chart. A medium pencil (No. 2) is best. Keep your pencils sharp; a dull pencil can cause considerable error in plotting a course due to the width of the lead and may also smudge up the chart. The new 0.5 mm mechanical pencils are excellent for chart work.

Nautical Slide Rule
The purpose of the nautical slide rule is to quickly solve problems in speed - time - distance, with minimal chance of error. Although there are many varieties of nautical slide rules available, they all function in the same manner. For any two values of a speed - time - distance problem, the third value can be readily determined. Fig. 4-2 depicts a commonly used nautical slide rule. The nautical slide rule has three clearly labeled scales: speed - time - distance. By turning the appropriate dials, values can be independently set into the indexes. With values set into any two scales, the third, or unknown value, will automatically appear at the appropriate index, Directions supplied with the rule will indicate its use and how to read the device. Note: With the advent of the newer, inexpensive electronic calculators, the nautical slide rule is now becoming a useful backup tool. The electronic digital hand held calculator is also satisfactory for navigation purposes. Use of such devices is encouraged.

Hand Bearing Compass
A special hand held compass may be used for "shooting" visual bearings to Aids to Navigation and other vessels. This is not a required tool if the steering compass may be readily used for this purpose. In most cases, bearings accurate enough for a precise fix cannot be determined with a steering compass unless the boat is first pointed at the object or the boat is equipped with a pelorus or has been carefully calibrated for beam bearings.
The hand bearing compass may be moved by the navigator, independent of the steering compass. Care should be exercised, however, to make sure the hand held compass is not influenced by nearby magnetic fields set up by masses (engines) of ferromagnetic (iron, steel) metals, such as standing rigging, rails, anchors and electrical equipment.

Binocular
A good 7 x 50 mm binocular is useful in locating and identifying Aids to Navigation.



The Nautical Slide Rule, A Speed, Time, Distance Calculator.

This is also useful in Search and Rescue (SAR) and other functions. Avoid larger powers, they are impossible to hold by hand steady enough. Avoid smaller objective lenses (the larger lenses at the away end of the binocular), they have too limited a field of view and gather too little light to be useful in the operational environment.

Hand-held Lead Line
Although much maligned by some, a hand- held lead line may be used to ascertain shallow depths of the water, when the depth sounder is not available or usable, like around a grounded vessel, perhaps from a dinghy. The lead line consists of a line marked in fathoms and a lead weight of 7 to 14 pounds, hollowed at one end in which tallow can be inserted (called "arming the lead") to gather samples of the bottom. It is difficult to use except in relatively shallow, calm water, at slow speed. Nonetheless, keep a lead line neatly stowed and ready for use at all times in the event the depth sounder becomes inoperative and soundings are required.

Depth Sounder
The depth of water is one of the key factors which a navigator considers in safety of navigation. The depth sounder is an electronic instrument designed to provide information on a continuous basis through the transmission of pulses of high frequency sound waves that reflect off the bottom and return to the receiver. The reflected waves or echoes are converted to electrical signals and read from a visual scale or indicating device. The sound waves are transmitted by a device called a transducer. The transducer is usually mounted above the low point of the hull; therefore, this distance must be subtracted from all readings to determine the actual water depth below the boat's hull.
You must also add in the distance from the water line to the transducer in comparing charted soundings, (corrected

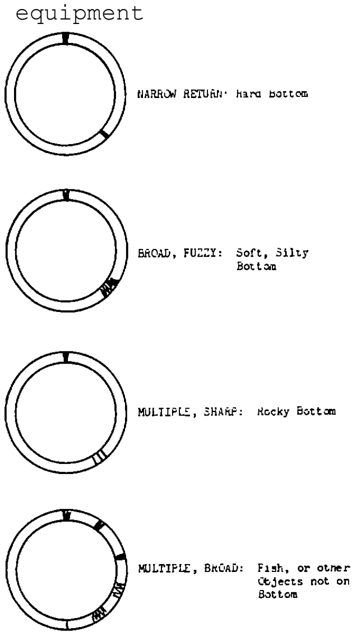
for the state of the tide) with observed depth sounder readings. Water depth is indicated on a screen, by a flashing light or on a recorder by a trace or, with modern, digital devices, directly as numbers on an electronic (LED or LCD) indicator. With practice and experience, you can also tell what the bottom characteristics and conditions are. The width of the flashing light or recorder trace may be generally interpreted with practice as follows: (See Fig. 4-3)
The principal controls of any depth sounder are the range switch and the sensitivity control:

1. The range switch, usual settings: "OFF", "FT" (feet) and "FAITH" (fathoms) provides switching from FT to FATH or vice versa, which may require a change in sensitivity. When switching from FT to FATH sensitivity should normally be increased and when switching from FATH to FT it should be decreased.

2. The sensitivity control normally is adjusted to get a good solid, sharp echo. This may be replaced by an automatic gain control.

RDF/ADF
A radio direction finder will allow you to take bearings on certain radio transmitters which are beyond visual range. There are two basic types of direction finders; those which you must operate manually (RDF) and those which take and display the bearings automatically (ADF). Radio bearings are used and plotted essentially in the same manner as visual relative bearings. Great care must be taken when using RDF data. The accuracy of RDF/ADF signals are adversely affected by a number of factors such as metal masts, other antennas, superstructure, etc. Radio signals from land based stations may also be affected by mountains which may bend the waves passing over them in such a manner that they appear to be coming from another direction. Also, signals received from very distant stations (hundreds of miles) will have to be corrected when plotted on Mercator charts.

Radio waves, unless refracted (bent) or reflected, travel along great circles on the earth's surface. On Mercator and polyconic projections great circles (other than the equator and the meridians), project as <u>curved lines</u> rather than straight lines. The radio waves travel along these curves, <u>not</u> the apparent "straight" line between the transmitter and the receiver. RDF/ADF equipment



Interpretation of Depth Sounder Flash Returns.

should be calibrated in much the same way as a magnetic compass. Corrections are applied as in deviation. It takes a great deal of experience to be able to effectively use RDF equipment for precise navigation. Radio direction finding is discussed thoroughly, later in Chapter 9.

VHF-FM Homer

A VHF-FM Homer (direction-finder homing device), although not a piloting tool, allows zeroing-in on the source of any FM radio signal being received. The majority of Coast Guard Auxiliary and private vessels will not have this instrument at this time since its use has primarily been by the Coast Guard. This unit will also function as a back-up VHF-FM receiver. The homer measures the angle of a signal and converts this into the direction of the source from the boat. This direction is indicated by a display which will show whether the transmitting source is to port, starboard, or dead ahead. The source must transmit each time the direction is measured.

Chapter 5

Dead Reckoning

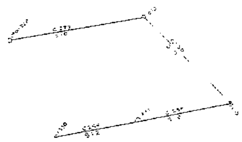
Dead Reckoning Defined

The practice of estimating position by advancing a known position for courses and distances run is called DEAD RECKONING (DR). It is generally accepted that the course known to have been steered and the speed through the water observed to have been made will be used. All directions plotted on the chart will be TRUE. The DR plot is always started from a known position, and always restarted at the time another known position is determined. The effects of current and wind drift are not considered in determining a position by dead reckoning. Such a position is termed a DEAD RECKONING POSITION (DR position). The term dead reckoning may also be used to refer to the determination of a predicted position by use of the course and speed expected to be made good over the ground (over the earth's surface without regard to lost motion through the water) taking into consideration the effects of wind and current. However, positions so determined by this process of dead reckoning may be considered improved, they are termed ESTIMATED POSITIONS (EP) and not DR positions.

Elements of Dead Reckoning

In the process of dead reckoning, courses are laid down on the chart from a known starting position called a FIX or Point of DEPARTURE. Course lines are identified by their true direction, which is written preceded by a "C" on top of and parallel to the line in the usual three digits (i.e. 000 for 000 - True North), the degree sign ( ) is not necessary and is not written. Beneath the course line is written the speed being run by the vessel. The vessel's speed is written in nautical miles per hour, knots (kn) using an "S" followed by one, two or three digits. The precision of speed can be measured to the nearest tenth of a knot. The speed may also be indicated in miles per hour (mph) if distances are measured in statute miles. The abbreviation kn (or mph) is not necessary and is not written.

The position at which the vessel would be expected to be after running that course at that speed for a particular length of time (expressed in minutes) is calculated and the resulting distance is marked off on the course line, and the DR position is plotted. The DR position is labeled by a dot surrounded by a semicircle, and the time, using the 24 hour military system, is written on the chart at an angle to the horizontal. A simple DR plot, starting from a known DEPARTURE, which has been labeled with its time, a complete circle above the dot is



A DEAD RECKONING PLOT (DR PLOT) SHOWING DEPARTURE, COURSE LINES, POSITION TIMES, COURSES AND SPEEDS.

Dead Reckoning Terms Defined

There are several important terms used in the practice of dead reckoning. Their definitions are universal among navigators and should be learned and understood. These terms are defined below:

Course (C). Course is the average heading and the horizontal direction in which a vessel is intended to be steered, expressed as the angular distance relative to north, usually from 000 at north, clockwise through 360 from the point of departure or start of the course to the point of arrival or other point of intended location. The reference direction is true and if so used, need not be labeled. However, some navigators find it more convenient to also use magnetic courses. These magnetic courses are labeled after the three digit direction with the letter "M."

Others have been tempted to proceed one step further and indicate compass courses, labeling them with the letter "C." This practice is to be discouraged, since a compass course depends upon the current value for deviation upon that heading. Deviation can and often does change with time especially if magnetic equipment has been moved around the compass.
Course lines left on charts for long periods of time may bear no relation to the correct value if they have been labeled as compass courses and the deviation has changed.

Course of Advance (COA). This indicates the direction of the path to be made good over the ground.

Course Over Ground (COG). This indicates the direction of the path actually followed, usually an irregular line.

Course Made Good (CMG). This indicates the single resultant direction from a point of departure to a point of arrival at a given time.

Current. The effect of the horizontal velocity of water over ground.

Dead Reckoning Position (DR). A position determined by dead reckoning.

Dead Reckoning Plot. A DR plot is the charted movement of a vessel as determined by dead reckoning.

Drift. The speed in knots at which the current is moving. Drift may also be indicated in mph in some areas - the Great Lakes for example. This term is also commonly used to mean the speed at which a vessel is deviated from an intended course by the combined effects of external forces such as wind and current.

Estimated Position (EP). An improved position determined through dead reckoning which may include, among other things, factoring in the effects of wind and current, or a single line of position or both.

Line of Position (LOP). A line of bearing to a known origin or reference, upon which a vessel is assumed to be located (see Chapter 6, Line of Position). An LOP is determined by observation (visual bearing) or measurement (LORAN-C, radar, etc.). An LOP is assumed to be a straight line for visual bearings, or an arc of a circle (radar range), or part of some

other curve such as a hyperbola (LORAN-C). LOP's resulting from a visual observation (bearing) should be converted to true prior to plotting on a chart.
Fix. A known position determined by passing close aboard an object of known position or determined by the intersection of two or more lines of position (LOPs) adjusted to a common time, determined from terrestrial, electronic and/or celestial data (see Chapter 6, The Fix). The accuracy, or quality of a fix, is of great importance, especially in coastal waters, and is dependent on a number of factors.

LOPs must be based on known and/or identified sources. Buoys and other floating objects should not be used to establish fixes. The angle between the intersecting LOP's is important. The ideal is 90. If the angle is small, a slight error in measuring or plotting will result in a relatively large error in the plotted position. LOPs from visual bearings to nearby objects are preferable to those obtained from objects at a distance.

The most accurate visual fix is obtained from 3 objects above the horizon 50 to 70 (or 110 to 130) apart in azimuth. A dead reckoning plot is always renewed at a fix.

Heading (HDG). The instant direction of a vessel's bow. It is expressed as the angular distance relative to north, usually 000 at north, clockwise through 360. Heading should not be confused with course. Heading is a constantly changing value as a vessel vaws back and forth across the course due to the effects of sea, wind and steering error. Heading is expressed in degrees of either true, magnetic or compass direction.

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

Running Fix (RFIX). A fix obtained by means of LOP's taken at different times and adjusted, to a common time. This practice involves advancing or retiring LOPs.

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

Speed (S). The rate at which a vessel advances over a horizontal distance. When expressed in terms of nautical miles per hour, it is referred to as knots (kn). One knot equals 1.15 statute miles per hour.

Speed Made Good (SMG). Indicates the overall speed actually accomplished along the course line.

Speed of Advance (SOA). Indicates the speed intended to be made along the track line.

Speed thru the Water. The apparent speed indicated by log type instruments or determined by use of tachometer and speed curve or table, as the instant value in time, along the course line.

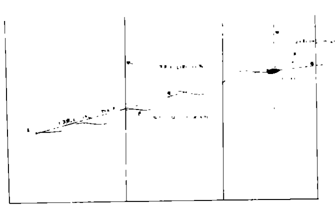


ILLUSTRATION OF COURSE, COURSE LINE, TRACK (OR TRACKLINE), HEADING (HDG) AND COURSE DIRECTION.

Speed Over Ground (SOG). The actual speed made good at any instant in time along the course being steered.

Track (TR). The intended or desired horizontal direction of travel with respect to the earth.

Speed, Time and Distance

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

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

Where: D = Distance, nautical miles
S = SPEED, kn
T = TIME, minutes

or

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

or

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

It is important to note that the time used in the above equations is the time of the run, or the interval of time between two DR positions. Since DR positions are to be labeled with their appropriate time, the interval is easy to determine. Remember, time is indicated in military time, in the twenty-four hour clock, where 1:00 p.m. is 1300, and 12:00 p.m. is 2400. To determine the interval between two times, simply subtract the smaller time from the larger, by hours and minutes.

Remember, however, that there are 60 minutes in each hour. If you do not have enough minutes from which to subtract, borrow 60 from the hours. If you cross into another day, and pass 2400, reverting back to 0000, then borrow 24 hours from that day, and add them to the old day to make the calculation. Examples of speed-time-distance calculations are provided below to illustrate the process of computation and determination of the proper time interval.

Example #1. Solving for distance when speed and time are known: Suppose you are running at 10 knots, how far will you travel in 20 minutes?

1. Since speed and time are known, the formula to use is:
D = ST / 60
2. Insert the values for S, speed - 10 knots, T, Time - 20 minutes:
D = 10 x 20 / 60
3. Carry out the arithmetic:
D = 200 / 60 = 3.3 nautical miles

Example #2. You can make it from your station to the shipping channel in 3 hours and 45 minutes if you maintain a speed of 10 knots. Obtain the distance to the shipping channel:

1. You must use minutes to solve the time-distance-speed formula. Convert the 3 hours to minutes. To do this, multiply 3 hours by 60 (60 minutes in an hour), which is 180 minutes, and then add 45 minutes. Time (T) is 225 minutes.
2. Write down the appropriate formula:
   D = ST / 60
3. Compute using information you have for the appropriate letter:
   D = 10 kn x 225 minutes / 60
   D = 2250 / 60 = 37.5 M (nearest tenth)

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

1. Since distance and time values for D, Distance = 12 miles, T, Time = 40 minutes: S = 60 x 12 / 40

2. Carry out the arithmetic:
   S = 720 / 40 = 18 knots

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

1. Find the time interval between 2030 and 2400. To do this subtract 2030 from 2400. Remember you are subtracting "hours" and "minutes." Determine the time interval as follows, (note that 23 hours and 60 minutes is the same as 24 hours and 00 minutes).

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

2. Remember you use minutes to solve the time-distance-speed equation. Con- vert the 3 hours to minutes. To do this, multiply 3 hours by 60 (60 minutes in an hour), which is 180 minutes. Add the 30 minutes remaining from Step 1. Time (T) = 210 minutes.

3. Write down the appropriate formula:
   S = 60D / T

4. Compute using information you have for appropriate letter.
   S = 60 x 30 miles / 210 minutes

5. S = 1800 / 210 = 8.6 knots
   (nearest tenth)

Example #5. Solving for time when speed and distance are known: You are cruising at 15 knots and have 12 miles to cover before arriving on station. How long will it take before you arrive at your destination?

1. Since distance and speed are known, use this formula:
   T = 60 D/S
   D = 12 miles
   S = 15 knots

2. Substitute appropriate values for D, Distance = 12 miles, S, Speed = 15 knots:
   T = 60 x 12/15

3. Carry out the arithmetic:
T = 48 minutes

Speed Curve

In order to be able to do time-speed-distance calculations, it is necessary to be able to have an accurate value for speed. Even if the small craft is equipped with a log of some kind to provide speed indication directly, this device must be calibrated against known speeds to determine any deviation of the indicated speed from actual speed. For boats equipped only with engine speed indicators (tachometers) some means must be provided to convert engine RPM (revolutions per minute) into speed through the water. The mechanism used to accomplish calibration of speed logs or tachometers in terms of actual speed through the water is the development of the speed curve, a graphic plot of observed speed versus RPM or log reading. Since the development of the curve is identical whether RPM or indicated log speed (kn) is used against actual speed, only one speed curve will be developed, that of RPM vs. Actual Speed through the water.

The mechanism is simple. A measured distance (usually one nautical mile) is run at various engine speeds (RPM), in both directions over a set course, and the speeds measured (calculated from the Time-Distance-Speed formula). A plot is made of RPM, usually in increments of 500 RPM (or other convenient interval) over the range of available engine speeds, against the average measured speed. The resulting curve can be used to predict the resulting speed for any RPM, or the appropriate RPM for any desired speed. As a by-product for planing boats, the planing point is clearly evident, and the most economical speeds are quickly indicated.

It is important to realize, however, that such a speed curve should be developed using a boat with a clean hull. If the hull is degraded by hull load from marine encrustations, the speed curve applying to the clean hull is invalid, and the hull must be restored to initial conditions or a new curve must be developed for the new conditions. For smaller craft, which are sensitive to load, it may be necessary to develop separate speed curves for different crew sizes.

The speed curve is developed as follows:

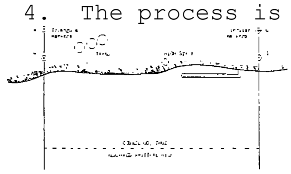
1. A measured mile or other measured course is located on the chart or laid out on the shore so that it is visible in an area safe enough for conducting speed trials. Usually, each end of the speed course is denoted by visible range markers, for example, diamond shapes at one end, and squares or circles at the other. These ranges form perpendiculars to the measured distance course to be run. (See Fig. 5-3)

2. A table is made up prior to conducting any speed runs. The table consists of several columns: RPM, time of run in initial direction, calculated speed in initial direction, time of run in reciprocal direction, calculated speed in reciprocal direction, average of the two speeds. For this discussion, rows are indicated for increments of 500 RPM engine speed from 500 RPM up to the maximum permissible engine speed RPM. The rest of the columns will be filled in during the speed trial.

3. The speed trial is conducted. The boat is taken out to the course, which is determined from either the chart, and the direction uncorrected from true to compass for the initial course and from true to compass for the reciprocal course. (Note that each course is developed individually. Remember, the deviation depends on the compass or magnetic heading, and reciprocal headings do not necessarily have the same deviation!)

When the boat is approaching the speed course, it is brought up to the RPM desired, and turned on to the course. A stop watch or chronograph is started when the vessel at speed crosses the first range and continued until the vessel crosses the second range, when it is stopped. The time is noted on the table, the resulting speed calculated, and the reciprocal course is then run. Again, the watch is started upon crossing the range and stopped when crossing the next range. The time is again noted, and the resulting speed calculated and entered into the table. The two speeds are averaged and the resulting value entered into the last column in the table. Speed runs are done in each direction to account for the effects of any current or wind. Thus, you end up with an" upwind" and a "downwind" leg. The speeds are calculated BEFORE they are averaged to reduce the speed of any current. Do not average times and then calculate a single speed.

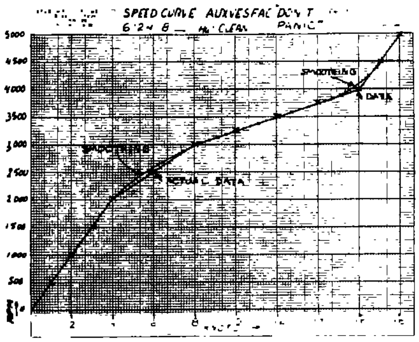
4. The process is continued for each value of RPM desired, until the table is



MEASURED SPEED TRIAL COURSE.

completely filled out (See Table 5-1).

5. The speed curve is then developed. A graph is drawn in an X-Y coordinate system. See Fig. 5-4. The X, or horizontal axis, is calibrated for speed in knots (kn), and the Y, or vertical axis, is calibrated for RPM. Taking the entries for columns 1 and 6 of the table, the values of RPM vs. Speed are plotted for each pair of RPM/Speed values in the table. Any symbol can be used for the plot. A smooth curve is then developed (possibly by "eyeball") through the data points, and the speed curve is thus developed. The graph may be used, sub- sequently, to determine the speed which would result for a specific RPM or the RPM which must be made to accomplish a specific speed. Note that the speed indicated from the curve is speed through the water, not speed over the ground. This speed can be used in the speed-time-distance calculations to develop your DR plots, or run your SAR patterns.



SAMPLE SPEED CURVE, RPM VS. KNOTS.

SPEED TRIAL TABLE (sample)

Distance, 1 nautical mile

(1) RPM	(2) Upwind Run Time Minutes	(3) Upwind Speed Knots	(4) Downwind Run Time Minutes	(5) Downwind Speed Knots	(6) Average Speed Knots
500	--	--	30.0	2.0	[illegible]
1000	60.0	1.0	20.0	3.0	2.0
1500	30.0	2.0	15.0	4.0	3.0
2000	20.0	3.0	12.0	5.0	4.0
2500	12.0	5.0	8.6	7.0	6.0
3000	8.6	7.0	6.7	9.0	8.0
3500	5.5	10.9	4.6	13.0	12.0
4000	4.0	15.0	3.5	17.1	16.0
4500	3.8	15.8	3.3	18.2	17.0
5000	3.5	17.1	3.2	18.8	18.0

Chapter 6

Piloting

Piloting Defined

Piloting is navigation involving frequent or continuous reference to charted landmarks, aids to navigation, and depth soundings. It is, in essence, a frequent or continuous comparison of the physical features of the earth's surface (including man-made features) and their relationships with those same features as they are indicated on the chart to reconstruct the same relationships of direction, angular differences, and distances to establish the position of the observer.

The charted features include natural ones such as promontories, hill and mountain tops, and fixed, man-made objects such as towers, outstanding buildings, smoke stacks, cooling towers, lighthouses and other constructions. Also included in these fixed features would be "invisible" aids to navigation such as active radio-beacons (RBn.) RACONS (Rad Bn.), and LORAN chains, as well as passive radar reflectors (Ra Ref.).

Buoys and other floating, non-fixed aids to navigation are also used in piloting, but the navigator treats these aids with caution since they are susceptible to accidental damage (sinking) or relocation (dragging), and cannot be guaranteed to be on station at all times.

Piloting is an important part of small craft navigation and demands the constant attention of the navigator, who is continuously analyzing the present to plan for the future, and, who is cautioned to use every means available to ascertain navigation hazards and to locate the vessel's position accurately and often to avoid danger and arrive safely at the intended destination.

The Line of Position (LOP)

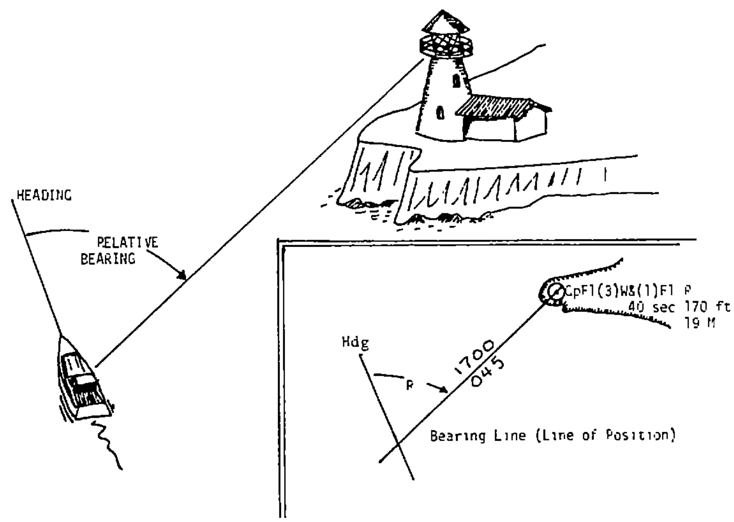
A LINE OF POSITION (LOP) is a line established by observations or measurement on which a vessel can be expected to be located. A vessel can be at an infinite number of positions along any single LOP. An LOP may be established by measured bearing to a known and charted object, or by an alignment of two visible and charted objects, or by a measured distance from a charted object.

LOP by Bearing from Charted Object

One of the simplest and most common LOPs is developed from a single bearing on a charted object. The bearing can be taken using a pelorus, a hand bearing compass, or by orienting the boat so that the resulting relative bearing is dead ahead (000R) or abeam (090R or 270R). The relative bearing of the object from the boat is converted to a true bearing by first determining the compass heading at the instant of the relative bearing observation, correcting this compass heading to a magnetic one and then to a true heading. The relative bearing is then applied to determine the true bearing of the object from the boat.

The bearing is plotted on the chart from the object as a solid line. However, it is not necessary to draw all the line from the charted object to the suspected area of the vessel. Drawing a segment within the area of the expected position is sufficient. The observer is somewhere on that line. This line of position is labeled on its top with the time of the observation (using military or 24 hour time) and may be labeled on the bottom with the true bearing from the boat to the object. The direction label is optional. The process is illustrated in Fig. 6-1.

1. The charted object is a lighthouse on a point. It is clearly visible to the vessel and is easily identified on the chart by its characteristics (magenta overlaying a dot within a circle, and the legend: Gp Fl(3)W & (1)Fl R, 40 sec 170 ft 19M). At 1700 the vessel is on a compass heading of 334C, when the lighthouse is observed at 075R. (75 starboard of the bow.) The heading, bearing and the line are recorded: 1700, Hdg 334C, RB 075R. The navigator quickly corrects the compass heading to a true heading (TH) using the deviation for that compass heading observed from the deviation table or deviation curve (334C, D=5E), and applies the local variation (V=9W):



Line of Position Established By Bearing To Charted Object.

Heading

Compass	334C
Deviation	5E
Magnetic	339M
Variation	9W
True	330

2. The true bearing (TB) of the object from the boat is then determined by adding the relative bearing (RB) (075R) to the true heading (TH) (330): True Bearing of Object from Vessel:

TH + RB = TB
330 + 075R = 405 = 045
-360
045

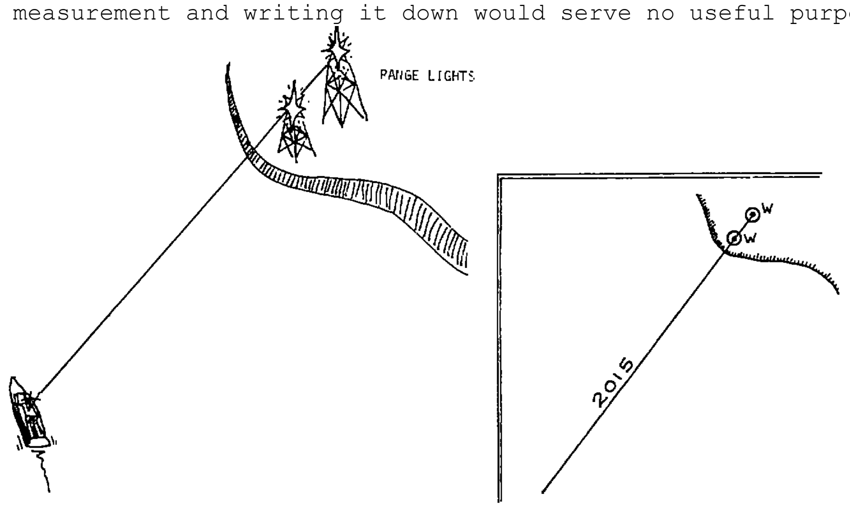
3. The line of position is plotted from the lighthouse on a bearing of 045, and labeled with the time of observation (1700) on top and the true bearing from the vessel to the object (045). The vessel is somewhere on that line.

LOP by Directional Range

A DIRECTIONAL RANGE consists of two objects in line, one behind the other, and defines a unique direction and a RANGE LINE (the line drawn through the two objects). Ranges can provide visual LOPs and be used in compass calibration. They are also helpful in steering difficult channel approaches. The objects may be man-made, i.e. range markers for a channel, a steeple and a tank, etc., or natural, i.e. two tangents of land (taken carefully to account for slope of land and curvature of earth's surface), a large rock and a waterfall, etc., or a combination of both. The important factor is that objects in range have to be on the chart to to used in piloting.

Any two stationary objects in range give the observer an indication of movement to either the right or the left of the LOP provided by the range. The TOP OBJECT appears to move to the left of the lower object when the observer is moving to the left of the range, and thetop object appears to move to the right of the lower object when the observer is moving to the right of the range.

An LOP by range is the easiest LOP to determine because no calculation is required, only the time need be noted and indicated on the chart. A range LOP is illustrated in Fig. 6-2. Here, the navigator noted that the two lights indicated on the chart were in range at 2015. The range line was lightly drawn on the chart and labeled on top with the time. The direction need not be indicated since it is already uniquely defined on the chart, and further measurement and writing it down would serve no useful purpose, save practice.



Line of Position Established By a Range.

LOP by Distance from Charted Object

Distance to an object can be determined by measurement using a RADAR obser- vation or by measurement of vertical angle by use of a SEXTANT or STADIMETER. Both means are illustrated: Fig. 6-3, using the vertical angle, and Fig. 6-4, using a RADAR distance measurement. Note that the resulting circle or arc of position is labeled with the time and the distance. The time is placed on the "top" of the "line," the distance, "below," as the circle appears in the area of the labeling.

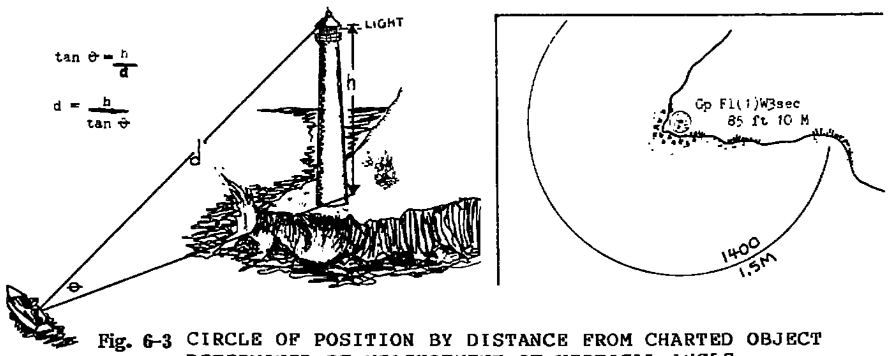


Fig. 6-3 **CIRCLE OF POSITION BY DISTANCE FROM CHARTED OBJECT DETERMINED BY MEASUREMENT OF VERTICAL ANGLE**

CIRCLE OF POSITION

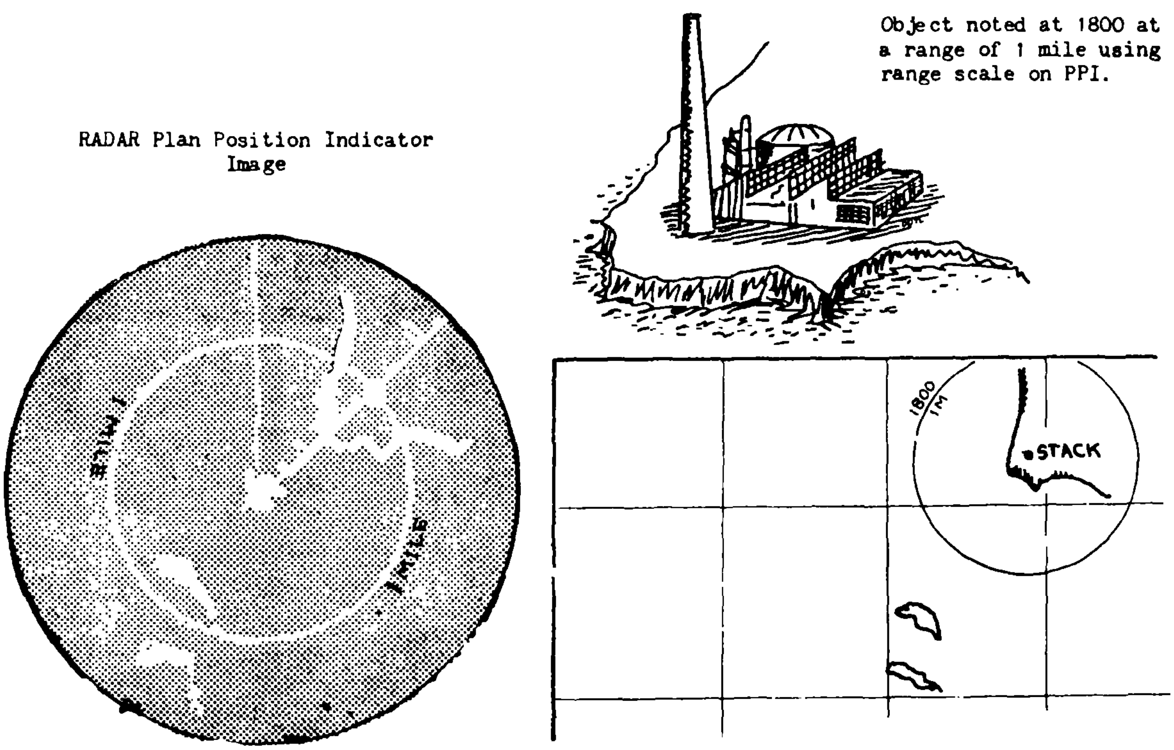


Fig. 6-4 **CIRCLE OF POSITION BY DISTANCE FROM CHARTED OBJECT DETERMINED BY RADAR OBSERVATION**

Distance by Vertical Angle
Using a sextant the vertical angle of a charted object whose height is indicated is measured. The distance in nautical miles to the object is simply the height of the object (from the water level to the height of the **light source**

- not the top of the structure - for a lighthouse) divided by the tangent (tan) of the angle measured (0), and divided by 6076, or:

$$d = \frac{h}{6076 \tan}$$

This calculation can be performed using one of the many electronic calculators available on the market, today, or by the use of trigonometric and logarithmic tables. As an example, the light in Fig. 6-3 was observed to have a vertical angle of 0.53 (31.8). For this angle ( ), tan = 0.00935, h = 85 ft. and:

$$d = \frac{85}{6076 \times 0.00935} \quad 1.5 \text{ M}$$

After the range of the object is determined, a circular line of position is drawn on the chart around the object (or an arc is swung from the object if it is clearly apparent as to which direction the vessel lies) using the drafting compass set on that range with the latitude scale. This circular LOP is labeled with the time (in this case, 1400) and with the distance (1.5 M). The vessel is somewhere on the circle or the arc.

Distance by RADAR Observations
Using a RADAR, the object is identified on the PLAN POSITION INDICATOR (PPI), the radar "scope" or "screen". The FIXED RANGE MARKERS or the VARIABLE RANGE MARKER are used to determine the range of the object from the vessel. A circular (or arc) line of position is then scribed around the object on the chart using the drafting compass set to the distance (here, 1 M) using the latitude or bar scale. The circle is labeled on the outside (or above the line) with the time (1800), and on the inside (or below the line) with the distance (1M). If an arc is drawn, the time is placed on the top and the distance on the bottom. The vessel is somewhere on this circle (or arc).

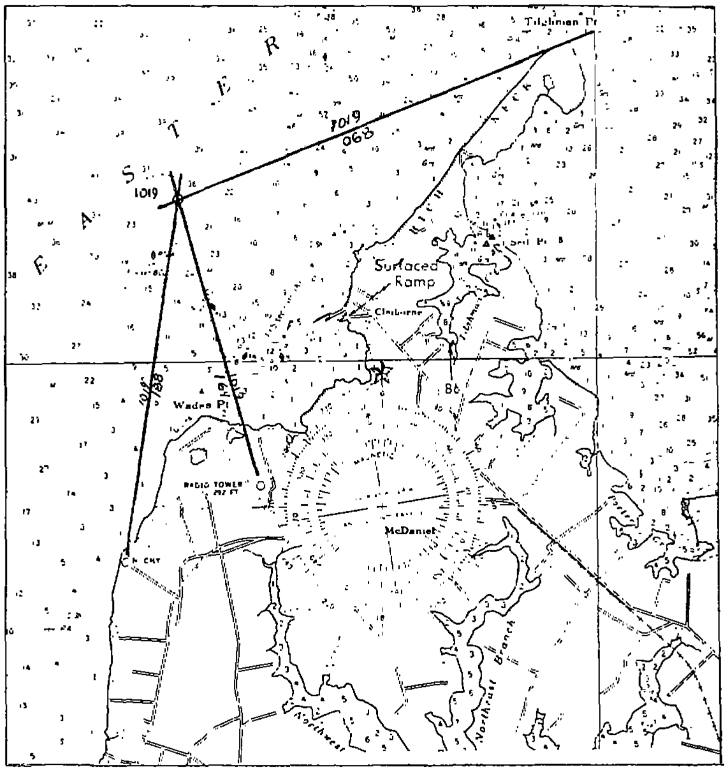
The Fix
The FIX is an accurate position established by simultaneous, or nearly simultaneous intersection (crossing) of two or more lines of position. Such

- cross bearing - intersection of two or more bearings
- a range and a bearing - intersection
- two ranges - intersection of the LOPs
- two distances - intersection of circular LOPs
- distance and bearing of object(s)
- passing close to a fixed aid to navigation.

To assure maximum accuracy of the FIX, it is important that the intersection angle of any two LOPs be as close to 90 as possible. If there are three LOPs, then they should intersect at angles as close to 60 or 120 as possible. Although following these criteria should result in minimizing errors in measurement, reasonable deviations by a few degrees (10-20) should still provide a valid fix (and such should not be discarded), but the accuracy will be degraded from maximum. Intersection angles of less than 40 should be avoided for fixes unless they are all that are available. Then, the rule of using all available information would prevail. Remember, a dead reckoning plot is always started over at a fix.

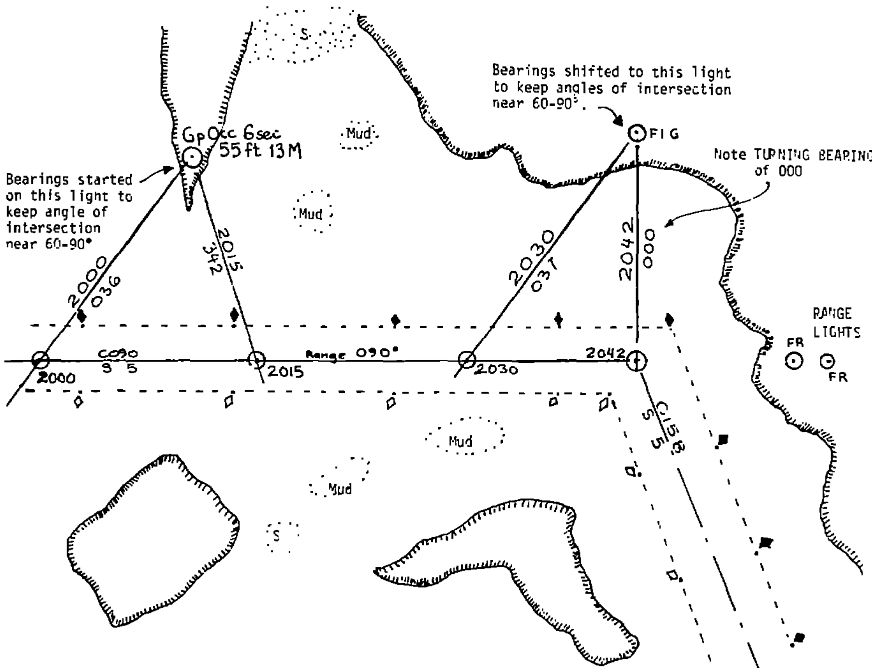
Cross Bearings
Crossing two or more lines of position based on bearings is a common means of establishing a FIX. Fig. 6-5 illustrated

crossing three bearing LOPs, two from bearings taken on man-made objects, a chimney (N. CHY) sighted on a true bearing of 188 from the vessel, and the RADIO TOWER (292 FT) on a true bearing from the vessel of 164, and a bearing of 068 taken from the clearly visible edge of a RICH NECK at Tilghman Point. The resulting FIX is plotted with a circle around the point of intersection, and the time (1019) written horizontally. Should the navigator be running a DR plot at this time, a new plot would be initiated using the 1019 FIX as its beginning.



Fix Established By Cross Lines of Position: Three Bearings - N. Chy., Radio Tower 292 Ft., and Edge of Rich Neck at 1019.

Range and Bearing
Establishing a FIX by the intersection oof a range LOP and that provided by a bearing LOP is a convenient way to determine a turning point while following the range down a channel at night. While the two objects (lights) are in range, the boat is known to be on this LOP. By taking frequent bearings on another object (light) to one side, a series of fixes are determined and the progress of the vessel is well known. When the bearing reaches that marking the turning point, the navigator notes the location and recommends a change to the new course.

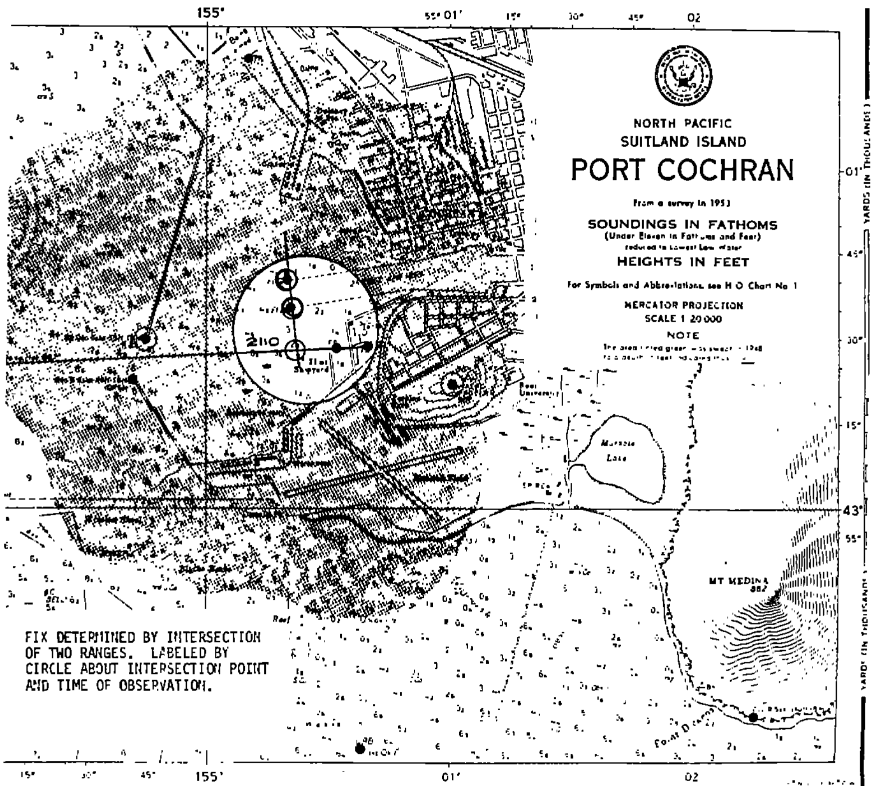


Fixes Determined By Intersection of Bearings With Range and illustration of Turning Bearing of 000 For Course Change to C158. All Directions Indicated Are True.

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

Two Ranges

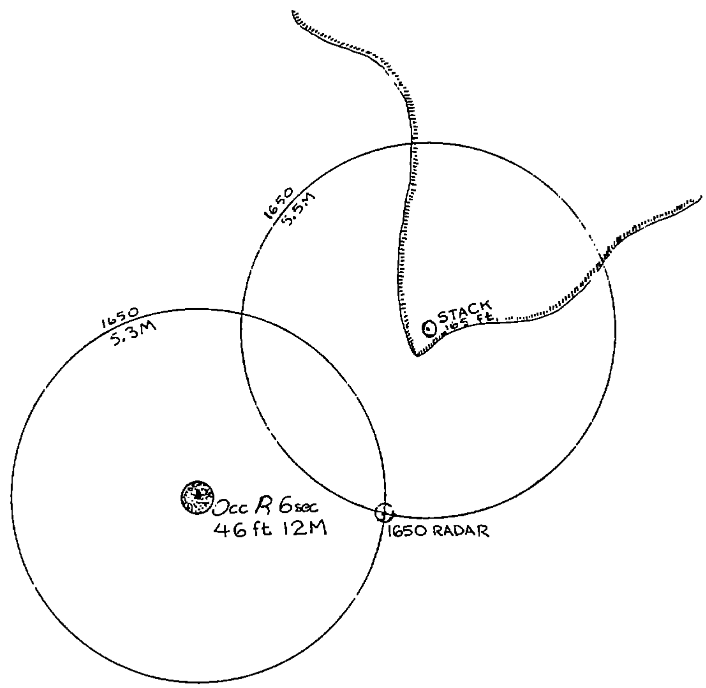
Perhaps the easiest fix is obtained at the intersection of two ranges. The only label required upon obtaining this condition is a circle around the point of intersection and the time of the fix.
Each range is an LOP, and the intersection constitutes a FIX. The FIX by two ranges is illustrated in FIG. 6-7. Again, time is labeled horizontally.



Fix Determined By Intersection of Two Ranges. Labeled By Circle About Intersection Point and Time of Observation.

Two Distances

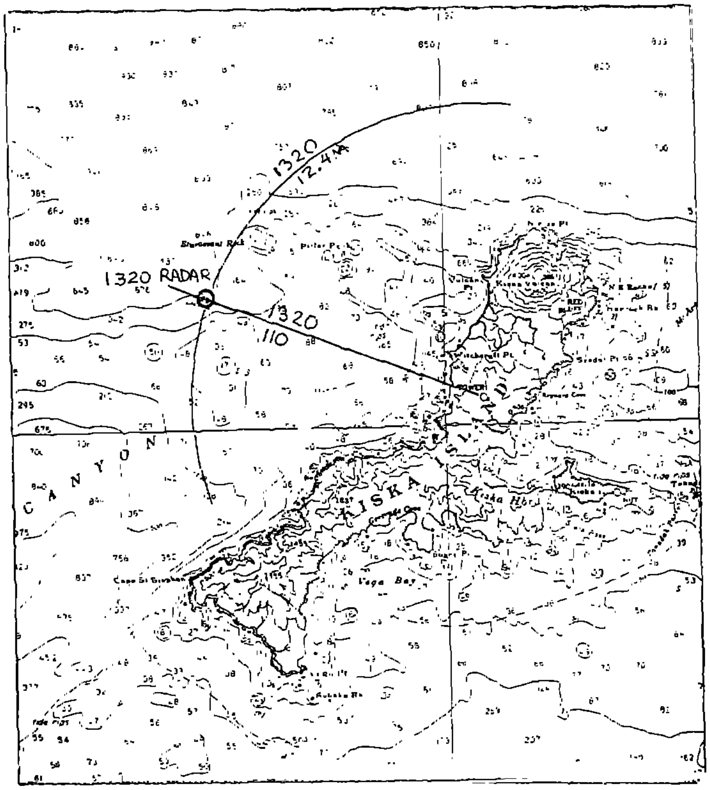
The intersection of two circular LOPs also establishes a FIX, although there is a possibility of ambiguity since circles intersect at two points. Unless the correct intersection is known, say by a rough bearing on some other reference, then two "fixes" are possible, but only one is valid. Circular LOPs are often developed by radar observations. This FIX is indicated in Fig. 6-8. The point of intersection would be labeled with acircle and the time if the LOPs were determined by visual means (i.e. sextant angle or stadimeter reading), and with acircle and the time if both of the LOPs were determined by electronic means. The triangle is used in lieu of a circle only if there is a mixture of visual and electronic fixes on the same plot. The word RADAR would also be added after the time if the LOP was determined by radar.



Fix Determined By Intersection of Two Circular Lines of Position. Ambiguity Resolved by Relationship of Vessel's Image on PPI Relative to Light and Stack. Electronic Fix Labeled By Circle About Point and Time of Observation.

Distance and Bearing to Object

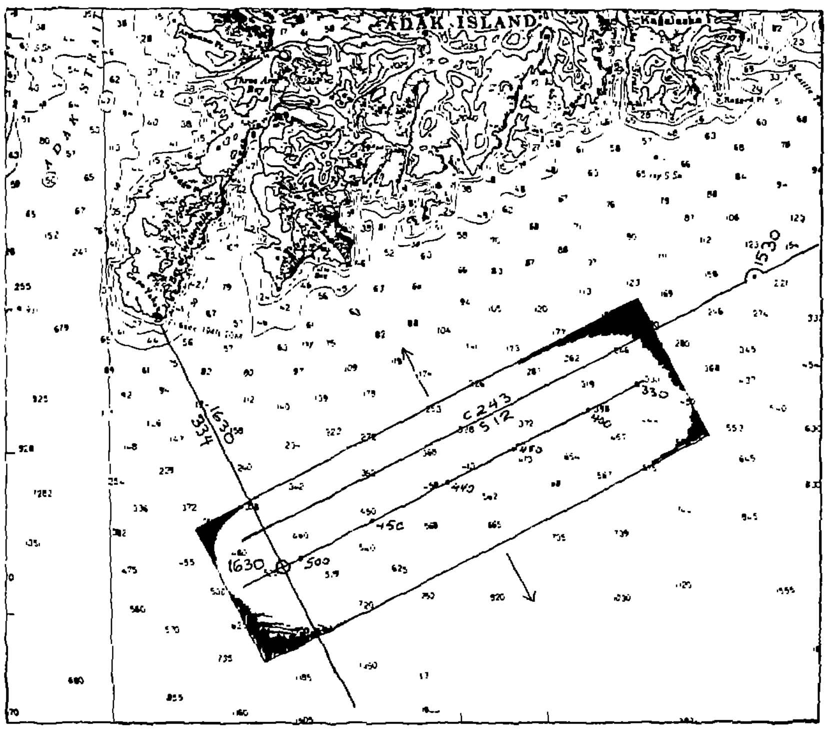
This fix is used often with radar where the PPI gives both bearing and distance. Caution should be used, however, with radar <u>bearings</u>, the precision of which is about 1-2 in azimuth. The precision of the distance measurement is usually much better. Fig. 6-9 illustrates this fix, where the bearing of 110 to the tower of Kiska Island at 1320 is plotted with the simultaneously observed arc line of position of distance, 12.4 M. This particular observations is exemplary, as no other man-made radar targets appear and the tower is easily identified on the radar indicator. Since the FIX was determined only by electronic means, it is labeled with a circle, the time, and the abbreviation RAD.



Fix By Bearing and Distance From Same Object.

Bearing and Line of Soundings

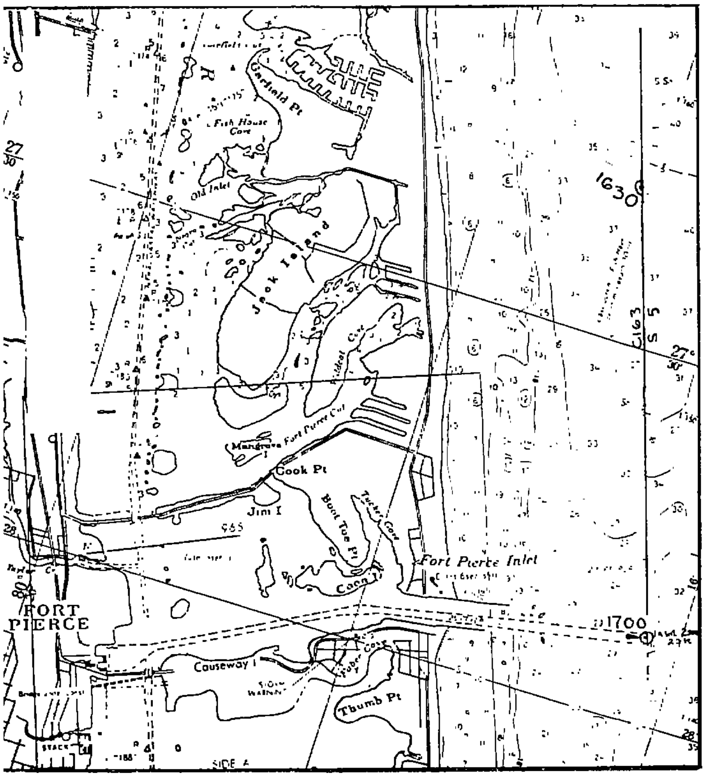
A vessel coasting - running offshore, essentially parallel with the coast - may make use of this FIX while taking soundings and a bearing when the convenience presents itself. As the course is run, the soundings are plotted at intervals, according to the speed and course of the vessel, on a piece of drafting parchment or vellum (a smooth, heavy tracing paper) using the same scale as on the chart. When the bearing is taken, the distance from the object is determined by aligning the soundings along the course and the bearing, and moving the sounding trace toward or away from the object (on the bearing line) until close agreement with the charted soundings is obtained. This determines a FIX. However, this FIX is not very precise unless the soundings change abruptly or offer some other, unique feature which distinguishes the specific area from others. This fix is illustrated in Fig. 6-10. A navigator may be more comfortable terming this an estimated position (see The Estimated Position, later in this chapter) and labeling this position "EP".



Fix Determined By Bearing and Line of Soundings.

Passing Close to a fixed Charted Aid to Navigation

Every time the vessel passes a fixed charted aid to navigation which is expected to be on station - such as a light tower - a FIX is obtained. In the example illustrated in Fig. 6-11, a DR plot on C 163 at S 5 predicts close passage near the light just at the entrance to the Fort Pierce Inlet. When the light is passed close aboard, the FIX is established and plotted with the time of observation and labeled with a circle.



Fix By Passing Close Aboard To Charted Aid To Navigation.

Running Fix (R Fix)

It is not always possible to obtain two LOP's at nearly the same time. In this case, a running fix may be used. A running fix uses an instant LOP on one object, with a previous (or subsequent) LOP on the same or another object, which is time corrected (advanced or retired) by dead reckoning calculation of the boat's direction and distance traveled during the interval between observations of the LOPs.

To plot a running fix, follow the steps below, which are also illustrated by Fig. 6-12.

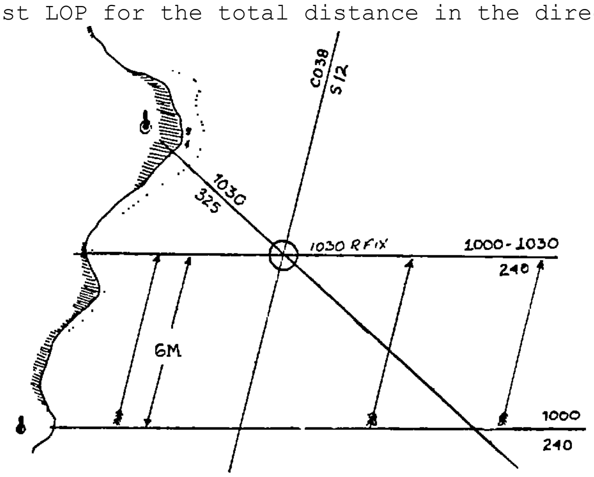
1. Allow for the time lapse between the first and second bearing. This is done by advancing (or retiring) the first LOP along your boat's dead reckoning plot as if it were advancing (or retiring) at the same speed and in the same direction as your boat's course and speed.

2. The first LOP is advanced (retired) by moving it parallel to itself, forward (backward) along the course line for the distance the boat traveled to the second LOP. The intersection of the advanced (or retired) LOP at the time of taking the second bearing represents the best estimate of position, and is called a running fix (R Fix).

3. A new dead reckoning plot is started at the position of the running fix.

4. Avoid advancing (or retiring) an LOP for more than 30 minutes, especially if you are in near-shore waters where currents are extremely variable, unpredictable and/or uncertain. The shorter the time interval between LOPs, the more accurate the running fix.

Example: At 1000, you observed a light bearing 240. There were no other well-defined objects from which to obtain a bearing. Since plotting the first LOP you have run at 12 knots on a true course of C 038. Further up the coast at 1030 you observed a second light bearing 325. Plot this as a second LOP and advance the first LOP for the total distance in the direction traveled.



Advancing The Line of Position, The Running Fix (R Fix).

1. Obtain the time interval and distance your boat traveled since your 1000 LOP. (Nautical slide rule may be used.)

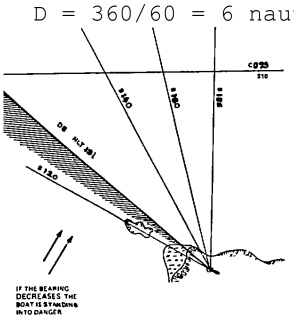
```
   10 hr  30 min
-10 hr
          30 min time interval
```

2. Apply the equation for distance (nautical slide rule may be used).

D = ST/60

D = 12 x 30/60

D = 360/60 = 6 nautical miles



The Danger Bearing.

3. Using your dividers, measure the distance (6 M) off the latitude or nautical mile scale along the 038 course line in the direction traveled.

4. Advance your first LOP, ensuring it is moved parallel to itself forward along the true course line for the distance traveled (6 M). Draw the LOP, labeling the new line (1000 - 1030) to indicate that it is an advanced LOP.

5. Plot the second bearing. You now have a running fix at the point of intersection with the advanced LOP. Label this point with a circle, and horizontally with 1030 R Fix, clear of the course line.

Danger Bearings

Danger bearings are used to keep a boat clear of a hazardous area in the vicinity of your track. Danger bearings are the maximum and minimum allowable bearings of a point used for safe passage. Locate a charted object, a bearing which will place you outside that hazardous area. Examples of such dangers are submerged rocks, reefs, wrecks and shoals. A danger bearing must be established in relation to two fixed objects, one of which is the danger area. The other object must be selected to satisfy three conditions: The object must be visible to the eye, it must be indicated on the chart and its bearing from the danger area should be in the same general direction as the course of the boat as it proceeds past the area. To plot a danger bearing follow the procedure below:

1. On the chart, draw a line from the object selected (the leading object) to a point tangent to the danger area closest to where you intend to pass. The reciprocal of the measured direction of the line from the leading object to the danger area is the danger bearing. Fig. 6-13 illustrates a danger bearing.

2. Label the bearing with the abbreviation "DB" followed by the direction (DB 131). The bearing should also be labeled NLT ___ (not less than) or NMT ___ (not more than). Frequent visual bearings should be taken. In this example, if these bearings are greater than the danger bearing, your boat is in safe water. If however, a bearing is observed to be less than the danger bearing, such as (B 120), your boat is standing into danger. Danger bearings may be lightly marked by shading the bearing line on the danger side for easy identification as shown in the above illustration.

3. For danger bearings to be meaningful, ensure that all crew members are aware of what the danger is and where it lies. That is, whether the danger includes all degrees less than the danger bearing or all degrees greater than the danger bearing.

Special Cases
Doubling the Angle on the Bow and the Bow and Beam Bearing are two special cases in which use is made of the properties of the isosceles triangle to provide the distance from a charted object which is then combined with its bearing to develop a running fix.

If a vessel is running on a set course at a set speed and sights an object off its bow at an angle of A (in this case, 45), notes the time of the observation, and continues on course and at speed until the angle on the bow is now 2 x A (90), again notes the time, and the bearing to the object, a running fix is established by bearing and distance LOPs. When thea angle on the bow (an interior angle) was doubled during the run, the two sides of the triangle, the distance run and the distance to the object, are the same length. A simple Speed-Time- Distance calculation provides the distance.

The Bearing taken on the second observation provides the bearing, and the fix is established. This technique works for any triangle whereby the angle on the bow is doubled. The Bow and Beam Bearing illustrated is a specific case of this phenomenon - the angles are specific, the first is 45, and the second, 90 , the bow bearing and the beam bearing. This distance run between observations is the same as that of the object at the time of the bearing, and the fix is established. This technique is illustrated in Fig. 6-14.

There are several other triangles which have particular use in doubling the angle on the bow and provide some convenient

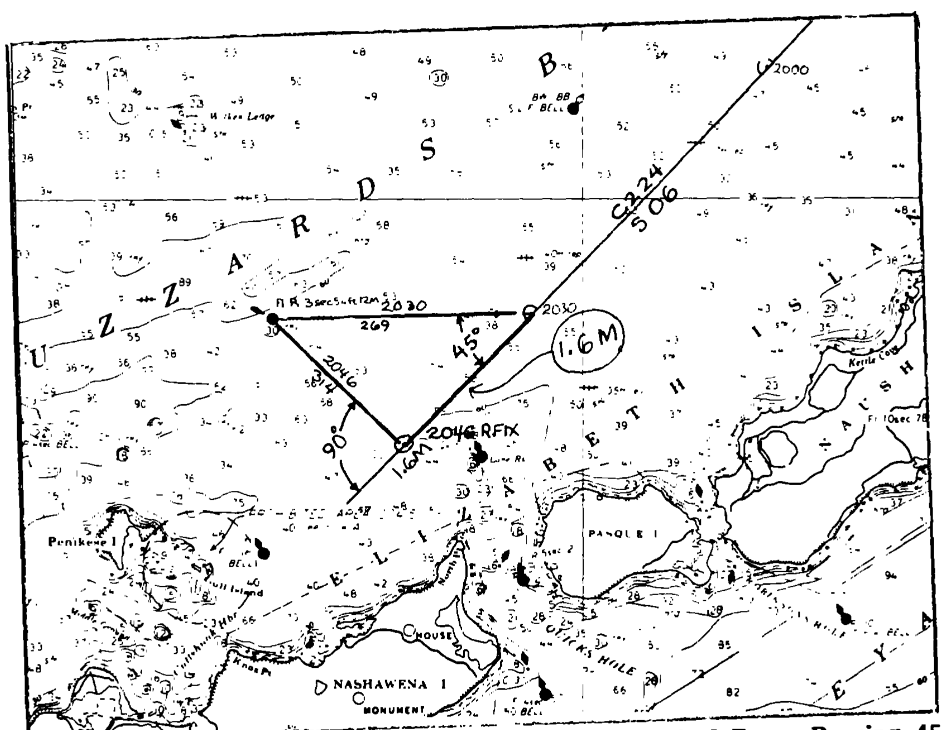


Fig. 6-14 Doubling The Angle On The Bow. The Bow And Beam Bearing 45°-90°.

Doubling The Angle On The Bow. The Bow And Beam Bearing 45-90 .

"rules-of-thumb". Among the more useful of these are the 22 1/2 - 45 triangle and the 20 - 60 triangle. The easiest way to take such bearings is with a pelorus.

22 1/2 - 45 Triangle - the "7/10 Rule"

When the initial bow angle is 22 1/2 (022.5R, 337.5R), and the second angle is 45 (045R, 315R), then not only are the two legs of the triangle the same length, but if the course is maintained, when the beam bearing (090^, 270^) is obtained, the distance, which will be the CLOSET POINT OF APPROACH (CPA) to the object on that course, will be 7/10 of the 22 1/2 - 45 leg. This relationship is termed the "seventh-tenths rule" and is illustrared in Fig. 6-15.
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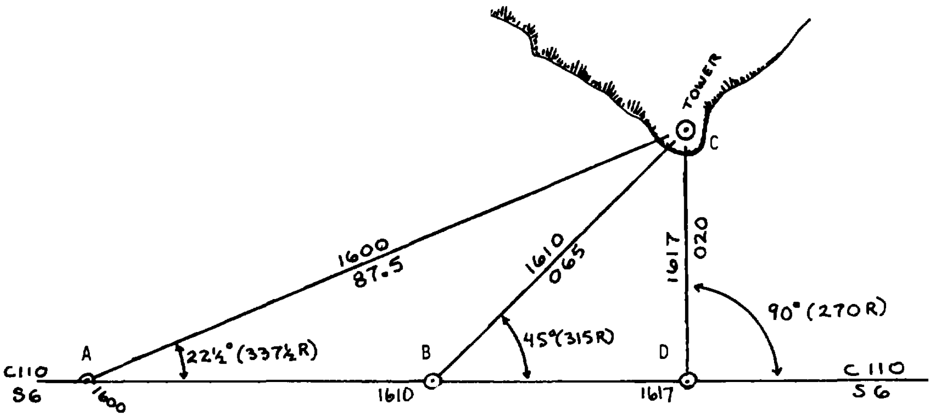
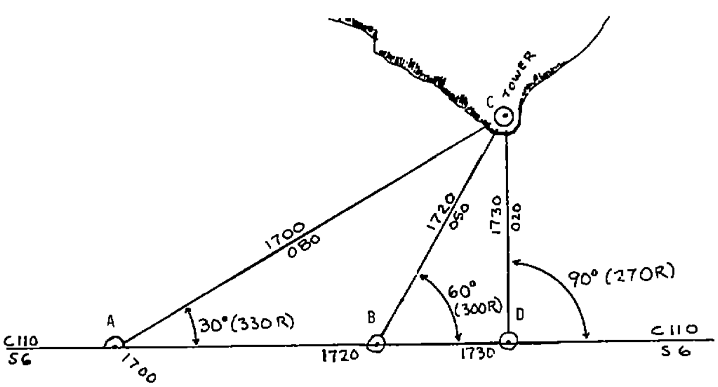


$\overline{AB} = \overline{BC} = 1$ M $\overline{DC} = \overline{BD} = \frac{7}{10}\overline{AB} = 0.7$ M

Fig. 6-15 The 22 1/2° - 45° Triangle: (The 7/10 Rule).

30 - 60 Triangle - the "7/8 Rule"

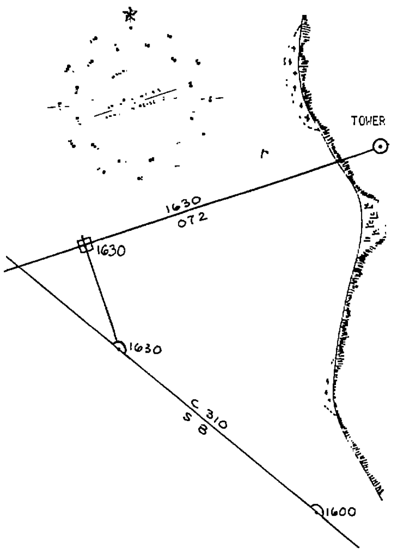
A situation similar to the 7/10 rule exists for the 30 - 60 traingle, only here for an initial bow angle of 30 (030R, 330R), and a subsequent bow angle of 60 (060R, 300R), the closet point of approach (at the beam angle of 090R or 270R) would be 7/8 of the length of the 30 - 60 leg. This relationship is termed the "seven-eights rule" and is illustrated in Fig.6-16.



$\overline{AB} = \overline{BC} = 2$ M $\overline{DC} = \frac{7}{8}\overline{AB} = 1.75$ M

The 30 - 60 Triangle: (The 7/8 Rule).

The Most Probable Position (MPP)
Because there are always errors associated with all measurement, it is almost impossible to establish the EXACT position of the vessel on the chart relative to the earth. However, when the information is fully sufficient, such as three reliable lines of position crossing at a point (or within a very small triangle), little judgement is necessary to establish a satisfactory position. On the other hand, there are cases when the navigator has conflicting information regarding the position. This situation requires careful weighing of the information at hand and intelligent and cautious rejection of suspicious information. The resulting position, adjusted for such discrepncies, is termed the MOST PROBABLE POSITION (MPP).



An Estimatd Position (EP) Developed On A Visual LOP From A DR Plot.

The Estimated Position (EP)

When positional information is incomplete, or considered unreliable, then the MPP could be termed an ESTIMATED POSITION (EP). An EP could be determined from a single LOP, several LOPs which may be inconsistant, or by applying current correction to a DR position. The symbol for an EP is a SQUARE about a dot at the position. An EP is also labeled horizontally with the time.

An example of the development of an EP would be when a visual bearing crossed a DR track at a significant distance different from that predicted from that time by the DR plot. Fig. 6-17 illustrates such a case, where the vessel is coasting on a course of C310 at a speed of S8. The navigator has kept a DR plot and takes advantage, at 1630, of a bearing on a tower off to starboard. The bearing, 072, is plotted on the chart, and noted, without much surprise, that the LOP thus established does <u>not</u> cross the DR track at the 1630 DR position, because of the suspected longshore current toward the north east.

Knowing the vessel to be on the bearing LOP, but not having sufficient information to establish a FIX, the navigator develops the 1630 EP by determining the closest point on the bearing to the 1630 DR. This is done by drawing a line from the 1630 DR perpendicular to the 1630 bearing LOP using the parallel rulers along 072 + 090 = 16.2. The EP is established at the intersection of the 1630 LOP and the perpendicular drawn through the 1630 DR. (Note: The line is perpendicular to the known LOP which makes it the <u>shortest</u> distance between the DR position and the known LOP, <u>not</u> the DR track.) The EP is labeled with a <u>square</u> and the time written horizontally.

Chapter 7

Current Sailing

Introduction
The process of allowing for current in determining the predicted course made good, or of determining the effect of a current on the direction of motion of a vessel is termed CURRENT SAILING. For the purposes of this discussion, the term current as used in current sailing includes:

1. The motion of water over the ground, including ocean current, tidal and river current,

2. the effect of wind and seas,

3. errors in steering due to the helmsman, compass error, speed curve error, tachometer or other engine error, log or speedometer error, fouled bottom or unusual trim.

Application
Current sailing may also be used to correct course and speed for the effects of known (measured or calculated) or suspected current in order to arrive at the intended destination at the intended time. Current sailing may be applied directly to a DR plot to correct a DR position into an EP, or it may be applied, before the DR plot to adjust a course prior to its running.

Current Sailing Terms
The following terms are used in current sailing:

Estimated Current. The current developed from evaluation of known or predicted forces using calculations, current tables, diagrams and/or charts.

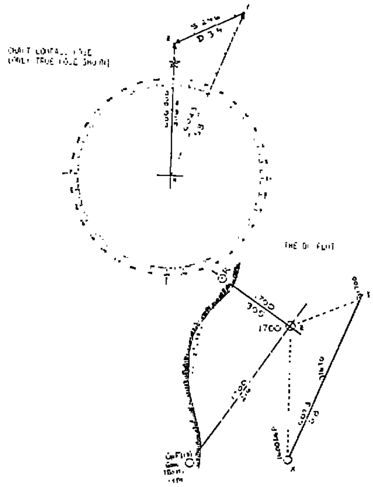
Actual Current. This is the current measured as the difference between the vessel's actual position (FIX) and that predicted without taking into account the effects of current (i.e. the DR position). The actual current incorporates all of the effects of current described, above.

Set. The direction toward which a current flows, or the direction toward which the vessel has been moved as a result of the current. SET is expressed in degrees, true.

Drift. The magnitude or speed of the current. DRIFT is expressed in knots (kn) or mph depending on the units used in the area.

The Current Triangle
Graphical calculation of current effects involves the use of the CURRENT TRIANGLE, which is a simple vector diagram. The components of the current triangle have magnitude and direction. The current triangle can be constructed on a separate piece of blank paper, or directly on the chart using the compass rose as a convenient means of measuring direction, and the latitude scale as a means of determining magnitude in units of speed (kn or mph).

Determination of Set and Drift
Set and drift are usually determined from simple analysis of the DR plot when a fix



The Current Triangle To Determine Set and Drift (D)
is obtained. The intended course and speed are compared to the actual COURSE MADE GOOD (CMG), COURSE OVER THE GROUND (COG) and SPEED MADE GOOD, SPEED OVER THE GROUND (SOG) using the current triangle. This is illustrated in Fig. 7-1 and the following examples.

The intended course was 023, at a speed of S8, from point X to point Y. Departure from X was taken at 1600, and the DR plot was run until at 1700 (point Y) bearings were taken on an object at 305 and another at 214, and a FIX was obtained (point Z). The navigator noted the discrepancy and attributed it to current.

Considering it useful to know the set and drift so that an EP could be developed from the future DR plots, the current triangle was set up. First, the course and speed were set down using the compass rose on the chart (true only!) and minutes of latitude as a scale for units of speed (kn). A line was drawn from the center of the rose in the direction of the course, 023, with length equal to the vessel's speed (S 8), eight minutes of latitude long. Mark the end of this line with an arrowhead and label this point, Y.

Next, the actual course over the ground (COG) was measured (COG 000) as well as the distance covered during the time from departure to the determination of the fix. (6 miles in 60 minutes). The actual speed over the ground (SOG) was calculated (60D = ST, SOG = 6 kn). This vector was also plotted from the center of the rose, outward, along 000 for a length of 6 minutes of latitude. Also, mark the end of this line with an arrowhead and label this point, Z. A line was then drawn from Y to Z. The direction of this line was measured using the parallel rules and the rose. This direction is the SET of the current (SET 246). The length of the line, YZ, is the DRIFT of the current (D 3.4 kn). The current affecting the vessel from 1600 to 1700 can be characterized by its SET 246, and DRIFT, D 3.4 kn.

Determination of Course to Steer and Speed to Run
Once the set and drift of the current have been determined, by actual measurement as in the example, above, or by calculation using current tables or diagrams, the navigator may apply corrections to the next course and speed to determine what course to steer and speed to run to arrive at the intended destination, or to adjust the next DR to develop an EP. In each case, the procedure is the same using the current triangle. Extending the example, above, the navigator now uses the set and drift measured to adjust the course and speed to correct for the effects of current. This is a legitimate procedure unless

there is reason to believe that the measured current was not representative of the current to be experienced in the next area to be run.

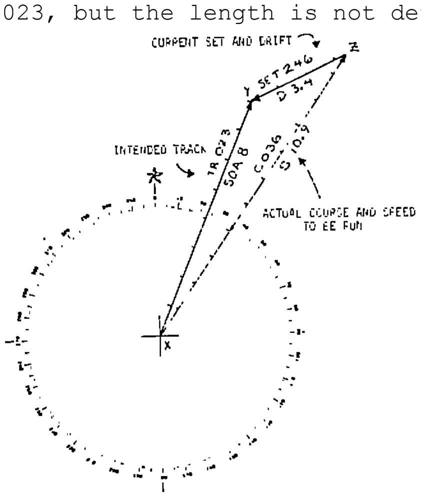
Assuming the navigator wishes to continue on an INTENDED TRACK (TR) of TR 023, at an actual speed of advance (SOA), SOA 8, the navigator calculates the new course and speed to be run with the current triangle, illustrated in Fig. 7-2. First, the intended track and SOA are set down from the center of the compass rose (label this origin, X) a line on TR 023, with a length equal to the intended SOA, of 8 units. Next, at the outward end of this line, which has been labeled, Y, draw a line in the opposite direction of the set, with its length equal to the drift (D 3.4) units. Label the end of this line, Z. A line is then drawn from X, the center of the compass rose, to point Z. The direction of this line is the course to be steered, (036) and its length, in units, is the speed to be run, S 10.9.

With Specified Speed of Advance, Determination of Course to Be Run to Advance Along Intended Track

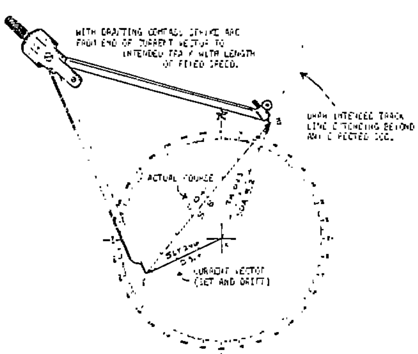
Often the capability of the vessel does not allow the navigator a wide selection of speeds to accommodate particular current situations, and the only choice is course, with the speed of advance of the vessel fixed at its maximum or optimum. In this case, the current triangle is used, with the current, the intended track, and the fixed speed of advance to develop the actual course and speed, and the duration of the run, and the resulting ESTIMATED TIME OF ARRIVAL (ETA).

As an example, illustrated in Fig. 7-3, using the current set and drift measured in the example, above, the navigator wishes to proceed on an intended track of TR 023, but can only make a speed of 8 kn.

First, the TR is laid down from the center of the compass rose (point X) along TR 023, but the length is not determined, just drawn several units



The Current Triangle Used To Determine Course To Steer and Speed To Run.



The Current Triangle Used To Determine Course To Steer At Fixed Speed.

beyond the available speed of 8 kn (the current may, at times, be favorable, and the actual SOA may exceed the speed). Next, the current vector, with SET 246, D 3.4, is plotted from the center of the rose. Label the end of this current vector, Y, and the center of the rose, X.

Finally, using the drafting compass, set at a radius of 8 units - the available speed, scribe a short arc with center at point Y, intersecting the intended track line at Z. Draw line, YZ. This is the actual course to be steered at the speed of 8 kn. Measure the direction off the rose (041). The length of the TR, XZ, in units, will be the actual SOA (SOA 5.2) and can be used to compute the time required for the run. If the departure time is 1700, and the distance to be run is 12 M, then it will take 138 minutes (2 hr. 18 min.) to get to the destination, and the ETA will be 1700 + 2 hr. 18 min. = 1918.

Leeway

Leeway is the leeward motion of a vessel, due to wind, expressed as distance, speed or an angle. However, expressed, its amount varies with the speed and relative direction of the wind, type of vessel, amount of freeboard, trim, speed of the vessel, state of the sea, and depth of water.

Chapter 8

Tides and Currents

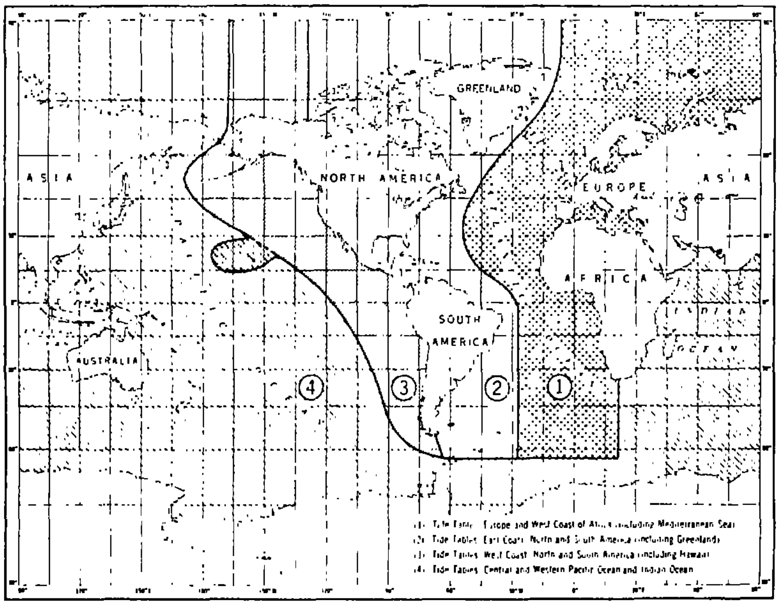
Introduction
Tides and currents can, to some degree, be predicted by the mariner well in advance using various publications available to the public. Excellent predictions are provided by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) of the U. S. Department of Commerce. In addition, commercial tide and pilot books which draw upon and often republish (not always without error) government data, and other such tables and charts are always available. This chapter will discuss prediction of tides and currents using the NOAA/NOS Tide Tables, and Current Tables, both sets of tables issued annually.

Tide Tables
The tide tables are currently issued in four volumes, as follows: Europe and West Coast of Africa (including the Mediterranean Sea); East Coast of North and South America (including Greenland); West Coast of North and South America (including the Hawaiian Islands); Central and Western Pacific Ocean and Indian Ocean. Together, they contain daily predictions for 198 reference ports and differences and other constants for about 6,000 stations. (See Figure 8-1).
As an example, the Tide Tables, East Coast of North and South America contain full daily predictions for 48 reference ports with differences and other constants for about 2,000 stations in North America, South America, and Greenland. All volumes contain a table for obtaining the approximate height of the tide at any time, a table of local mean time of sunrise and sunset for every 5th day of the year for different latitudes, a table for the reduction of local mean time to standard time, a table of moonrise and moonset for 8 places, a table of the Greenwich mean time of the Moon's phases, apogee, perigee, greatest north and south and zero declination, and the time of the solar equinoxes and solstices, and a glossary of terms.

For the most part, tide predictions for U. S. reference stations are based upon analyses of tide observations for periods of at least one year. Since the extremes of meteorological conditions have been excluded from the analyses and predictions, the predicted tidal heights should be considered those expected under average weather conditions. The mariner is cautioned that during times when weather conditions differe from what is considered average for the area, corresponding differences between predicted levels and those actually observed will be noted. Generally, prolonged onshore winds or a low barometric pressure can produce higher levels than predicted, while the opposite can result in lower levels than those predicted.

Exclusive of weather conditions, the astronomical tide is subject to range variations which should be noted. Decreased ranges may be expected near the times when the Moon is in apogee (apogean tides) or in quadrature (neap tides) and increased ranges when the moon is in perigee (perigean tides) or in

TIDE TABLE COVERAGE



Tide Table Coverage

a new or full position (spring tides). A larger diurnal range may also result when the Moon is in its maximum declination (topic tides). The actual range will depend upon the extent to which combinations of these positions reinforce or detract one from the other. The effect of these astronomical line-ups is included in the predictions and may be apparent upon inspection. The mariner may be kept aware of the times of these astronomical events by referring to the astronomical data listed in the Tide Tables. Realize, however, that there is generally a time lag from a few hours to several days from the time of the astronomical event to the time of the resultant tide. During times of storm surges or when extreme weather conditions are imminent, it would be prudent for the mariner to keep closely advised by local weather forecasts as they relate to the effects upon the tide levels.

The following terms, among others, are defined in and used in the prediction of tides and currents using the NOAA/NOS tables:

Chart Datum. The tidal datum to which soundings on a chart are referred. It is usually taken to correspond to a low water elevation of the tide.

Current. Generally, a horizontal movement of water. Currents may be classified as tidal and nontidal. Tidal currents are caused by gravitational interactions between the Sun, Moon and Earth and are a part of the same general movement of the sea that is manifested in the vertical rise and fall, called tide. Nontidal currents include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from more pronounced meterological variability.

Current Difference. Difference between the time of slack water (or minimum current) or strength of current in any locality and the time of the corresponding phase of the tidal current at a reference station, for which predictions are given in the Tidal Current Tables.

Current Ellipse. A graphic representation of a rotary current in which the velocity of the current at different hours of the tidal cycle is represented by radius vectors and vectorial angles. A line joining the extremities of the radius vectors will form a curve roughly approximating an ellipse. The cycle is completed in one-half tidal day or in a whole tidal day according to whether the tidal current is of the semidiurnal or the diurnal type. A current of the mixed type will give a curve of two unequal loops each tidal day.

Datum (vertical). For marine applications, a base elevation used as a reference from which to reckon heights or depths. It is called a tidal datum when defined by a certain phase of the tide.

Tidal datums are local datums and should not be extended into areas which have differing topographic features without substantiating measurements. In order that they may be recovered when needed, such datums are referenced to fixed points known as bench marks.

Diurnal. Having a period or cycle of approximately 1 tidal day. Thus, the tide is said to be diurnal when only one high water and one low water occur during a tidal day, and the tidal current is said to be diurnal when there is a single flood and single ebb period in the tidal day. A rotary current is diurnal if it changes its direction through all points of the compass once each tidal day.

Diurnal Inequality. The difference in height of the two high waters or of the two low waters of each day; also the difference in speed between the two flood tidal currents or the two ebb tidal currents of each day.

Double Ebb. An ebb tidal current where after ebb begins, the speed increases to a maximum called first ebb; it then decreases, reaching a minimum ebb near the middle of the ebb period (and at some places it may actually run in aflood direction for a short period); it then again ebbs to a maximum speed called second ebb after which it decreases to slack water.

Double Flood. A flood tidal current where, after flood begins, the speed increases to a maximum called first flood; it then decreases, reaching a minimum flood near the middle of the flood period (and at some places it may actually run in an ebb direction for a short period); it then again floods to a maximum speed called second flood after which it decreases to slack water.

Double Tide. A double-headed tide, that is, a high water consisting of two maxima of nearly the same height separated by a relatively small depression, or a low water consisting of two minima separated by a relatively small elevation. Sometimes, it is called an agger.

Duration of Flood and Duration of Ebb. Duration of flood is the interval of time in which a tidal current is flooding, and the duration of ebb is the interval in which it is ebbing. 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.

In a normal semidiurnal tidal current, the duration of flood and duration of ebb will each be approximately equal to 6.21

hours, but the times may be modified greatly by the presence of a nontidal flow. In a river the duration of ebb is usually longer than the duration of flood because of the freshwater discharge, especially during the spring when snow and ice melt are the predominant influences.

Duration of Rise and Duration of Fall.
Duration of rise is the interval from low water to high water, and duration of fall is the interval from high water to low water. Together they cover, on an average, a period of 12.42 hours for a semidiurnal tide or a period of 24.84 hours for a diurnal tide. In a normal semidiurnal tide, the duration of rise and duration of fall will each be approximately equal to 6.21 hours, but in shallow waters and in rivers there is a tendency for a decrease in the duration of rise and a corresponding increase in the duration of fall.

Ebb Current. The movement of a tidal current away from shore or down a tidal river or estuary. In the mixed type of reversing tidal current, the terms greater ebb and lesser ebb are applied respectively to the ebb tidal currents of greater and lesser speed of each day. The terms maximum ebb and minimum ebb are applied to the maximum and minimum speeds of a current running continuously ebb, the speed alternately increasing and decreasing without coming to a slack or reversing. The expression maximum ebb is also applicable to any ebb current at the time of greatest speed.

Flood Current. The movement of a tidal current toward the shore or up a tidal river or estuary. In the mixed type of reversing current, the terms greater flood and lesser flood are applied respectively to the flood currents of greater and lesser speed of each day. The terms maximum flood and minimum flood are applied to the maximum and minimum speeds of a flood current, the speed of which alternately increases and decreases without coming to a slack or reversing. The expression maximum flood is also applicable to any flood current at the time of greatest speed.

High Water (HW). The maximum height reached by a rising tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meterological conditions. Use of the synonymous term, high tide, is discouraged.

Higher High Water (HHW). The higher of the two high waters of any tidal day.

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 or canal connecting two bodies of water in which the tides differ in time or range. The current in the East River, N.Y., connecting Long Island Sound and New York Harbor, is an example.

Low Water (LW). The minimum height reached by a falling tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of meterological conditions. Use of the synonymous term, low tide, is discouraged.

Lower High Water (LHW). The lower of the two high waters of any tidal day.

Lower Low Water (LLW). The lower of the two low waters of any tidal day.

Mean High Water (MHW). A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. (See High Water.)

Mean Higher High Water (MHHW). A tidal datum. The average of the highest high water height of each tidal day observed over the National Tidal Datum Epoch.

Mean Higher High Water Line (MHHWL). The intersection of the land with the water surface at the elevation of mean higher high water.

Mean Low Water (MLW). A tidal datum. The average of all the low water heights observed over the National Tidal Datum Epoch.

Mean Low Water Springs (MLWS). A tidal datum. Frequently abbreviated spring low water. The average of the low water heights occurring at the time of the spring tides observed.

Mean Lower Low Water (MLLW). A tidal datum. The average of the lowest low water height of each tidal day observed over the National Tidal Datum Epoch.

Mean Range of Tide (Mn). The difference in height between mean high water and mean low water.

Mean River Level. A tidal datum. The average height of the surface of a tidal river at any point for all stages of the tide observed usually determined from hourly height readings. In rivers subject to occasional freshets, the river level may undergo wide variations, and for practical purposes certain months of the year may be excellent in the determination of tidal datums. For charting purposes, tidal datums for rivers are usually based on observations during selected periods when the river is at or near low water stage.

Mean Sea Level (MSL). A tidal datum. The arithmetic mean of hourly water elevations observed over a specific 19-year Metonic cycle (The National Tidal Datum Epoch). Shorter series are specified in the name; e.g., monthly mean sea level and yearly mean sea level.

Mean Tide Level (MTL). Also called half-tide level. A tidal datum midway between mean high water and mean low water.

Mixed Tide. Type of tide with a large inequality in the high and/or low water heights, with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed but the name is usually applied to the tides intermediate to those predominantly semidiurnal and those predominantly diurnal.

Neap Tides Or Tidal Currents. Tides of decreased range or tidal currents of decreased speed occurring semimonthly as the result of the Moon being in quadrature. The neap range (Np) of the tide is the average semidiurnal range occurring at the time of neap tides. It is smaller than the mean range where the type of tide is either semidiurnal or mixed and is of no practical significance where the type of tide is diurnal. The average height of the high waters of the neap tides is called neap high water or high water neaps (MHWN) and the average height of the corresponding low waters is called neap low water or low water neaps (MLWN).

Range of Tide. The difference in height between consecutive high and low waters. The mean range is the difference in height between mean high water and mean low water. Where the type of tide is diurnal the mean range is the same as the diurnal range.

Reference Station. A tide or current station for which independent daily predictions are given in the Tide Tables and Tidal Current Tables, and from which corresponding predictions are obtained for subordinate stations by means of differences and ratios.

Reversing Current. A tidal current which flows alternately in approximately opposite directions with a slack water at each reversal of direction. Currents of this type usually occur in rivers and straits where the direction of flow is more or less restricted to certain channels. When the movement is towards the shore or up a stream, the current is said to be flooding, and when in the opposite direction it is said to be ebbing. The combined flood and ebb movement including the slack water covers, on an average, 12.42 hours for the semidiurnal current. If unaffected by a nontidal flow, the flood and ebb movements will each last about 6 hours, but when combined with such a flow, the durations of flood and ebb may be quite unequal. During the flow in each direction the speed of the current will vary from zero at the time of slack water to a maximum about midway between the slacks.

Rotary Current. A tidal current that flows continually with the direction of flow changing through all points of the compass during the tidal period. Rotary currents are usually found offshore where the direction of flow is not restricted by any barriers. The tendency for the rotation in direction has its origin in the Coriolis force and, unless modified by local conditions, the change is clockwise in the Northern Hemisphere and counter-clockwise in the Southern.
The speed of the current usually 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 time of maximum speed.

Semidiurnal. Having a period or cycle of approximately one-half of a tidal day. The predominating type of tide throughout the world is semidiurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semidiurnal when there are two flood and two ebb periods each day.

Set (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. The term is also applied to the entire period of low speed near the time of turning of the current when it is too weak to be of any practical importance in navigation.
The relation of the time of slack water to the tidal phases varies in different localities. For standing tidal waves, slack water occurs near the times of high and low water, while for progressive tidal waves, slack water occurs midway between high and low water.

Spring Tides or Tidal Currents. Tides of increased range or tidal currents of increased speed occurring semimonthly as the result of the Moon being new or full.

Stand of Tide. An interval at high or low water when there is no sensible change in the height of the tide. The water level is stationary at high and low water for only an instant, but the change in level near these times is so slow that it is not usually perceptible. In general, the duration of the apparent stand will depend upon the range of tide, being longer for a small range than for a large range, but where there is a tendency for a double tide the stand may last for several hours even with a large range of tide.

Strength of Current. Phase of tidal also the speed at this time. Beginning with slack before flood in the period of a reversing tidal current (or minimum before flood in a rotary current), the speed gradually increases to flood strength and then diminishes to slack before ebb (or minimum before ebb in a rotary current), after which the current turns in direction, the speed increases to ebb strength and then diminishes to slack before flood completing the cycle.

Subordinate Current Station. A current station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a control current station.
A station listed in the Tidal Current Tables for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station.

Subordinate Tide Station. A tide station from which a relatively short series of

observations is reduced by comparison with simultaneous observations from a tide station with a relatively long series of observations.
A station listed in the Tide Tables for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station.

Tidal Current Tables. Tables which give daily predictions of the times and speeds of the tidal currents. These predictions are usually supplemented by current differences and constants through which additional predictions can be obtained for numerous other places.

Tidal Difference. Difference in time or height of a high or low water at a subordinate station and at a reference station for which predictions are given in the Tide Tables. The difference, when applied according to sign to the prediction at the reference station, gives the corresponding time or height for the subordinate station.

Tide. The periodic rise and fall of the water resulting from gravitational interactions between the Sun, Moon, and Earth. The vertical component of the particulate motion of a tidal wave. Although the accompanying horizontal movement of the water is part of the same phenomenon, it is preferable to designate the motion as tidal current.

Tide Tables. Tables which give daily predictions of the times and heights of high and low waters. These predictions are usually supplemented by tidal differences and constants through which additional predictions can be obtained for numerous other places.

Time Meridian. A meridian used as a reference for time.

Type of Tide. A classification based on characteristic forms of a tide curve. Qualitatively, when the two high waters and two low waters of each tidal day are approximately equal in height, the tide is said to be semidiurnal; when there is a relatively large diurnal inequality in the high or low waters or both, it is said to be mixed; and when there is only one high water and one low water in each tidal day, it is said to be diurnal.

Vanishing Tide. In a mixed tide with very large diurnal inequality, the lower high water (or higher low water) frequently becomes indistinct (or vanishes) at time of extreme declinations. During these periods the diurnal tide has such overriding dominance that the semidiurnal tide, although still present, cannot be readily seen on the tide curve.
Seven tables are provided in the Tide Tables:

Table 1. Daily tide predictions.
- Explanation of table.
- Typical tide curves for United States ports.
- Daily predictions for reference stations.

Table 2. Tidal differences and other constants.
- Explanation of table.
- Tidal difference and other constants.

Table 3. Height of tide at any time.
- Explanation of table.
- Height of tide at any time.

Table 4. Local mean time of sunrise and sunset.
- Explanation of table.
- Sunrise and sunset.

Table 5. Reduction of local mean time to standard time.

Table 6. Moonrise and moonset.
- Explanation of table.
- Moonrise and moonset

Table 7. Conversion of feet to meters.

In addition, the Tide Tables also provide a list of NOAA/NOS publications relating

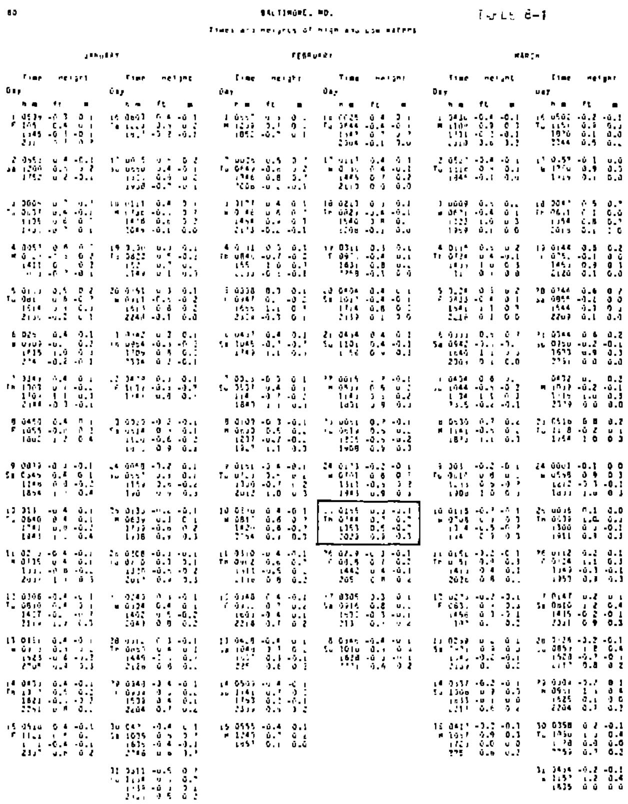

BALTIMORE, MD.

Table 8-1

Times and Heights of High and Low Waters

JANUARY | FEBRUARY | MARCH

Time meridian 75° W. 0000 is midnight. 1200 is noon.
Heights are referred to mean low water which is the chart datum of soundings.

Times and Heights of High and Low Waters to tides and tidal currents, a glossary of terms (many of which have been indicated, above), and an index to the stations appearing in the predictions. Each table will now be described and explained. Examples will be provided to illustrate the use of the individual tables.

Table 1. Daily Tide predictions, explanation of the table:

1. This table contains the predicted times and heights of the high and low waters for each day of the year at a number of places which are designated as reference stations. By using tidal differences from Table 2, one can calculate the approximate times and heights of the tide at many other places which are called subordinate stations. Instructions on the use of the tidal

differences are found in the explanation of Table 2.

2. High water is the maximum heightreached by each rising tide, and low water is the minimum height reached by each falling tide. High and low waters can be selected from the predictions by the comparison of consecutive heights. Because of diurnal inequality at certain places, however, there may be a difference of only a few tenths of a foot between one high water and low water. It is essential, therefore, in using the tide tables to note carefully the heights as well as the times of the tides.

3. Time. The kind of time used for the predictions at each reference station is indicated by the time meridian at the bottom of each page.

   Daylight saving time is not used in the Tide Tables.

4. Datum. The datum from which the predicted heights are reckoned is the same as that used for the charts of the locality. The datum for the Atlantic coast of the United States is mean low water. For the Pacific and Gulf of Mexico coasts, the datum is mean lower low water (MLLW). For foreign coasts a datum approximating to mean low water springs, Indian spring low water, or the lowest possible low water is generally used. The depression of the datum below mean sea level for each of the reference stations of this volume is given in the tables, also.

5. Depth of Water. The nautical charts published by the United States and other maritime nations show the depth of water as referred to a low water datum corresponding to that from which the predicted tidal heights are reckoned. To find the actual depth of water at any time the height of the tide should be added to the charted depth. If the height of the tide is negative - that is, if there is a minus sign (-) before the tabular height - it should be substracted from the charted depth. For any time between high and low water, the height of the tide may be estimated from the heights of the preceding and following tides, or Table 3 may be used. The reference stations in Table 1 now contain the heights in meters as well as feet. In addition, Table 7 may be used to convert feet to meters, if desired.

6. Variation in sea level. Changes in winds and barometric conditions cause variations in sea level from day to day. In general, with onshore winds or a low barometer the heights of both the high and low waters will be higher than predicted while with offshore winds or a high barometer they will be lower. There are also seasonal variations in sea level, but these variations have been included in the predictions for each station. At ocean stations the seasonal variation in sea level is usually less than half a foot.

7. At stations on tidal rivers the average seasonal variation in river level due to freshets and droughts may be considerably more than a foot. The predictions for these stations include an allowance for this seasonal variation representing average freshet and drought conditions. Usual freshets or droughts, however, will cause the tides to be higher or lower, respectively, than predicted.

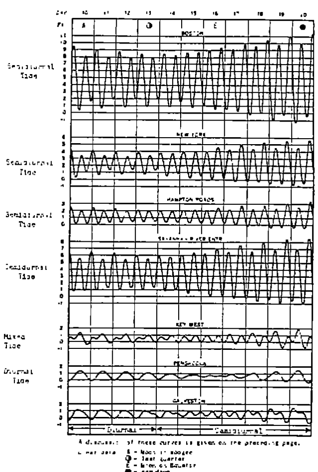
8. Number of tides. There are usually two high and two low waters in a day. Tides follow the Moon more closely than they do the Sun, and the lunar or tidal day is about 50 minutes longer than the solar day. This causes the tide to occur later each day, and a tide that has occurred near the end of one calendar day will be followed by a corresponding tide that may skip the next day and occur in the early morning of the third day. Thus on certain days of each month only a single high or a single low water occurs. At some stations, during portions of each month, the tide becomes diurnal - that is, only one high and one low water will occur during the period of a lunar day.

9. Relation of tide to current. In using these tables of tide predictions it must be born in mind that they give the times

and heights of high and low waters and not the times of turning of the current or slack water. For stations on the outer coast there is usually but little difference between the time of high or low water and the beginning of ebb or flood current, but for places in narrow channels, landlocked harbors, or on tidal rivers, the time of slack water may differ by several hours from the time of high or low water stand.

The relation of the times of high and low water to the turning of the current depends upon a number of factors, so that no simple or general rule can be given. For the predicted times of slack water, reference should be made to the Tidal Current Tables published by the National Ocean Service in two separate volumes, one for the Atlantic coast of North America and the other for the Pacific coast of North America and Asia.

10. Typical tide curves. The variation in the tide from day to day and from place to place are illustrated in FIG. 8-2 by the tide curves for representative ports along the Atlantic and Gulf coasts of the United States. It will be noted that the range of tide for stations along the Atlantic coast varies from place to place but that the type is uniformly semidiurnal with the principal variations following the changes in the Moon's distance and phase.



Typical Tide Curves For United States Ports

In the Gulf of Mexico, however, the range of tide is uniformly small but the type of tide differs considerably. At certain ports such as Pensacola there is usually but one high and one low water a day while at other ports such as Galveston the inequality is such that the tide is semidiurnal around the times the Moon is on the Equator but becomes diurnal around the times of maximum north or south declination of the Moon. In the Gulf of Mexico, consequently, the principal variations in the tide are due to the changing declination of the Moon.

Key West, at the entrance to the Gulf of Mexico, has a type of tide which is a mixture of semidaily and daily types. Here the tide is semidiurnal but there is considerable inequality in the heights of high and low waters. By reference to the curves it will be seen that where the inequality is large there are times when there is but a few tenths of a foot difference between high water and low water.

11. Use of Table 1, Times and Heights of High and Low Waters: The use of Table 1 is simple and straightforward. Table 8-1 is an example of a page from Table 1, for the reference station, Baltimore, Maryland. Times and heights are indicated on this page for the month of January-March 1982. To determine the time and height of the tides at this reference station (Baltimore) simply go to the appropriate day and read the

information. For example, the tide information for February 25, would be:

FEBRUARY

DAY	TIME	HEIGHT	
	h m	ft	m
25	0155	-0.3	-0.1
Th	0744	0.7	0.2
	1353	-0.5	-0.2
	2020	0.9	0.3

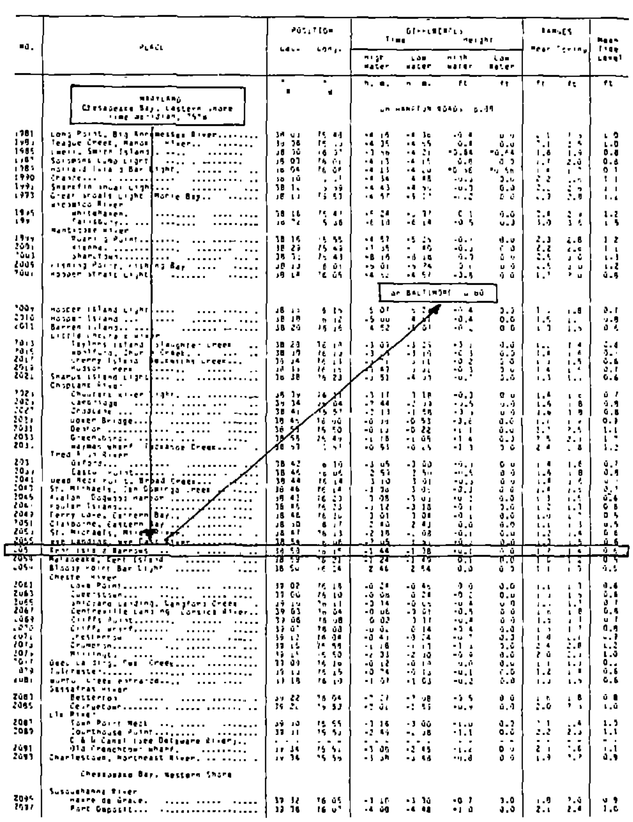


TABLE 2. - TIDAL DIFFERENCES AND OTHER CONSTANTS

Endnotes can be found at the end of table 2.

Tidal Differences and Other Constants

For Thursday, February 25, in Baltimore, there would be two low tides: the higher low of -0.3 feet, or -0.1 meters, would occur at 0155 in the morning, the lower low of -0.5 feet, or -0.2 meters (rounded off to nearest 1/10 meter), would occur at 1353 in the afternoon. The lower high tide of 0.7 feet, or 0.2 meters, would occur at 0744 in the morning, and the higher high tide of 0.9 feet, or 0.3 meters, would occur at 2020 in the evening. The times are all STANDARD (Eastern for Baltimore) TIME for the tide predictions in the tables.

Table 2. Tidal differences and other constants, explanation:

1. This table contains differences in tides for SUBORDINATE STATIONS which are to be added or subtracted to the predictions provided in Table 1, for the appropriate reference station upon which the subordinate station is based.

2. Place. The name and location of the subordinate station is indicated.

3. Position. The position of the subordinate station is provided in latitude and longitude coordinates.

4. Differences. The differences in time and height for high and low water are provided for the subordinate station. These differences are to be added to the predictions for the reference station to obtain the predictions for the subordinate station. In some cases a factor is provided for the differences rather than an additive value. In such cases, the height data are multiplied by the factor rather than adjusted by addition or subtraction.

5. Ranges. The ranges for the mean and spring tides are indicated for the subordinate station.

6. Mean Tide Level. The mean tide level for the subordinate station is also provided, although seldom used.

7. The use of Table 2 is also straightforward and simple. Its use will be illustrated by example. Table 8-2 is a sample page from Table 2, with subordinate stations based on Baltimore, Maryland. It is desired to know the tide situation for Station 2057, Kent Island Narrows, in Chesapeake Bay, Maryland. Table 8-2 (Table 2 page 218) indicates this station is subordinate to BALTIMORE, (page 80 of Table 1), so the information provided here would be applied to the Baltimore tide data for the day of interest. Assume the day is Thursday, February 25. First, the data for this day at the reference station, BALTIMORE, Maryland, refer to Table 8-1 (Table 1, page 80) for this information. Using the information for Kent Island Narrows, provided in Table 8-2 (page 218 of Table 2), these data would be adjusted as follows:

KENT ISLAND NARROWS Lat. 38
Lo 76

DIFFERENCE			
TIME		HEIGHT	
High Water	Low Water	High Water	Low Water
h m	h m	ft	ft
-1 44	-1 38	+0.1	0.0

The Baltimore data are then adjusted with this information to construct a tide table for that day for Kent Island Narrows:

FEBRUARY 25, Th

	BALT Time	Ad-just	KIN New Time	BALT Hght	Ad-just	KIN New Hght
	h m	h m	h m	ft	ft	ft
LW	0155	-1 38	0017	-0.3	0.0	-0.3
HW	0744	-1 44	0600	0.7	+0.1	0.8
LW	1353	-1 38	1215	-0.5	0.0	-0.5
HW	2020	-1 44	1836	0.9	+0.1	1.0

The Kent Island Narrows Tide Table would then be:

FEBRUARY

DAY	TIME	HEIGHT	
	h m	ft	m*
25	0017	-0.3	-0.1

Th	0600	0.8	0.2
	1215	-0.5	-0.2
	1836	1.0	0.3

*The heights of the tides in meters were obtained by conversion from feet using Table 7, which is provided in this section as Table 8-3.

Table 3. Height of Tide at Any Time

TABLE 7.—CONVERSION OF FEET TO METERS 261

Feet	Tenths of a Foot 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Feet
0	0.00	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0
1	0.30	0.34	0.37	0.40	0.43	0.46	0.49	0.52	0.55	0.58	1
2	0.61	0.64	0.67	0.70	0.73	0.76	0.79	0.82	0.85	0.88	2
3	0.91	0.94	0.98	1.01	1.04	1.07	1.10	1.13	1.16	1.19	3
4	1.22	1.25	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.49	4
5	1.52	1.55	1.58	1.62	1.65	1.68	1.71	1.74	1.77	1.80	5
6	1.83	1.86	1.89	1.92	1.95	1.98	2.01	2.04	2.07	2.10	6
7	2.13	2.16	2.19	2.23	2.26	2.29	2.32	2.35	2.38	2.41	7
8	2.44	2.47	2.50	2.53	2.56	2.59	2.62	2.65	2.68	2.71	8
9	2.74	2.77	2.80	2.83	2.87	2.90	2.93	2.96	2.99	3.02	9
10	3.05	3.08	3.11	3.14	3.17	3.20	3.23	3.26	3.29	3.32	10
11	3.35	3.38	3.41	3.44	3.47	3.51	3.54	3.57	3.60	3.63	11
12	3.66	3.69	3.72	3.75	3.78	3.81	3.84	3.87	3.90	3.93	12
13	3.96	3.99	4.02	4.05	4.08	4.11	4.15	4.18	4.21	4.24	13
14	4.27	4.30	4.33	4.36	4.39	4.42	4.45	4.48	4.51	4.54	14
15	4.57	4.60	4.63	4.66	4.69	4.72	4.75	4.79	4.82	4.85	15
16	4.88	4.91	4.94	4.97	5.00	5.03	5.06	5.09	5.12	5.15	16
17	5.18	5.21	5.24	5.27	5.30	5.33	5.36	5.39	5.43	5.46	17
18	5.49	5.52	5.55	5.58	5.61	5.64	5.67	5.70	5.73	5.76	18
19	5.79	5.82	5.85	5.88	5.91	5.94	5.97	6.00	6.04	6.07	19
20	6.10	6.13	6.16	6.19	6.22	6.25	6.28	6.31	6.34	6.37	20
21	6.40	6.43	6.46	6.49	6.52	6.55	6.58	6.61	6.64	6.68	21
22	6.71	6.74	6.77	6.80	6.83	6.86	6.89	6.92	6.95	6.98	22
23	7.01	7.04	7.07	7.10	7.13	7.16	7.19	7.22	7.25	7.28	23
24	7.32	7.35	7.38	7.41	7.44	7.47	7.50	7.53	7.56	7.59	24
25	7.62	7.65	7.68	7.71	7.74	7.77	7.80	7.83	7.86	7.89	25
26	7.92	7.96	7.99	8.02	8.05	8.08	8.11	8.14	8.17	8.20	26
27	8.23	8.26	8.29	8.32	8.35	8.38	8.41	8.44	8.47	8.50	27
28	8.53	8.56	8.60	8.63	8.66	8.69	8.72	8.75	8.78	8.81	28
29	8.84	8.87	8.90	8.93	8.96	8.99	9.02	9.05	9.08	9.11	29
30	9.14	9.17	9.20	9.24	9.27	9.30	9.33	9.36	9.39	9.42	30
31	9.45	9.48	9.51	9.54	9.57	9.60	9.63	9.66	9.69	9.72	31
32	9.75	9.78	9.81	9.85	9.88	9.91	9.94	9.97	10.00	10.03	32
33	10.06	10.09	10.12	10.15	10.18	10.21	10.24	10.27	10.30	10.33	33
34	10.36	10.39	10.42	10.45	10.49	10.52	10.55	10.58	10.61	10.64	34
35	10.67	10.70	10.73	10.76	10.79	10.82	10.85	10.88	10.91	10.94	35
36	10.97	11.00	11.03	11.06	11.09	11.13	11.16	11.19	11.22	11.25	36
37	11.28	11.31	11.34	11.37	11.40	11.43	11.46	11.49	11.52	11.55	37
38	11.58	11.61	11.64	11.67	11.70	11.73	11.77	11.80	11.83	11.86	38
39	11.89	11.92	11.95	11.98	12.01	12.04	12.07	12.10	12.13	12.16	39
40	12.19	12.22	12.25	12.28	12.31	12.34	12.37	12.41	12.44	12.47	40
41	12.50	12.53	12.56	12.59	12.62	12.65	12.68	12.71	12.74	12.77	41
42	12.80	12.83	12.86	12.89	12.92	12.95	12.98	13.01	13.05	13.08	42
43	13.11	13.14	13.17	13.20	13.23	13.26	13.29	13.32	13.35	13.38	43
44	13.41	13.44	13.47	13.50	13.53	13.56	13.59	13.62	13.66	13.69	44
45	13.72	13.75	13.78	13.81	13.84	13.87	13.90	13.93	13.96	13.99	45
46	14.02	14.05	14.08	14.11	14.14	14.17	14.20	14.23	14.26	14.30	46
47	14.33	14.36	14.39	14.42	14.45	14.48	14.51	14.54	14.57	14.60	47
48	14.63	14.66	14.69	14.72	14.75	14.78	14.81	14.84	14.87	14.90	48
49	14.94	14.97	15.00	15.03	15.06	15.09	15.12	15.15	15.18	15.21	49
50	15.24	15.27	15.30	15.33	15.36	15.39	15.42	15.45	15.48	15.51	50

TABLE 8-3

Conversion of Feet to Meters

Tables 1 and 2 provide the heights of the tide only at specific times, at high and low water. Table 3 of the Tide Tables is used to determine the height of the tide at any other time. Its use is straightforward, and it is used without any interpolation. Table 3 is provided here as Table 8-4. The direction for its use are provided at the base of the table. An example of its use is provided below:

Find the height of the tide at 0755 at New York (The Battery), N.Y., on a day when the predicted tides from Table 1 are given as:

Low Water		High Water	
Time	Height	Time	Height
h m	ft	h m	ft
0522	0.1	1114	4.2
1741	0.6	2310	4.1

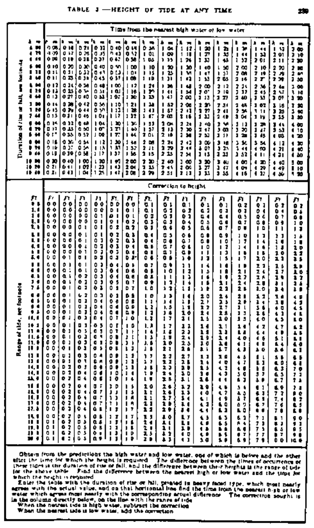


TABLE 3.—HEIGHT OF TIDE AT ANY TIME

Duration of rise or fall, see footnote

Time from the nearest high water or low water

Correction to height

Range of tide, see footnote

Obtain from the predictions the high water and low water, one of which is before and the other 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-faced 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 8-4

An inspection of the above example shows that the desired time falls between the two morning tides.

The duration of rise is 11 14 - 5 22 = 5 52

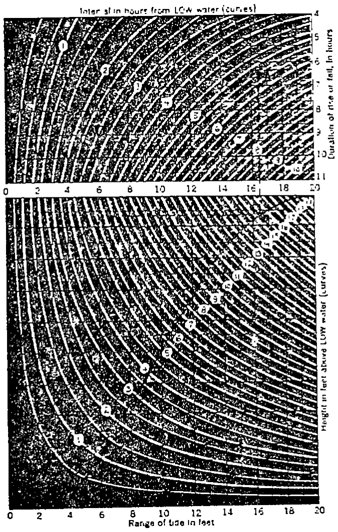
The time after low water for which the height is required is 7 55 - 22 = 2 33

The range of tide is 4.2 - 0.1 = 4.1 feet.

The duration of rise or fall in Table 3 is given in heavy-faced type for each 20 minutes from 4(h) 00(m) to 10(h) 40(m). The nearest tabular value to 5(h) 52(m), the above duration of rise, is 6(h) 00(m); and on the horizontal line of 6(h) 00(m) the nearest tabular time to 2(h) 33(m) after low water for which the height is required is 2(h) 36(m). Following down the column in which this 2(h) 36(m) is found to its intersection with the line of the range 4.0 feet (which is the nearest tabular value to the above range of 4.1 feet) the correction is found to be 1.6 feet, which being reckoned from low water must be added, making 0.1 + 1.6 = 1.7 feet, or 0.5 meters which is the required height above mean low water, the datum for New York.

A graphical method for determining the height of tide at any time is provided in Publication No. 9 of the Defense Mapping Agency Hydrographic/Typographic Center. This publication is popularly known as "Bowditch," or by part of its formal title, "The American Practical Navigator." The graphic method is reproduced here as Fig. 8-3. It is used as follows:

1. Enter the upper graph with the duration of rise or fall. This is represented by a horizontal line.
2. Find the intersection of this line and the curve representing the interval from the <u>nearest</u> LOW WATER (point A).
3. From A, follow a <u>vertical</u> line down to the sine curve of the lower diagram (point B).
4. From B, follow <u>horizontally</u> to the vertical line representing the range of tide (Point C).
5. Using C, read the correction from the series of curves.



Graphical Solution For Height of Tide at Any Time

6. Add (algebraically) the correction of step 5, above, to the LOW WATER HEIGHT to find the height at the given time.

Tables Indicating Time of Sunrise, Sunset,

Moonrise and Moonset.

There may be instances, during SAR activities, etc., when it is necessary to know the times of sunrise, sunset, moonrise and moonset. This information may be calculated for sunrise and sunset using Table 4 CC Local Mean Time of Sunrise and Sunset (provided here as Table 8-5). Local Mean Time (LMT) is the time based upon the local meridian of the observer (the meridian of Longitude passing through the instant location of the observer), rather than the zone time based upon the standard meridian. Moonrise and moonset times are provided for the major ports of the east and west coasts of the American continents in the Tide Tables as Table 6 CC Moonrise Moonset.

An example of this table is provided here as Table 8-7. Table 5 of the Tide Tables is Reduction of Local Mean Time to Standard Time, and is used to convert the local mean times of Table 4 to the standard time by the difference in longitude between the location of interest and the standard time meridian for the area. An example of this table is provided as part of the example on how to use Table 4.

Table 4. Local Mean Time of Sunrise and Sunset. This table gives the local mean time of the rising and setting of the Sun's upper limb (the top of disc of the sun) for every fifth day of the year. There is no allowance made for the elevation of the observer. Because of the sensible variations which may be made in the time of rising or setting of the Sun by a difference in elevation of the observer, and by changes in the refraction, any great refinement in the interpooation of intermediate dates or latitudes in this table is unnecessary. Again, the values of time obtained from Table 4 may be converted to standard time by the use of Table 5.

1. The use of Table 4 is demonstrated by an example using a portion of the table provided as Table 8-5.

2. The time of sunrise and sunset is required for the date of 3 September for the harbor at Avalon Bay, on the island of Santa Catalina, off the coast of California. The geographic coordinates for this location are: Lat. 33

   The standard meridian for this area, for which zone time is based, is Lo 120

Date		30° N Rise	30° N Set	32° N Rise	32° N Set	34° N Rise	34° N Set	36° N Rise	36° N Set	38° N Rise	38° N Set	40° N Rise	40° N Set
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan.	1	06 56	17 11	07 01	17 07	07 06	17 02	07 11	16 57	07 16	16 51	07 22	16 45
	6	06 57	17 15	07 02	17 11	07 06	17 06	07 11	17 01	07 17	16 56	07 22	16 50
	11	06 57	17 19	07 02	17 15	07 06	17 10	07 11	17 05	07 16	17 00	07 22	16 55
	16	06 57	17 23	07 01	17 19	07 05	17 15	07 10	17 10	07 15	17 05	07 20	17 00
	21	06 55	17 27	06 59	17 24	07 04	17 20	07 08	17 15	07 12	17 11	07 17	17 06
	26	06 54	17 32	06 57	17 28	07 01	17 25	07 05	17 21	07 09	17 16	07 14	17 11
	31	06 51	17 36	06 55	17 33	06 58	17 29	07 02	17 26	07 06	17 22	07 10	17 17
Feb.	5	06 48	17 40	06 51	17 37	06 54	17 34	06 58	17 31	07 01	17 27	07 05	17 23
	10	06 45	17 44	06 47	17 42	06 50	17 39	06 53	17 36	06 56	17 33	07 00	17 29
	15	06 40	17 48	06 43	17 46	06 45	17 44	06 48	17 41	06 50	17 38	06 54	17 35
	20	06 36	17 52	06 38	17 50	06 40	17 48	06 42	17 46	06 44	17 44	06 47	17 41
	25	06 31	17 56	06 32	17 55	06 34	17 53	06 36	17 51	06 38	17 49	06 40	17 47
Mar.	2	06 25	18 00	06 27	17 58	06 28	17 57	06 29	17 56	06 31	17 54	06 33	17 52
	7	06 20	18 03	06 21	18 02	06 22	18 01	06 23	18 00	06 24	17 59	06 25	17 58
	12	06 14	18 06	06 14	18 06	06 15	18 05	06 16	18 05	06 16	18 04	06 17	18 03
	17	06 08	18 09	06 08	18 09	06 08	18 09	06 09	18 09	06 09	18 09	06 09	18 08
	22	06 02	18 12	06 02	18 13	06 01	18 13	06 01	18 13	06 01	18 14	06 01	18 14
	27	05 56	18 15	05 55	18 16	05 55	18 17	05 54	18 18	05 53	18 18	05 53	18 19
April	1	05 50	18 18	05 49	18 20	05 48	18 21	05 47	18 22	05 46	18 23	05 45	18 24
	6	05 44	18 21	05 42	18 23	05 41	18 24	05 40	18 26	05 38	18 27	05 37	18 29
	11	05 38	18 24	05 36	18 26	05 35	18 28	05 33	18 30	05 31	18 32	05 29	18 34
	16	05 33	18 28	05 30	18 30	05 29	18 32	05 26	18 34	05 24	18 36	05 22	18 39
	21	05 27	18 31	05 25	18 33	05 22	18 36	05 20	18 39	05 17	18 41	05 14	18 44
	26	05 22	18 34	05 19	18 37	05 16	18 40	05 13	18 43	05 10	18 46	05 07	18 49
May	1	05 18	18 37	05 14	18 40	05 11	18 43	05 08	18 47	05 04	18 51	05 01	18 54
	6	05 13	18 40	05 10	18 44	05 06	18 47	05 02	18 51	04 59	18 55	04 55	18 59
	11	05 10	18 43	05 06	18 47	05 02	18 51	04 58	18 55	04 54	19 00	04 49	19 04
	16	05 06	18 47	05 02	18 51	04 58	18 55	04 54	18 59	04 49	19 04	04 44	19 09
	21	05 04	18 50	04 59	18 54	04 55	18 58	04 50	19 03	04 45	19 08	04 40	19 13
	26	05 01	18 53	04 57	18 57	04 52	19 02	04 47	19 07	04 42	19 12	04 37	19 18
	31	05 00	18 56	04 55	19 00	04 50	19 05	04 45	19 11	04 40	19 16	04 34	19 22
June	5	04 59	18 59	04 54	19 03	04 49	19 08	04 43	19 14	04 38	19 19	04 32	19 25
	10	04 58	19 00	04 53	19 05	04 48	19 11	04 43	19 16	04 37	19 22	04 31	19 28
	15	04 59	19 02	04 53	19 07	04 48	19 13	04 43	19 18	04 37	19 24	04 30	19 30
	20	04 59	19 04	04 54	19 09	04 49	19 14	04 43	19 20	04 37	19 25	04 31	19 32
	25	05 00	19 05	04 55	19 10	04 50	19 15	04 44	19 21	04 38	19 26	04 32	19 33
	30	05 02	19 05	04 57	19 10	04 51	19 15	04 46	19 21	04 40	19 27	04 34	19 33
July	5	05 04	19 05	04 59	19 10	04 54	19 15	04 48	19 20	04 43	19 26	04 37	19 32
	10	05 06	19 04	05 02	19 09	04 57	19 14	04 51	19 19	04 46	19 25	04 40	19 30
	15	05 09	19 01	05 04	19 07	05 00	19 12	04 54	19 17	04 49	19 22	04 43	19 28
	20	05 11	19 01	05 07	19 05	05 03	19 10	04 58	19 14	04 53	19 19	04 47	19 25
	25	05 14	18 58	05 10	19 02	05 06	19 06	05 02	19 11	04 57	19 15	04 51	19 21
	30	05 17	18 55	05 14	18 59	05 10	19 03	05 05	19 07	05 01	19 11	04 56	19 16
Aug.	4	05 20	18 51	05 17	18 55	05 13	18 58	05 09	19 02	05 05	19 06	05 00	19 11
	9	05 23	18 47	05 20	18 50	05 17	18 54	05 13	18 57	05 09	19 01	05 05	19 05
	14	05 26	18 43	05 24	18 45	05 21	18 48	05 17	18 52	05 14	18 55	05 10	18 59
	19	05 29	18 38	05 27	18 40	05 24	18 43	05 21	18 45	05 18	18 48	05 15	18 52
	24	05 32	18 32	05 30	18 34	05 28	18 37	05 25	18 39	05 23	18 42	05 20	18 45
	29	05 35	18 27	05 33	18 28	05 31	18 30	05 29	18 32	05 27	18 34	05 24	18 37
Sept.	3	05 38	18 21	05 36	18 22	05 35	18 24	05 33	18 25	05 31	18 27	05 29	18 28
	8	05 40	18 15	05 39	18 16	05 38	18 17	05 37	18 18	05 35	18 19	05 34	18 21
	13	05 43	18 09	05 42	18 09	05 42	18 10	05 41	18 11	05 40	18 12	05 39	18 13
	18	05 46	18 02	05 46	18 02	05 45	18 03	05 45	18 03	05 44	18 04	05 44	18 05
	23	05 48	17 56	05 49	17 56	05 49	17 55	05 49	17 56	05 48	17 56	05 48	17 56
	28	05 51	17 50	05 52	17 49	05 52	17 49	05 52	17 49	05 53	17 48	05 53	17 48
Oct.	3	05 54	17 44	05 55	17 43	05 56	17 42	05 56	17 41	05 57	17 41	05 58	17 40
	8	05 57	17 38	05 58	17 36	05 59	17 35	06 01	17 34	06 02	17 33	06 03	17 32
	13	06 00	17 32	06 02	17 30	06 03	17 29	06 05	17 27	06 06	17 26	06 08	17 24
	18	06 03	17 27	06 05	17 25	06 07	17 23	06 09	17 21	06 11	17 19	06 13	17 17
	23	06 07	17 21	06 09	17 19	06 11	17 17	06 14	17 15	06 16	17 12	06 18	17 10
	28	06 11	17 17	06 13	17 14	06 16	17 12	06 18	17 09	06 21	17 06	06 24	17 03
Nov.	2	06 14	17 13	06 17	17 10	06 20	17 07	06 23	17 04	06 26	17 00	06 30	16 57
	7	06 18	17 09	06 22	17 06	06 25	17 02	06 28	16 59	06 32	16 55	06 35	16 52
	12	06 22	17 06	06 26	17 02	06 29	16 59	06 33	16 55	06 37	16 51	06 41	16 47
	17	06 26	17 03	06 30	16 59	06 34	16 56	06 38	16 52	06 43	16 47	06 47	16 43
	22	06 30	17 01	06 35	16 57	06 39	16 53	06 43	16 49	06 48	16 44	06 53	16 39
	27	06 35	17 00	06 39	16 56	06 44	16 52	06 48	16 47	06 53	16 42	06 58	16 37
Dec.	2	06 39	17 00	06 43	16 55	06 48	16 51	06 53	16 46	06 58	16 41	07 03	16 35
	7	06 43	17 00	06 47	16 56	06 52	16 51	06 57	16 46	07 02	16 40	07 08	16 35
	12	06 46	17 01	06 51	16 56	06 56	16 52	07 01	16 46	07 07	16 41	07 12	16 35
	17	06 49	17 03	06 54	16 58	06 59	16 53	07 04	16 48	07 10	16 42	07 16	16 36
	22	06 52	17 05	06 56	17 00	07 01	16 55	07 07	16 49	07 12	16 44	07 18	16 38
	27	06 54	17 08	06 59	17 03	07 04	16 58	07 09	16 53	07 15	16 47	07 20	16 41
Jan.	1	06 56	17 11	07 01	17 07	07 06	17 02	07 11	16 57	07 16	16 51	07 22	16 44

Local mean time. To obtain standard time of rise or set, see table 5.

Sunrise and Sunset

Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time	Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time	Difference of longitude between local and standard meridian	Correction to local mean time to obtain standard time
° ′ ° ′	Minutes	° ′ ° ′	Minutes	°	Hours
0 00 to 0 07	0	7 23 to 7 37	30	15	1
0 08 to 0 22	1	7 38 to 7 52	31	30	2
0 23 to 0 37	2	7 53 to 8 07	32	45	3
0 38 to 0 52	3	8 08 to 8 22	33	60	4
0 53 to 1 07	4	8 23 to 8 37	34	75	5
1 08 to 1 22	5	8 38 to 8 52	35	90	6
1 23 to 1 37	6	8 53 to 9 07	36	105	7
1 38 to 1 52	7	9 08 to 9 22	37	120	8
1 53 to 2 07	8	9 23 to 9 37	38	135	9
2 08 to 2 22	9	9 38 to 9 52	39	150	10
2 23 to 2 37	10	9 53 to 10 07	40	165	11
2 38 to 2 52	11	10 08 to 10 22	41	180	12
2 53 to 3 07	12	10 23 to 10 37	42		
3 08 to 3 22	13	10 38 to 10 52	43		
3 23 to 3 37	14	10 53 to 11 07	44		
3 38 to 3 52	15	11 08 to 11 22	45		
3 53 to 4 07	16	11 23 to 11 37	46		
4 08 to 4 22	17	11 38 to 11 52	47		
4 23 to 4 37	18	11 53 to 12 07	48		
4 38 to 4 52	19	12 08 to 12 22	49		
4 53 to 5 07	20	12 23 to 12 37	50		
5 08 to 5 22	21	12 38 to 12 52	51		
5 23 to 5 37	22	12 53 to 13 07	52		
5 38 to 5 52	23	13 08 to 13 22	53		
5 53 to 6 07	24	13 23 to 13 37	54		
6 08 to 6 22	25	13 38 to 13 52	55		
6 23 to 6 37	26	13 53 to 14 07	56		
6 38 to 6 52	27	14 08 to 14 22	57		
6 53 to 7 07	28	14 23 to 14 37	58		
7 08 to 7 22	29	14 38 to 14 52	59		

If local meridian is east of standard meridian, subtract the correction from local time.

If local meridian is west of standard meridian, add the correction to local time.

For differences of longitude less than 15°, use the first part of the table. For greater differences use both parts thus: 47°23′ is equivalent to 45°+2°23′, the correction for 45° is 3 hours, the correction for 2°23′ is 10 minutes; therefore the total correction for the difference in longitude 47°23′ is 3 hours and 10 minutes.

REDUCTION OF LOCAL MEAN TIME TO STANDARD TIME

3. Turning to the table, use the data for 34 nearest latitude to that of the location of interest. For the date of interest (9-3) the data from the table are:

SUNRISE SUNSET
0535 1824
(for Local Mean Time)

4. This must be converted to standard time. The difference in longitude between the location of interest and the standard time meridian is calculated:

Lo	STD	120
Lo	Avalon Bay	118
Difference (D Lo)		1

5. Referring to Table 5 (herein Table 8-6), the correction applying to a D Lo between 1 be 7 minutes in time. Since the D Lo is east of the standard meridian, the local mean time is earlier, and the correction is subtracted from the local mean time to obtain the standard time of the event.

Recapitulating the data:

SUNRISE	SUNSET	(Local Mean Time)
0535	1824	
-7	-7	Correction (East)
0528	1817	(Standard Time)

Thus, sunrise would be expected to occur at Avalon Harbor at 0528, Pacific Standard Time and sunset at 1817 Pacific Standard Time. However, during the month of September, this area is using Daylight Savings Time, which is one hour later. Thus, to convert the Pacific Standard Time to Pacific Daylight Time, one hour is added:

SUNRISE	SUNSET	(Pacific Standard Time)
0528	1817	
0628	1917	(Pacific Daylight Time)

Table 6. Moonrise and Moonset. This table gives the standard time of the rising and setting of the Moon's upper limb (the top of the disc of the Moon) for every day in the year at specific locations, usually major ports, on the Atlantic and Pacific coasts of North America. The times indicated should be within 0 and 4 minutes of the actual event time within a distance of

TABLE 6—MOONRISE AND MOONSET

GALVESTON, TEXAS

Day	January Rise h m	January Set h m	February Rise h m	February Set h m	March Rise h m	March Set h m	April Rise h m	April Set h m	May Rise h m	May Set h m	June Rise h m	June Set h m	Day
1	1132	2321	1201	0023	1042	....	1203	0128	1309	0200	1456	0219	1
2	1208	....	1244	0126	1128	0034	1311	0224	1410	0242	1551	0302	2
3	1244	0027	1332	0231	1213	0131	1413	0315	1508	0313	1645	0334	3
4	1322	0138	1425	0337	1315	0232	1515	0400	1605	0353	1739	0408	4
5	1404	0232	1525	0441	1415	0332	1616	0440	1700	0426	1833	0444	5
6	1450	0338	1629	0543	1519	0427	1714	0517	1755	0459	1927	0523	6
7	1543	0447	1735	0637	1622	0517	1812	0551	1850	0532	2019	0605	7
8	1641	0555	1840	0726	1720	0602	1908	0625	1945	0607	2109	0651	8
9	1745	0700	1943	0809	1827	0642	2003	0658	2039	0644	2156	0740	9
10	1851	0759	2043	0848	1926	0719	2058	0737	2132	0724	2239	0833	10
11	1957	0851	2141	0923	2023	0753	2153	0808	2223	0808	2319	0927	11
12	2100	0937	2236	095[illegible]	2119	0827	2246	084[illegible]	2312	0855	2356	1022	12
13	2201	1017	2331	1021	2214	0901	2337	0926	2358	0936	....	1118	13
14	2258	1054	....	1104	2308	0935	....	1013	....	1039	0032	1215	14
15	2354	1128	0025	1139	....	1012	0029	1102	0040	1134	0106	1313	15
16	....	1200	0118	1217	0002	1052	0117	1154	0120	1230	0141	1413	16
17	0048	1233	0211	1257	0055	1134	0202	1248	0157	1328	0217	1516	17
18	0141	1306	0304	1342	0146	1221	0244	1345	0233	1427	0257	1623	18
19	0234	1342	0355	1430	0236	1311	0323	1443	0309	1523	0341	1732	19
20	0327	1420	0444	1522	0323	1405	0401	1543	0345	1631	0431	1842	20
21	0419	1502	0530	1618	0408	1502	0437	1644	0424	1738	0528	1950	21
22	0512	1549	0614	1715	0449	1600	0514	1748	0506	1846	0621	2057	22
23	0602	1639	0655	1814	0528	1700	0552	1853	0554	1956	0737	2147	23
24	0650	1732	0733	1913	0606	1800	0633	2000	0648	2105	0845	2237	24
25	0736	1829	0810	2014	0643	1902	0718	2109	0741	2210	0951	2319	25
26	0818	1925	0846	2115	0720	2006	0807	2215	0851	2308	1054	2357	26
27	0857	2023	0923	2217	0759	2110	0902	2321	0956	2356	1153	....	27
28	0934	2122	1001	2320	0840	2216	1001	....	1101	....	1250	0031	28
29	1010	2221	....	....	0925	2322	1104	0021	1203	0040	1346	0104	29
30	1045	2321	....	....	1015	....	1207	0114	1303	0121	1440	0137	30
31	1122	....	....	....	1110	0027	....	....	1400	0156	....	....	31

Day	July Rise h m	July Set h m	August Rise h m	August Set h m	September Rise h m	September Set h m	October Rise h m	October Set h m	November Rise h m	November Set h m	December Rise h m	December Set h m	Day
1	1534	0210	1701	0245	1757	0403	1743	0443	1803	0630	1816	0730	1
2	1628	0245	1750	0332	1834	0500	1817	0541	1846	0735	1915	0839	2
3	1722	0322	1835	0423	1910	0557	1855	0641	1935	0843	2021	0944	3
4	1815	0403	1919	0516	1944	0654	1929	0742	2030	0950	2128	1042	4
5	1905	0448	1958	0611	2018	0752	2009	0845	2130	1055	2235	1132	5
6	1954	0537	2036	0707	2053	0851	2053	0950	2234	1155	2339	1216	6
7	2038	0628	2109	0804	2130	0951	2142	1055	2339	1248	....	1255	7
8	2119	0722	2143	0900	2210	1053	2237	1200	....	1334	0041	1330	8
9	2158	0817	2217	0958	2255	1157	2338	1301	0043	1416	0140	1404	9
10	2233	0912	2252	1056	2346	1301	....	1358	014[illegible]	14[illegible]	0237	1436	10
11	2307	1008	2329	1157	....	1405	0041	1449	0246	1527	0334	1509	11
12	2341	1105	....	1259	0043	1506	0146	1534	0345	1601	0430	1544	12
13	....	1203	0011	1404	0145	1602	0250	1614	0443	1634	0526	1622	13
14	0015	1303	0059	1510	0251	1652	0353	1651	0540	1708	0622	1702	14
15	0052	1406	0153	1615	0357	1737	0454	1726	0637	1744	0716	1747	15
16	0132	1511	0254	1716	0503	1817	0554	1800	0733	1823	0808	1835	16
17	0218	1617	0400	1812	0606	1854	0652	1835	0829	1906	0857	1926	17
18	0310	1727	0508	1901	0708	1924	0750	1910	0923	1952	0942	2019	18
19	0403	1832	0616	1944	0807	2004	084[illegible]	1948	1014	2041	1024	2110	19
20	0514	1932	0721	2023	0905	2038	0943	2028	1101	2132	1101	2207	20
21	0622	2025	0824	2059	1003	2115	1038	2112	1145	2226	1136	2301	21
22	0731	2112	0924	2134	1059	2153	1131	2153	1225	2320	1209	2356	22
23	0837	2151	1022	2208	1154	2234	1220	2249	1302	....	1241	....	23
24	0940	2229	1119	2243	1247	2319	1306	2342	1337	0015	1314	0053	24
25	1040	2304	1214	2319	1338	....	1349	....	1410	0111	1348	0151	25
26	1137	2337	1309	2358	1427	0007	1429	0036	1443	0208	1426	0252	26
27	1233	....	1403	....	1511	0059	1505	0132	1518	0307	1506	0356	27
28	1328	0010	1455	0040	1553	0153	1540	0228	1555	0409	1551	0504	28
29	1423	0045	1545	0126	1632	0248	1619	0326	1635	0513	1654	0611	29
30	1517	0122	1632	0216	1708	0345	1648	0425	1722	0621	1758	0722	30
31	1610	0202	1716	0309	....	....	1724	0526	....	....	1907	0825	31

Time meridian 90° W. 0000 is midnight. 1200 is noon.

MOONRISE AND MOONSET

approximately 20 miles from the port indicated. Table 6 of the Tide Tables is illustrated by Table 8-7, which presents the data for Galveston, Texas. The reading of the table is straightforward, simply pick the date and read the data. For example, on 10 November 1982, Moonrise occurred at 0146, and Moonset, at 1453.

Tidal Current Tables
Accompanying the rise and fall of the tide is a periodic horizontal flow of the water known as the tidal current. Advance information relative to these currents is made available in annual Tidal Current Tables which include daily predictions of the times of slack water and the times and velocities of strength of flood and ebb currents for a number reference stations on waterways together with differences for obtaining predictions for numerous other places. The coverage of the Tidal Current Tables is considerably less than that available by the Tide Tables. Only two volumes of Tidal Current Tables are issued annually:

1. Tidal Current Tables, Atlantic Coast of North America.

2. Tidal Current Tables, Pacific Coast of North America and Asia.

The following tables are found in the Tidal Current Tables:

Table 1. Daily current predictions.
Explanation of table.
Typical current curves.
Daily predictions for reference stations.

Table 2. Current differences and other constants and rotary tidal currents.
Explanation of table current differences and Rotary tidal currents.
Other constants.

Table 3. Velocity of current at any time.

3. (cont) Explanation of table. Velocity of current at any time.

Table 4. Duration of slack.

Table 5. Rotary tidal currents.
Explanation of table.
Rotary tidal current stations.

In addition, other useful information is provided in the tables, including astronomical data (Lunar data such as new moon, quarters, apogee/perigee, etc., Solar data, solstice and equinox), discussions of wind-driven currents, the combination of currents, current diagrams, a list of NOS publications related to tidal currents and a Glossary of terms.
Each table will now be described and explained. Examples will be provided to illustrate the use of each table.

Table 1. Daily Current Predictions, explanation of the table:
This table gives the predicted times of slack water and the predicted times and velocities of maximum current - flood an ebb - for each day of the year at a number of stations on the Atlantic coast of North America or the Pacific Coast of North America and Asia. The times are given in hours and minutes and the velocities in knots.

Time. The kind of time used for the predictions at each reference station is indicated by the time meridian at the bottom of each page.

Slack water and maximum current. The columns headed "Slack water" contains predicted times at which there is no current; or, in other words, the times at which the current has stopped setting in a given direction and is about to begin to set in the opposite direction. Offshore, where the current is rotary, slack water denotes the time of minimum current. Beginning with the slack water before flood the current increases in velocity until the strength or maximum velocity of the flood current is reached; it then decreases until the following slack water or slack before ebb. The ebb current now begins, increases to a maximum velocity, and then decreases to the next slack. The predicted times and velocities of maximum current are given in the columns headed "Maximum Current." Flood velocities are marked with an "F" the ebb velocities with an "E." An entry in the "Slack Water" column will be "slack, flood begins" if the maximum current which follows it is marked "F." Otherwise the entry will be "slack, ebb begins."

Direction of set. Since the terms flood and ebb do not in all cases clearly indicate the direction of the current, the approximate directions towards which the currents flow are given at the top of each page to distinguish the two streams. **Number of Slacks and Strengths.** There are usually four slacks and four maximums each day. When a vacancy occurs in any day, the slack or maximum that seems to be missing will be found to occur soon after midnight as the first slack or maximum of the following day. At some stations where the diurnal inequality is large, there may be on certain days a continuous flood or ebb current with varying velocity throughout half the day giving only two slacks and two maximums on that particular day.

Current and Tide. It is important to notice that the predicted slacks and strengths given in this table refer to the horizontal motion 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 velocity of the current usually coincide with the time of most rapid change in the vertical height of the tide. At stations located on a tidal river or bay the time of slack water may differ from 1 to 3 hours from the time of high or low water. The times of high and low waters are given in the Tide Tables published by the National Ocean Service.

Variations From Predictions. In using this table it should be borne in mind that actual times of slack or maximum occasionally differ from the predicted times by as much as half an hour and in rare instances the difference may be as much as an hour. Comparisons of predicted with observed times of slack water indicate that more than 90 percent of the slack waters occurred within half an hour of the predicted times. To make sure, therefore, of getting the full advantage of a favorable current or slack water, the navigator should reach the entrance or strait at least half an hour before the predicted time of the desired condition of current. Currents are frequently disturbed by wind or variations in river discharge. On days when the current is affected by such disturbing influences the times and velocities will differ from those given in the table, but local knowledge will enable one to make proper allowance for these effects.

Typical Current Curves. The variation in the tidal current from day to day and from place to place are illustrated in Fig. 8-4 by the current curves for representative ports along the Atlantic and Gulf Coasts of the United States. Flood current is represented by the solid line curve above the zero velocity (slack water) line and the ebb current by the broken line curve below the slack water line. The curves show clearly that the currents along the Atlantic coast are semi-daily (two floods and two ebbs in a day) in character with their principal variations following changes in the Moon's distance and phase.

In the Gulf of Mexico, however, the currents are daily in character. As the dominant factor is the change in the Moon's declination the currents in the Gulf tend to become semi-daily when the Moon is near the equator. By reference to the curves it will be noted that with

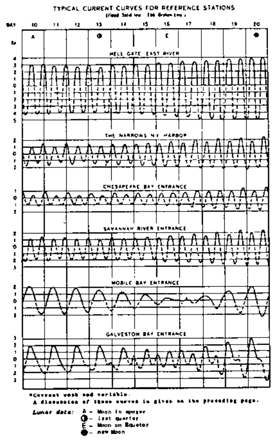


Fig. 8-4 Typical Current Curves For Reference Stations

this daily type of current there are times when the current may be erratic (marked with an asterisk), or one flood or ebb current of the day may be quite weak. Therefore, in using the predictions of the current it is essential to carefully note the velocities as well as the times.

Use of Table 1. Daily Current Predictions: The use of Table 1 is simple and straightforward. Table 8-8 is an example of a page (page 70) from Table 1, for the reference station, BALTIMORE HARBOR APPROACH (off Sandy Point),

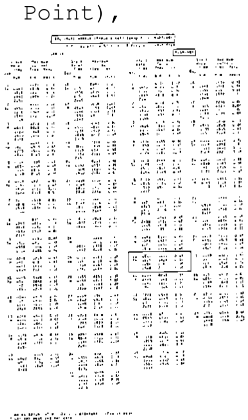


Table 8-8

MARYLAND. Slack water time and time and velocity of maximum current are indicated for the months of January and February by day. To determine this information at this reference station (Baltimore) simply go to the appropriate day and read the information. For example, the current information for February 10 would be:

FEBRUARY
Slack Water Time | Time | Maximum Current Vel.

Day			
h m	h m	knots	
10	0131	0353	0.4F
Th	0625	0918	0.5E
1154	1542	1.0F	
1908	2227		

For Thursday, February 10, in Baltimore, there would be two periods of flooding current and two of ebbing current. For these tides slack water would occur at 0131 and 0625 and 1154 in the morning and at 1908 in the evening. Maximum currents would occur at 0353, a flood current with a velocity of 0.4 kn; at 0918, an ebb current with a velocity of 0.5 kn; at 1542, a velocity of 1.0 kn; and at 2227, with an ebb current of 1.0 kn.

Table 2. Current Differences and Other Constants and Rotary Tidal Currents.
In the Tidal Current Tables, reference stations are those for which daily predictions are listed in Table 1. Those stations appearing in Table 2 are called subordinate stations. The primary purpose of Table 2 is to present data that will enable one to determine the approximate times of minimum currents (slack waters) and the times and speeds of maximum currents at numerous subordinate stations on the Atlantic Coast and Pacific Coast of North America. By applying the specific corrections given in Table 2 to the predicted times and speeds of the current at the appropriate reference station, reasonable approximations of the current at the subordinate station may be compiled.

Locations and Depth.
Because the latitude and longitude are listed according to the exactness recorded in the original survey records, the locations of the subordinate stations are presented in varying degrees of accuracy. Since a minute of latitude is nearly equivalent to a mile, a location given to the nearest minute may not indicate the exact position of the station. This should be remembered, especially in the case of a narrow stream, where the nearest minute of latitude or longitude may locate a station inland. In such cases, unless the description locates the station elsewhere, reference is made to the current in the center of the channel. In some instances, the charts may not present a convenient name for locating a station. In those cases, the position may be described by a bearing from some prominent place on the chart.

Although current measurements may have been recorded at various depths in the past, the data listed here for most of the subordinate stations are mean values determined to have been representative of the current at each location. For that reason, no specific current meter depths for those stations are given in Table 2. Beginning with the Boston Harbor tidal current survey in 1971, data for individual meter depths were published and subsequent new data may be presented in a similar manner.
Since most of the current data in Table 2 came from meters suspended from survey vessels or anchored buoys, the listed depths are those measured downward from the surface. Some later data have come from meters anchored at fixed depths from the bottom. Those meter positions were defined as depths below chart datum. Such defined depths in this and subsequent editions will be accompanied by the small letter "d."

Minimum Currents.
At many locations the current may not diminish to a true slack water or zero speed stage. For that reason, the phrases, "minimum before flood" and "minimum before ebb" are used in Table 2 rather than "slack water" although either or both minimums may actually reach a zero speed value at some locations. Table 2 lists the average speeds and directions of the minimums.

Maximum Currents.
Near the coast and in inland tidal waters, the current increases from minimum current (slack water) for a period of about 3 hours until the maximum speed or the strength of the current is reached. The speed then decreases for another period of about 3 hours when minimum current is again reached and the current begins a similar cycle in the opposite

direction. The current that flows toward the coast or up a stream is known as the flood current; the opposite flow is known as the ebb current. Table 2 lists the average speeds and directions of the maximum floods and maximum ebbs. The directions are given in degrees true, reading clockwise from 000 359 the currents flow.

Time Differences and Speed Ratios.
Table 2 contains mean time differences by which the navigator can compile approximate times for the minimum and maximum current phases at the subordinate stations. Time differences for those phases should be applied to the corresponding phases at the reference station. It will be seen upon inspection that some subordinate stations exhibit either a double flood or a double ebb stage or both. Explanations of these stages can be found in the terms previously discussed in this subsection. In those cases, a separate time difference is listed for each of the three flood (or ebb) phases and these should be applied only to the daily maximum flood (or ebb) phase at the reference station. The results obtained by the application of the the subordinate station. Differences of time meridians between a subordinate station and its reference station have been accounted for and no further adjustment is needed. Summer or daylight saving time is not used in the tables.

The speed ratios are used to compile approximations of the daily current speeds at the subordinate stations and refer only to the maximum floods and ebbs. No attempt is made to predict the speeds of the minimum currents. Normally, these ratios should be applied to the corresponding maximum current phases at

ROTARY TIDAL CURRENTS

(Time. Hours after Minimum before Flood at Boston Harbor)

Station No.	Depth (ft)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
373	15	0.03	0.22	0.23	0.24	0.23	0.25	0.24	0.27	0.32	0.33	0.33	0.32	0.31	knots
		265	266	265	268	270	258	282	305	319	327	333	340	357	degrees
395	10	0.30	0.43	0.45	0.43	0.46	0.48	0.50	0.53	0.51	0.52	0.53	0.51	0.51	knots
		210	261	258	247	248	247	262	280	290	302	320	345	009	degrees
397	10	0.29	0.30	0.30	0.31	0.32	0.34	0.34	0.35	0.37	0.36	0.35	0.35	0.34	knots
		200	209	212	222	229	243	247	257	265	268	284	331	002	degrees
399	10	0.50	0.47	0.42	0.45	0.46	0.47	0.54	0.53	0.55	0.54	0.55	0.55	0.52	knots
		159	140	220	243	282	265	282	281	250	244	240	229	211	degrees
401	10	0.20	0.20	0.21	0.22	0.24	0.24	0.25	0.25	0.26	0.24	0.26	0.25	0.24	knots
		336	342	340	244	228	232	223	212	200	210	216	271	290	degrees
403	10	0.42	0.44	0.43	0.45	0.46	0.46	0.46	0.47	0.48	0.48	0.49	0.46	0.48	knots
		221	223	214	221	213	211	211	219	219	227	235	230	221	degrees
405	10	0.42	0.44	0.44	0.45	0.47	0.50	0.46	0.47	0.45	0.44	0.44	0.40	0.45	knots
		213	197	193	182	174	135	178	183	222	247	267	306	330	degrees
417	15	0.11	0.26	0.51	0.53	0.55	0.42	0.40	0.54	0.47	0.40	0.40	0.45	0.46	knots
		191	276	275	304	303	312	308	319	313	331	354	359	010	degrees
419	10	0.33	0.30	0.38	0.39	0.38	0.36	0.37	0.37	0.36	0.36	0.35	0.34	0.30	knots
		251	307	331	342	332	316	343	341	343	350	347	006	029	degrees
461	10	0.34	0.39	0.41	0.42	0.35	0.35	0.34	0.37	0.39	0.38	0.35	0.35	0.32	knots
		257	264	261	261	259	251	235	230	220	209	199	197	126	degrees
489	10	0.33	0.35	0.36	0.35	0.36	0.34	0.40	0.39	0.40	0.42	0.45	0.37	0.35	knots
		007	010	024	014	010	343	348	007	023	025	095	064	081	degrees
*513	10	0.17	0.16	0.18	0.16	0.13	0.17	0.19	0.21	0.22	0.18	0.19	0.21	0.18	knots
		086	095	090	088	092	095	090	093	085	083	081	077	082	degrees
545	10	0.22	0.27	0.29	0.39	0.37	0.40	0.44	0.45	0.44	0.44	0.44	0.48	0.50	knots
		217	199	209	199	052	061	074	077	066	047	052	028	029	degrees
565	20	0.15	0.25	0.24	0.09	0.28	0.30	0.31	0.36	0.34	0.33	0.35	0.36	0.40	knots
		271	238	271	251	050	071	076	073	064	040	029	021	021	degrees
61[illegible]	10	0.20	0.29	0.27	0.45	0.41	0.47	0.35	0.30	0.28	0.32	0.34	0.34	0.33	knots
		246	232	285	154	313	024	044	009	355	343	338	337	345	degrees
617	20	0.15	0.19	0.20	0.33	0.34	0.30	0.24	0.21	0.22	0.28	0.31	0.33	0.32	knots
		220	214	232	301	020	027	004	007	345	340	333	332	331	degrees

Station No.	Depth (ft)	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	
373	15	0.28	0.29	0.28	0.27	0.27	0.28	0.27	0.26	0.29	0.23	0.21	0.21	knots
		025	047	062	073	074	073	080	076	079	073	073	081	degrees
395	10	0.52	0.49	0.50	0.48	0.52	0.49	0.45	0.46	0.43	0.40	0.40	0.36	knots
		024	029	051	068	070	074	079	082	081	090	081	123	degrees
397	10	0.34	0.36	0.35	0.34	0.36	0.35	0.34	0.36	0.35	0.34	0.32	0.18	knots
		018	042	056	058	064	065	075	080	085	086	095	132	degrees
399	10	0.53	0.52	0.50	0.49	0.51	0.51	0.51	0.50	0.51	0.49	0.50	0.49	knots
		165	075	082	081	099	095	093	094	087	095	116	110	degrees
401	10	0.24	0.23	0.24	0.23	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.20	knots
		351	357	054	059	028	045	028	077	042	029	035	011	degrees
403	10	0.33	0.50	0.50	0.49	0.48	0.47	0.47	0.47	0.47	0.45	0.42	0.41	knots
		254	019	015	009	357	052	043	055	070	[illegible]	173	206	degrees
405	10	0.47	0.44	0.44	0.47	0.44	0.42	0.42	0.43	0.47	0.40	0.43	0.45	knots
		346	328	344	335	327	334	341	337	338	336	274	240	degrees
417	15	0.45	0.48	0.51	0.57	0.62	0.66	0.67	0.64	0.62	0.51	0.40	0.25	knots
		070	016	049	089	108	109	122	121	137	142	129	134	degrees
419	10	0.20	0.19	0.29	0.30	0.33	0.35	0.36	0.38	0.38	0.34	0.36	0.32	knots
		081	112	138	145	160	165	172	175	173	190	203	233	degrees
461	10	0.32	0.36	0.40	0.41	0.35	0.31	0.32	0.31	0.27	0.07	0.20	0.45	knots
		087	069	070	071	026	090	018	044	046	041	269	274	degrees
489	10	0.32	0.33	0.37	0.34	0.33	0.35	0.35	0.34	0.03	0.29	0.31	0.24	knots
		103	102	103	104	117	135	139	158	215	339	353	355	degrees
*513	10	0.22	0.24	0.24	0.26	0.27	0.28	0.25	0.29	0.28	0.25	0.23	0.18	knots
		072	072	070	069	067	070	070	077	077	085	082	085	degrees
545	10	0.51	0.47	0.42	0.39	0.37	0.37	0.37	0.36	0.32	0.30	0.23	0.10	knots
		041	061	077	082	076	071	070	070	064	069	070	085	degrees
565	20	0.43	0.39	0.30	0.28	0.34	0.35	0.34	0.32	0.29	0.25	0.16	0.09	knots
		050	049	037	047	058	054	040	350	047	[illegible]	032	305	degrees
61[illegible]	10	0.29	0.29	0.32	0.33	0.33	0.33	0.32	0.32	0.30	0.25	0.22	0.24	knots
		007	013	308	002	346	345	356	337	341	337	320	307	degrees
617	20	0.29	0.26	0.27	0.28	0.29	0.31	0.29	0.26	0.21	0.17	0.14	0.10	knots
		351	004	308	007	355	337	344	327	324	342	315	244	degrees

* In Reserved Channel, the tidal current is weak, averaging less than 0.1 knot. During a 7-day observation period, the total current set was consistently eastward.

ROTARY TIDAL CURRENTS

TABLE 2. - CURRENT DIFFERENCES AND OTHER CONSTANTS

NO.	PLACE	METER DEPTH	POSITION Lat.	Long.	TIME DIFFERENCES Min. before Flood	Flood	Min. before Ebb	Ebb	SPEED RATIOS Flood	Ebb	AVERAGE SPEEDS AND DIRECTIONS Minimum before Flood	Maximum Flood	Minimum before Ebb	Maximum Ebb
		ft	° N	° W	h. m.	h. m.	h. m.	h. m.			knots deg.	knots deg.	knots deg.	knots deg.
	SEVERN and MAGOTHY RIVERS, Time meridian, 75° W				on BALTIMORE HARBOR APPROACH, p. 70									
5676	Greenbury Point, 1.0 miles east of......	6	38 58 40	76 25.00	-0 57	-1 05	-0 51	-0 47	0.8	0.8	0.0 - -	0.6 0.0	0.0 - -	0.6 245
5681	Annapolis..........................		38 58.95	76 [illegible]	- - -	-3 35	- - -	-2 26	0.5	0.4	0.0 - -	0.4 320	0.0 - -	0.3 110
5686	Brewer Point, Severn River..............		39 01.[illegible]	76 31.73	- - -	-1 22	- - -	-1 50	0.4	0.4	0.0 - -	0.3 275	0.0 - -	0.3 155
5691	Mountain Point, Magothy River entrance..		39 03.47	76 26.23	-2 20	-2 00	-1 29	-2 04	0.8	0.4	0.0 - -	0.6 315	0.0 - -	0.3 135
	CHESTER RIVER													
5696	Love Point, 1.0 miles southeast of......		39 01.3	76 16.4	-0 40	-0 40	0 40	-0 40	0.1	0.5	0.0	0.1 205	0.0 - -	0.4 135
5701	Kent Island Narrows (highway bridge)....	4	38 58.23	76 14.83	-2 07	-2 25	-2 11	[illegible]	1.2	1.1	0.0 - -	1.0 005	0.0 - -	0.9 190
5706	Hail Point, 0.6 mile east of.		39 00.68	76 11.17	0 41	-0 51	0 46	-0 19	0.5	0.5	0.0 -	0.4 030	0.0 - -	0.4 160
5711	Deep Point.........		39 06.39	76 07.23	-0 31	0 33	-0 32	-0 18	0.6	0.9	0.0 - -	0.5 045	0.0 -	0.7 260
5716	Chestertown.....................		39 12.43	76 03.67	-0 21	+0 05	-0 02	-0 17	0.8	0.6	0.0 - -	0.6 0.5	0.0 - -	0.5 220
	PATAPSCO RIVER													
5721	Brewerton Channel, south of North Pt....		39 10 97	76 26.92	- - -	-1 14	- - -	-1 02	0.3	0.2	0.0 - -	0.2 300	0.0 - -	0.2 120
5726	Brewerton Angle.......................		39 12 08	76 30.18	Current weak and variable									
5731	Fort McHenry Angle...................		39 15.45	76 34.53	Current weak and variable									
5736	Bear Creek entrance....................		39 13.8	76 29.9	Current weak and variable									
5741	Curtis Creek entrance..................		39 13.1	76 34.6	Current weak and variable									
5746	Fort McHenry, NW. Harbor entrance.......		39 15.8	76 34.5	Current weak and variable									
5751	Middle Branch entrance........		39 15.4	76 3[illegible]	Current weak and variable									
	BACK, GUNPOWDER and BUSH RIVERS													
5756	Lynch Point, Back River		39 15.0	76 26.3	0 00	-0 10	0 00	0 10	0.7	0.5	0.0 - -	0.6 310	0.0 - -	0.4 130
5761	Gunpowder River entrance		39 18.7	76 18.5	-0 24	-0 41	-0 25	-0 05	0.5	0.3	0.0 - -	0.4 040	0.0 - -	0.3 205
5766	Bush River, 0.4 mi. SW of Bush Point....		39 21.4	76 15.4	-0 07	0 24	-0 21	+0 20	0.6	0.6	0.0 - -	0.6 [illegible]	0.0 - -	0.5 165
	SASSAFRAS RIVER													
5771	Grove Point....................		39 22.7	76 02.6	-0 46	-0 36	-0 51	-0 44	0.5	0.4	0.0 -	0.4 095	0.0 - -	0.3 260
5776	Ordinary Point, 0.4 mile west of.. .		39 22.45	75 59.25	-0 30	-0 [illegible]	+1 [illegible]	-0 58	0.6	0.5	0.0 - -	0.5 165	0.0 -	0.4 345
5781	Georgetown....................... .		39 21.6[illegible]	75 53 1[illegible]	+1 00	+0 25	-0 56	-1 25	0.4	0.5	0.0 - -	0.3 090	0.0 - -	0.4 200
	ELK RIVER													
5786	Arnold Point, 0.4 mile west of.........		39 2[illegible].83	75 58.45	+1 34	-1 45	+1 24	-1 30	1.0	1.0	0.0 - -	0.8 040	0.0	0.8 215
5791	Hendersons Point		39 33.2	75 51.6	- - -	- - -	- - -	- - -	0.6	0.9	0.0 - -	0.5 030	0.0 - -	0.7 210
	CHESAPEAKE and DELAWARE CANAL				on CHESAPEAKE AND DELAWARE CANAL, p.76									
5796	Back Creek entrance		39 31.58	75 5[illegible].13	-0 4[illegible]	-0 06	+0 43	-0 24	0.5	0.6	0.0 - -	1.0 055	0.0 - -	1.2 240
5801	C&D CANAL, Chesapeake City bridge.......		39 31.7	75 48.7	Daily predictions						0.0 - -	2.0 110	0.0 - -	1.9 290
5806	Reedy Point bridge (35)...... .		39 33.5	75 35 0	-0 47	-1 16	-0 45	-1 16	1.1	1.1	0.0 - -	2.6 085	0.0 - -	2.1 265

Endnotes can be found at the end of Table 2

CURRENT DIFFERENCES AND OTHER CONSTANTS

the reference station. As mentioned above, however, some subordinate stations may exhibit either a double flood or a double ebb or both. As with the time differences, separate ratios are listed for each of the three flood (or ebb phases) and should be applied only to the daily maximum flood (or ebb) speed at the reference station. It should be noted that although the speed of a given current phase at a subordinate station is obtained by reference to the corresponding phase at the reference station, the directions of the current at the two places may differ considerably. Table 2 lists the average directions of the various current phases at the subordinate stations.

Rotary Tidal Currents.
The last page of Table 2 (which is illustrated here as Table 8-9) is a listing of data for those stations which exhibited rotary current patterns. Briefly, a rotary current can be described as one which flows continually with the direction of flow changing through all points of the compass during the tidal period. The average speeds and directions are listed in half-hour increments as referred to the predicted time fo "minimum before flood" at the reference station in Table 1. The Moon, at times of new, full, or perigee may increase these speeds 15-20 percent above average; or 30 to 40 percent if perigee occurs at or near the time of new or full Moon. Conversely, the Moon at times of quadrature or apogee may decrease the speeds 15 to 20 percent or 30 to 40 percent if they occur together. Near average speeds may be expected when apogee occurs near or at new or full Moon, or when perigee occurs at or near quadrature. The direction of the currents is given in degrees, true reading

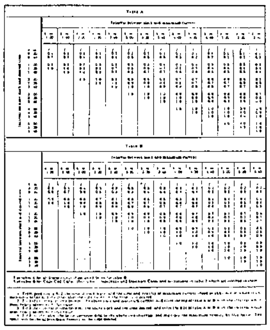


TABLE 3.—VELOCITY OF CURRENT AT ANY TIME

TABLE 8-11

VELOCITY OF CURRENT AT ANY TIME

clockwise from 000 is the direction toward which the water is flowing.

Example of the Use of Table 2.

Suppose we wish to calculate the times of the minimum currents and the times and speeds of the maximum currents on a particular morning at the location listed as Kent Island Narrows (highway bridge) from Table 2 (illustrated here as Table 8-10) we learn that the reference station is Baltimore Harbor Approach (page 70).

Currents for Kent Island Narrows can be approximated by using the Table 2 corrections indicated:

Baltimore Harbor Table 2 corrections for Kent Island Narrows.

On February 10

Minimum before flood	Maximum flood		Minimum before ebb	Maximum ebb	
h m	h m	kn	h m	h m	kn
0131	0353	0.4	0625	0918	0.5
-207	-225	x1.2*	-211	-256	
2324**	0128	0.5	0414	0622	0.6

* Ratio.

** The previous day.

Table 2 states that the average speed and directions of the minimums before flood and ebb are 0.0 knots. The average speed and directions of the maximum flood and maximum ebb are 1 knot at 005

Table 3. Velocity of Current at Any Time, Explanation of Table.
Though the predictions in the Tidal Current Tables give only the slacks and maximum currents, the velocity of the current at any intermediate time can be obtained approximately by the use of this table. Directions for its use are given below the table. Table 3 is illustrated as Table 8-11. Before using the table for a place listed in Table 2, the predictions for the day in question should first be obtained by means of the differences and ratios given in Table 2.

The examples below follow the numbered steps in the directions.

Example 1. Find the velocity of the current in the race at 0600 on a day when the predictions which immediately precede and follow 0600 are as follows:

Time	Time	Velocity
0418	0736	3.2 kn

Directions under the table indicate Table A is to be used for this station.

2. Interval between slack and maximum flood is 0736 - 0418 = 3(h)18(m). Column heading nearest to 3(h)18(m) is 3(h)20(m).

3. Interval between slack and time desired is 0600 - 0418 = 1(h)42(m). Line labeled 1(h)40(m) is nearest to 1(h)42(m).

4. Factor in column 3(h)40(m) and on line 1(h)40(m) is 0.7. The above flood velocity of 3.2 knots multiplied by 0.7 gives a flood velocity of 2.24 knots (or 2.2 knots, since one decimal is sufficient) for the time desired.

Example 2. Find the velocity of the current in the Harlem River at Broadway Bridge at 1630 on a day when the predictions (obtained using the difference and ratio in Table 2) which immediately precede and follow 1630 are as follows:

1. Maximum (Ebb) Slack Water

Time	Velocity	Time
1349	2.5 kn	1725

Directions under the table indicate Table B is to be used, since this station in Table 2 is referred to Hell Gate.

2. Interval between slack and maximum ebb is 1725 - 1349 = 3(h)36(m). Hence, use column headed 3(h)40(m).

3. Interval between slack and time desired is 1725 - 1630 = 0(h)55(m). Hence, use line labeled 1(h)00(m).

Duration of weak current near time of slack water

TABLE A

Maximum current	Period with a velocity not more than—				
	0.1 knot	0.2 knot	0.3 knot	0.4 knot	0.5 knot
Knots	*Minutes*	*Minutes*	*Minutes*	*Minutes*	*Minutes*
1.0	23	46	70	94	120
1.5	15	31	46	62	78
2.0	11	23	35	46	58
3.0	8	15	23	31	38
4.0	6	11	17	23	29
5.0	5	9	14	18	23
6.0	4	8	11	15	19
7.0	3	7	10	13	16
8.0	3	6	9	11	14
9.0	3	5	8	10	13
10.0	2	5	7	9	11

TABLE B

Maximum current	Period with a velocity not more than—				
	0.1 knot	0.2 knot	0.3 knot	0.4 knot	0.5 knot
Knots	*Minutes*	*Minutes*	*Minutes*	*Minutes*	*Minutes*
1.0	13	28	46	66	89
1.5	8	18	28	39	52
2.0	6	13	20	28	36
3.0	4	8	13	18	22
4.0	3	6	9	13	17
5.0	3	5	8	10	13

DURATION OF SLACK

4. Factor in column 3(h)40(m) and on line 1(h)00(m) is 0.5. The above ebb velocity of 2.5 knots multiplied by 0.5 gives an ebb velocity of 1.2 knots for the desired time.

When the interval between slack and maximum current is greater than 5(h)40(m), enter the table with one-half the interval between slack and maximum current and one-half the interval between slack and the desired time and use the factor thus found.

Table 4. Duration of Slack, Explanation of Table.

The predicted times of slack water given in the Tidal Current Tables indicate the instant of zero velocity, which is only momentary. There is a period each side of slack water, however, during which the current is so weak that for practical purposes it may be considered as negligible.
The following tables (illustrated here as Table 8-12) 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<u>except</u> those listed below for Table B.

Table B should be used for Cape Cod Canal, Hell Gate, Chesapeake and Delaware Canal, and all stations in Table 2 which are referred to them.
When there is a difference between the velocities 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 velocity and take the average of the two as the duration of the weak current.

Table 5. Rotary Tidal Currents, Explanation of Table.
Offshore and in some of the wider indentations of the coast, the tidal current is quite different from that found in the more protected bays and rivers. In these inside waters the tidal current is of the reversing type. It sets in one direction for a period of about 6 hours after which it ceases to flow mementarily and then sets in the opposite direction during the following 6 hours. Offshore the current, not being confined to a definite channel, changes its direction continually and never comes to a slack, so that in a tidal cycle of about 12 1/2 hours it will have set in all directions of the compass. This type of current is therefore called a rotary current. A characteristic feature of the rotary current is the absence of slack water. Although the current generally varies

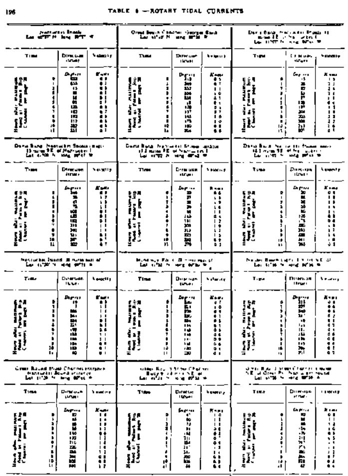


TABLE 8-13

ROTARY TIDAL CURRENTS
from hour to hour, this variation from greatest current to least current and back again to greatest current does not give rise to a period of slack water. When the velocity of the rotary tidal current is least, it is known as the minimum current, and when it is greatest it is known as the maximum current. The minimum and maximum velocities of the rotary current are thus related to each other in the same way as slack and strength of current, a minimum velocity of the current following a maximum velocity by an interval of about 3 hours and being followed in turn by another maximum after a further interval of 3 hours.

In the following table, a portion of which is illustrated as Table 8-13, there are given for a number of offshore stations the direction and average velocity of the rotary tidal current for each hour of the tidal cycle referred to predictions for a station in Table 1. All times are Eastern Standard for the 75th meridian, for the Atlantic Coast Tables.
The velocities given in the table are average. The Moon at new, full, or perigee tends to increase the velocities 15 to 20 percent above average. Quadrature and apogee tends to decrease the velocities below average by 15 to 20 percent. When apogee occurs at or near quadrature they will be 30 to 40 percent below average. The velocities will be about average when apogee occurs at or near the time of new or full Moon and also when perigee occurs at or near quadrature. (See table of astronomical data.)
The direction of the current is given in degrees, true reading clockwise from 0 at north, and is the direction toward which the water is flowing.

The velocities and directions are for the tidal current only and do not include the effect of winds. When a wind is blowing, a wind-driven current will be set up which will be in addition to the tidal current, and the actual current encountered will be a combination of the wind-driven current and tidal current.

As an example, in the following table the current at Nantucket Shoals is given for each hour after maximum flood at Pollock Rip Channel. Suppose it is desired to find the direction and velocity of the current at Nantucket Shoals at 3:15 p.m. (1515) eastern standard time on a day when maximum flood at Pollock Rip Channel is predicted in Table 1 to occur at 1320 Eastern Standard Time. The desired time is therefore about 2 hours after maximum flood at Pollock Rip Channel, and from the following table the tidal current at Nantucket Shoals at this time is setting 15 velocity of 0.8 knot. If this day is near the time of new Moon and about halfway between apogee and perigee, then the distance effect of the Moon will be nil and the phase effect alone will operate to increase the velocity by about 15 percent, to 0.9 knot. If a wind has been blowing, determine the direction and velocity of the wind-driven current from the subchapter on "Wind-Driven Currents," below, and combine it with the above tidal current as explained in the subsection on "The Combination of Currents," below.

Caution - Velocities from 1 1/2 to 3 knots have been observed at most of the stations in this table. Near Diamond Shoal Light a velocity of 4 knots has been recorded.

At some offshore stations, such as near the entrance to Chesapeake Bay, the tidal current is directed alternately toward and away from the bay entrance with intervening periods of slack water, so that it is essentially a reversing current. For such places, differences for predicting are given in Table 2.

Astronomical Data.
Astronomical data are also provided in the Tidal Current Tables, in tabular form, herein illustrated as Table 8-14. They do not have a table number in the Tidal Current Tables. The astronomical data indicated are intended to provide the navigator with information necessary to predict currents and consist of lunar data (phases, apogee/perigee dates, equatorial distance) and solar data (equinox and solstice dates).

Wind Driven Currents.
A wind continuing for some time will produce a current the velocity of which depends on the velocity of the wind, and unless the current is deflected by some other cause, the deflective force of the earth's rotation will cause it to set to the right of the direction of the wind in in the southern hemisphere. The current produced at offshore locations by local winds of various strengths and directions has been investigated from observations made at 20 lightships (some of which have since been moved from Portland, Maine, to St. Johns River, Florida). This is shown as Table 8-15. The observations were made hourly and varied in length from 1 to 2 years at most of the locations to 5 1/2 years at Nantucket Shoals and 9 years at Diamond Shoal. The averages obtained are given below and may prove helpful in estimating the probable current that may result from various winds at the several locations.

Caution - There were of course many departures from these averages of velocity and direction for the wind-driven current often depends not only on the length of time the wind blows but also on factors other than the local wind at the time and place of the current. The mariners must not, therefore, assume that the given wind will always produce the indicated current.
It should be remembered, too, that the current which a vessel experiences at any time is the resultant of the combined actions of the tidal current, the wind-

ASTRONOMICAL DATA

January

	d.	h	m
E	5	22	..
◑	6	04	00
S	13	06	..
A	14	05	..
●	14	05	08
E	20	17	..
◐	22	05	33
N	27	05	..
P	28	11	..
O	28	22	26

February

	d.	h	m
E	2	06	..
◑	4	19	17
S	9	12	..
A	10	08	..
●	13	00	32
E	16	22	..
◐	20	17	32
N	23	14	..
P	25	22	..
O	27	08	58

March

	d.	h	m
E	1	16	..
◑	6	13	16
S	8	18	..
A	9	23	..
●	14	17	43
E	16	04	..
O_1	21	04	39
◐	22	02	25
N	22	20	..
P	25	22	..
O	28	19	27
E	29	02	..

April

	d.	h	m
S	5	01	..
◑	5	08	38
A	6	18	..
E	12	11	..
●	13	07	58
N	19	02	..
◐	20	08	58
P	21	08	..
E	25	11	..
O	27	06	31

May

	d.	h	m
S	2	10	..
A	4	13	..
◑	5	03	43
E	9	20	..
●	12	19	25
N	16	08	..
P	16	16	..
◐	19	14	17
E	22	18	..
O	26	18	48
S	29	18	..

June

	d.	h	m
A	1	08	..
◑	3	21	07
E	6	05	..
●	11	04	37
N	12	17	..
P	13	06	..
◐	17	19	46
E	18	23	..
O_2	21	23	09
O	25	08	32
S	26	01	..
A	28	23	..

July

	d.	h	m
◑	3	12	12
E	3	14	..
N	10	03	..
●	10	12	18
P	11	10	..
E	16	05	..
◐	17	02	50
S	23	07	..
O	24	23	27
A	26	07	..
E	30	20	..

August

	d.	h	m
◑	2	00	52
N	6	13	..
P	8	19	..
●	8	19	18
E	12	13	..
◐	15	12	47
S	19	12	..
A	22	09	..
O	23	14	59
E	27	01	..
◑	31	11	22

September

	d.	h	m
N	2	21	..
P	6	05	..
●	7	02	35
E	8	22	..
◐	14	02	24
S	15	18	..
A	18	17	..
O	22	06	36
E	23	06	..
O_3	23	14	42
◑	29	20	05
N	30	04	..

October

	d.	h	m
P	4	11	..
E	6	08	..
●	6	11	16
S	13	02	..
◐	13	19	42
A	16	08	..
E	20	13	..
O	21	21	53
N	27	10	..
◑	29	03	37

November

	d.	h	m
P	1	03	..
E	2	18	..
●	4	22	21
S	9	10	..
◐	12	15	49
A	13	03	..
E	16	22	..
O	20	12	29
N	23	16	..
P	26	02	..
◑	27	10	50
E	30	01	..

December

	d.	h	m
●	4	12	26
S	6	19	..
A	11	01	..
◐	12	13	09
E	14	07	..
O	20	02	00
N	21	00	..
O_4	22	10	30
P	22	18	..
◑	26	18	52
E	27	06	..

LUNAR DATA.

● - new Moon
◐ - first quarter
O - full Moon
◑ - last quarter
A - Moon in apogee
P - Moon in perigee
N - Moon farthest north of Equator
E - Moon on Equator
S - Moon farthest south of Equator

SOLAR DATA

O_1 - March equinox
O_2 - June solstice
O_3 - September equinox
O_4 - December solstice

Greenwich mean time (GMT) or universal time (UT) is the mean solar time on the Greenwich meridian reckoned in days of 24 mean solar hours written as 00^h at midnight and 12^h at noon. To convert the above times to those of other standard time meridians, add 1 hour for each 15° of east longitude of the desired meridian and subtract 1 hour for each 15° of west longitude.

This table was compiled from data taken from the American Ephemeris and Nautical Almanac.

ASTRONOMICAL DATA

Average deviation of current to 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
Old Lightship Stations	Lat	Long																
	° ′	° ′	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Portland	43 32	70 06	24	14	9	8	−2	−14	0	26	16	18	18	24	15	34	13	16
Boston	42 20	70 45		−1		21		32		29		20		2		19		15
Pollock Rip Slue	41 37	69 54	6	5	48	−38	30	−53	−24	−75	−25	167	70	59	36	53	30	29
Nantucket Shoals	40 37	69 37	44	46	28	24	9	16	12	3	25	0	6	18	30	30	41	48
Hen and Chickens	41 27	71 01	16	14	−7	−1	−14	3	−30	−36	25	55	35	30	20	16	16	8
Brenton Reef	41 26	71 23	34	25	22	19	25	1	−7	8	27	48	23	41	41	31	21	24
Fire Island	40 29	73 11	35	23	15	8	2	−17	31	55	40	41	31	14	−2	0	25	37
Ambrose Channel	40 27	73 49	30	40	21	11	18	72	27	112	82	70	63	46	37	22	23	21
Scotland	40 27	73 55	16	−12	−26	−36	−61	−38	−92	−150	90	33	77	44	15	30	27	13
Barnegat	39 46	73 56	6	5	−13	−1	−16	−7	33	54	55	30	14	8	0	−5	21	29
Northeast End	38 58	74 30	30	14	−3	−11	−20	−31	−42	−28	37	44	25	18	7	16	25	18
Overfalls	38 48	75 01	28	−6	−1	2	−40	−56	−78	−22	68	28	55	54	32	31	32	45
Winter Quarter Shoal	37 55	74 56	18	−1	−5	−21	−27	−35	−19	31	23	20	4	14	9	8	28	27
Chesapeake	36 59	75 42	15	−2	−4	5	−6	23	73	71	57	38	27	26	22	15	15	22
Diamond Shoal	35 05	75 20	11	3	−3	36	65	68	74	52	40	22	7	−10	−13	−17	−25	−4
Cape Lookout Shoals	34 18	76 24	30	24	2	2	−29		21	80	54	31	32	21	2	18	5	−5
Frying Pan Shoals	33 34	77 49	34	34	18	6	2	9	48	55	48	38	26	14	−7	−12	−27	−6
Savannah	31 57	80 40	12	12	−9	−18	−23	−46	17	50	43	17	7	−8	−10	7	15	33
Brunswick	31 09	81 10	17	−2	−10	−28	−18	−21	37	29	23	2	6	−21	−21	−26	16	18
St. Johns	30 23	81 18	3	−12	−27	−47	−84	30	35	28	28	27	1	16	−8	−17	6	8

TABLE 8-15

AVERAGE DEVIATION OF CURRENT TO RIGHT OF WIND DIRECTION

driven current, and any other currents such as the Gulf Stream or currents due to river discharge.

Velocity. The table below shows the average velocity of the current due to winds of various strengths.

Wind Velocity (miles per hour)	10	20	30	40	50
Average current velocity(knots) due to wind at following light ship stations:					
Boston and Barnegat	0.1	0.1	0.2	0.3	0.3
Diamond Shoal and Cape Lookout Shoals	0.5	0.6	0.7	0.8	1.0
All other locations	0.2	0.3	0.4	0.5	0.6

Direction. The position of the shore line with respect to the station influences considerably the direction of the currents due to certain winds. Table 8-15 shows for each station the average number of degrees by which the wind-driven current is deflected to the right or left (-) of the wind. Thus at Cape Lookout Shoals the table indicates that with a north wind the wind-driven current flows on the average 030 wind it flows 029

The Combination of Currents.
In determining from the current tables the velocity and direction of the current at any time, it is frequently necessary to combine the tidal current with the winddriven current. The following methods indicated how the resultant of two or more currents may be easily determined.

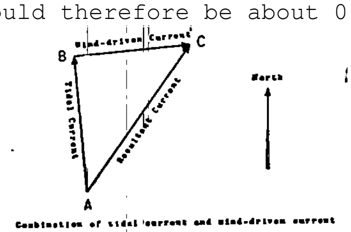
Currents In the Same Direction. When two or more currents set in the same direction.
For example, a vessel is near the Nantucket Shoals station at a time when the tidal current is setting 120 velocity of 0.6 knot, and at the same time a wind of 40 miles per hour is blowing from west; what current will the vessel be subject to at that time? Since a wind of 40 miles from west will give rise to a current setting 120 velocity of 0.5 knot, the combined tidal and wind-driven currents will set in the same direction (120 0.6 + 0.5 = 1.1 knots.

Currents In Opposite Directions. The combination of currents setting n opposite directions is likewise a simple matter. The velocity of the resultant current is the difference between the opposite setting currents, and the direction of the resultant current is the
As an example, let it be required to determine the velocity of the current at

the Nantucket Shoals station when the tidal current is setting 205 velocity of 0.8 knot, and when a wind of 40 miles per hour from south would set 025 tidal and wind-driven currents therefore set in opposite directions, the tidal current being the stronger. Hence the resultant current will set in the direction of the tidal current (205 of 0.8 - 0.5 = 0.3 knot.

Currents In Different Directions. The combination of two or more currents setting neither in the same nor in opposite direction, while not as simple as in the previous cases, is nevertheless not difficult, the best method being a graphic method. Taking the combination of two currents as the simplest case, we draw from a given point as origin, a line the direction of which is the direction of one of the currents to be combined and whose length represents the velocity of that current to some suitable scale; from the end of this line we draw another line the direction and length of which, to the same scale, represents the other of the currents to be combined; then a line joining the origin with the end of our second line gives the direction and velocity of the resultant current.

As an example, let us take Nantucket Shoals station at a time when the tidal current is 0.7 knot setting 355 wind of 50 miles per hour is blowing from west-southwest; the wind-driven current according to the preceding chapter would therefore be about 0.6 knot setting 085



Combination of Tidal Current and Wind-Driven Current

Using a scale of 2 inches to the knot we above, the line AB 1.4 inches in length directed 355

BC 1.2 inches in length directed 085 represent the wind current. The line AC represents the resultant current and on being measured is found to be about 1.8 the resultant current sets 035 velocity of 0.9 knots.

The combination of three or more currents is made in the same way as above, the third current to be combined being drawn from the point C, the resultant current being given by joining the origin A with the end of the last line.

For drawing the lines, a parallel rule and compass rose will be found convenient, or a protractor or polar coordinate paper may be used.

Current Diagrams.

"Current diagram" is a graphic table that shows the velocities of the flood and ebb currents and the time of slack and strength over a considerable stretch of the channel of a tidal waterway. At definite intervals along the channel the velocities of the current are shown with reference to the times of turning of the current at some reference station. This the approximate velocity of the current along the channel for any desired time.

In using the diagrams, the desired time after the time of the nearest predicted slack water at the reference station. Besides showing in compact form the velocities of the current and their changes through the flood and ebb cycles, the current diagram serves two other useful purposes. By its use the mariner can determine the most advantageous time to pass through the waterway in order to carry the most favorable current and also the velocity and direction of the current that will be encountered in the channel at any time.

Each diagram represents average durations and average velocities of flood and ebb. The duration and velocities of flood and ebb vary from day to day. Therefore predictions for the reference station at times will differ from average conditions and when precise results are desired the diagrams should be modified to represent conditions at such particular times. This can be done by changing the width of the shaded and unshaded portions of the diagram to agree in hours with the durations of flood and ebb, respectively, as given by the predictions for that time. The velocities in the shaded area should then be multiplied by the ratio of the predicted flood velocity to the average flood velocity (maximum flood velocity given opposite the name of the reference station on the diagram) and the velocities in the unshaded area by the ratio of the predicted ebb velocity to the average ebb velocity.

In a number of cases approximate results can be obtained by using the diagram as drawn and modifying the final result by the ratio of velocities as mentioned above. Thus if the diagram in a particular case gives a favorable flood velocity averaging about 1.0 knot and the ratio of the predicted flood velocity to the average flood velocity is 0.5 the approximate favorable current for the particular time would be 1.0 x 0.5 = 0.5 knot.
An example of a current diagram is provided as the diagram for the Chesapeake Bay. This diagram is illustrated as Fig. 8-6.

CHESAPEAKE BAY

EXPLANATION OF CURRENT DIAGRAM

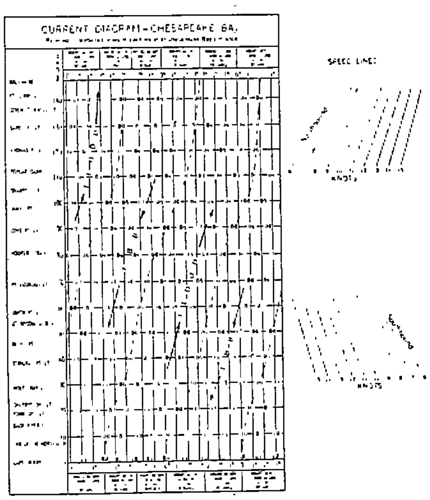
This current diagram represents only average conditions of the surface currents along the middle of the channel from Cape Henry Light to Baltimore, the scale being too small to show details.

Northerly streams are designated "Flood" and southerly streams "Ebb." The small figures in the diagram denote the velocity of the current in knots and tenths. The times are referred to slack waters at Chesapeake Bay entrance, daily predictions for which are given in Table 1 of the Current Tables.
The speed lines are directly related to the diagram. By transferring to the diagram the direction of the speed line which corresponds to the vessel's speed, the diagram will show the general direction and velocity of the current encountered by the vessel in passing up or down the bay or the most favorable time, with respect to currents, for leaving any place shown in the left margin.

To determine velocity and direction of current. With parallel rulers transfer to the diagram the direction of the speed line corresponding to the normal speed of vessel, moving the edge of the ruler to the point where the horizontal line representing place of departure intersects the vertical line representing the time in question. If the ruler's edge lies within the shaded portion of the diagram, a flood current will be encountered; if within the unshaded, an ebb current, and if along the boundary of both, slack water.
The figures in the diagram along the edge of the ruler will show the velocity of the current encountered at any place indicated in the left margin of the diagram.

Example. A 12-knot vessel bound for Baltimore passes Cape Henry Light at 1430 of a given day, and it is desired to ascertain the velocity and direction of the current which will be encountered. Assuming that on the given day flood begins at Chesapeake Bay entrance at 1256 and ebb begins at 1803, the time 1430 will be about 1 1/2 hours after flood begins. With parallel rulers transfer to diagram the 12-knot speed line "Northbound," placing the edge of the ruler so that it will be found that the edge of the ruler passes through strength of current in the shaded portion of diagram averaging about 0.7 knot. The vessel will, therefore, have a favorable current averaging about 0.7 knot all the way to Baltimore.

The following procedure is used to determine the time of a favorable current for passing through the bay. With parallel rulers transfer to the diagram the direction of the speed line corresponding to normal speed of vessel, moving the ruler over the diagram until its edge runs approximately through the general line of greatest current of unshaded portion of southbound and shaded portion if northbound. An average of the figures along the edge of the ruler will give



CURRENT DIAGRAM-CHESAPEAKE BAY

average strength of current. The time (before or after ebb or flood begins at the entrance) for leaving any place in the left margin of diagram will be found vertically above the point where the parallel ruler cuts the horizontal line opposite the place in question.

Example. A 12-knot vessel in Baltimore Harbor desires to leave for Cape Henry Light on the afternoon of a day when flood begins at Chesapeake Bay entrance at 1148 and ebb begins at 1718. At what time should she get under way so as to carry the most favorable current?

Place parallel rulers along the 12-knot speed line "Southbound." Transfer this direction to the diagram and move it along so as to include the greatest possible number of larger current velocities in the unshaded portion of the diagram. The most favorable time for leaving Baltimore thus found is about 1 hour after flood begins at the entrance, or about 1248. There will be an unfavorable current of about 0.2 knot as far as Seven Foot Knoll Light; after passing this light there will be an average favorable current of about 0.3 knot as far as Cove Point Light; from Cove Point Light to Bluff Point a contrary current averaging about 0.3 knot will be encountered; from Bluff Point to Tail of the Horseshoe there will be an average favorable current of about 0.9 knot; and from Tail of the Horseshoe to Cape Henry an average contrary current of about 0.2 knot will again be encountered.

Chapter 9

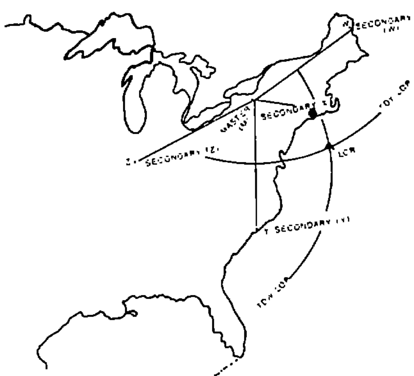
Radio Navigation

Introduction.
Radio navigation is accomplished through the use of electronic navigation tools and aids to navigation. There are three main radio systems available to the small craft navigator: Loran-C, Radio Direction-Finding, and Radar. Each of these systems deserves the close attention of the Vessel Operator, and will be treated in considerable detail in the sections of this chapter.

Loran-C.

Loran-C is a long-range, hyperbolic, radionavigation system using time and phase measurement of the received radio signal to provide a line of position with excellent accuracy. The system uses radio transmitters operating on a carrier frequency of 100 kHz (wavelength of about 3000 meters) emitting a pulsed signal. Because of the use of low frequency (LF), long baselines between transmitters (1000 miles), and pulsed signal, the system suffers low losses passing over land and water masses, provides most of the radiated energy in the pulses, and thus, enhances the reception of the signals at great distances.

The pulsed signals are received on equipment which automatically processes them by time and phase difference to provide accurate, reliable and repeatable position information. The range of the Loran-C system is from 800-1200 nautical miles using the groundwave and up to 2300 nautical miles with a one hop skywave. Transmitter power is within the



Loran-C Chain With GRI 9966.

range of 250 kW to 3 MW. Loran-C position accuracies for ground wave only are indicated in Table 9-1.

Loran-C Chains. The Loran-C system uses several transmitters in a group termed a Loran-C Chain. Each chain is composed of a master station (designated by the letter "M"), which transmits its pulse group first, followed by two or more secondary stations (designated by the letters, W, X, Y or Z), which transmit on the same frequency groups of pulses slightly delayed from those transmitted by the master. The secondary stations are located at long distances from the master station on baselines (the line between pairs of stations) which are as much as 1000 nautical miles long. A Loran-C chain operating on the east coast of the United States is shown in Fig. 9-1. Some of the important Loran-C chains near or in the United States are indicated in Table 9-2.

TYPICAL LORAN-C POSITION ACCURACIES
USING GROUNDWAVE ONLY

RANGE TO MASTER STATION	ACCURACY
200 M	50 - 300 ft.
500 M	200 - 700 ft.
750 M	300 - 1,100 ft.
1000 M	500 - 1,700 ft.

Typical Loran-C Position Accuracies Using Groundwave Only.

SOME IMPORTANT LORAN-C CHAINS
IN OR NEAR THE UNITED STATES

Northeast Coast of United States and Gulf of Mexico		
Chain 9960	Master (M)	Seneca, NY
	Secondary (W)	Caribou, ME
	Secondary (X)	Nantucket, MA
	Secondary (Y)	Carolina Bch., NC
	Secondary (Z)	Dana, IN
Southeast Coast of United States and Gulf of Mexico		
Chain 7980	Master (M)	Malone, FL
	Secondary (W)	Grangeville, LA
	Secondary (X)	Raymondville, TX
	Secondary (Y)	Jupiter, FL
	Secondary (Z)	Carolina Beach, NC
West Coast of United States, California		
Chain 9940	Master (M)	Fallon, NV
	Secondary (W)	George, WA
	Secondary (X)	Middletown, CA
	Secondary (Y)	Searchlight, NV
Canadian West Coast		
Chain 5990	Master (M)	Williams Lake, BC, Canada
	Secondary (X)	Shoal Cove, AK
	Secondary (Y)	George, WA
	Secondary (Z)	Port Hardy, BC, Canada
North Pacific		
Chain 9990	Master (M)	St. Paul, AK
	Secondary (X)	Attu I., AK
	Secondary (Y)	Port Clarence, AK
	Secondary (Z)	Narrow Cape, AK
Gulf of Alaska		
Chain 7960	Master (M)	Tok, AK
	Secondary (X)	Narrow Cape, AK
	Secondary (Y)	Shoal Cove, AK
Great Lakes		
Chain 8970	Master (M)	Dana, IN
	Secondary (W)	Malone, FL
	Secondary (X)	Seneca, NY
	Secondary (Y)	Baudette, MN
Central Pacific (Hawaiian Islands)		
Chain 4990	Master (M)	Johnston Island
	Secondary (X)	Upolu, Hawaii, HI
	Secondary (Y)	Midway, I.
Canadian East Coast		
Chain 5930	Master (M)	Caribou, ME
	Secondary (X)	Nantucket, MA
	Secondary (Y)	Cape Race, NFLD, Canada
	Secondary (Z)	Fox Harbour, NFLD, Canada

Some Important Loran-C Chains In or Near the United States.

Each station in the chain operates independently with synchronization controlled by multiple individual cesium frequency standards which provide a very high degree of precision and accuracy. For each pair of stations (the master and one of the secondaries) the TIME DIFFERENCE (TD) between pulses transmitted from each station is measured at the point of reception. This time difference is constant on a hyperbolic line developed on the two stations, and upon measurement provides a line of position.
Time differences between master and secondary are designated by the letter of the secondary, W, X, Y or Z. Thus, the time difference between the master (M) and the secondary station W, the M-W pair, would be TDW. For M-X pair, it would be TDX, for the M-Y pair, TDY, and for M-Z TDZ. Coarse measurement is accomplished by measuring the time difference between the pulses from master and secondary stations. Fine measurement is accomplished, then by a comparison of the phase of the signal within the pulse CC automatically CC to provide a very precise determination of line of position.

Loran-C Signal Format. The master station transmits a group of nine pulses, eight at 1000 usec intervals and then a ninth for identification purposes. (usec is the abbreviation for microsecond, 1/1,000,000 sec.) Each secondary station transmits, after a specific delay, a group of only eight pulses, again at 1000 usec intervals. These groups are repeated at intervals termed the GROUP REPETITION INTERVAL (GRI). The stations of a given chain all transmit their pulses at the same GRI, which is selected for chain identification purposes and to minimize signals (called Cross Rate Interference) from stations in other Loran-C chains. In theory, GRI's for Loran-C are limited from 00010 to 99990 usec in 10 usec steps. However, in actual practice, GRI's range between 40000 and 99990 usec. GRI's are designated by the first four digits of the GRI. Thus, the GRI of a signal with a group repeating interval of 99600 usec would be designated GRI 9960.

Blink. In the event that one or more of the stations in a chain either go "off air" (i.e. stop transmitting) begin transmitting their signals outside of prescribed tolerances, users are notified by causing certain transmitted pulses to "blink" (i.e. turn on and off at a slow rate). Prior to September 1984 the Master Signal's ninth pulse was blinked according to a specific code to indicate which station was at fault. Master stations no longer display ninth pulse blink to notify users of system abnormalities. (It may be used for special purposes from time to time by the Coast Guard, however). Instead, the following methods are used for the situations described:

1. **Master Off-Air.** When the master is off-air either for a scheduled or unscheduled period, no stations blink. Receivers can detect the loss of master signal and display an alarm warning the user that the entire chain is unuseable for hyperbolic navigation (i.e. navigation with TD's).

2. **Master Out of Tolerance.** When the master signal is out of tolerance, all of the secondary signals blink their first two pulses. Receivers can detect this blinking and display alarms warning the user that the entire chain is unuseable.

3. **Secondary Off Air.** When a secondary signal is off air, no stations blink. More than one secondary can be off air at the same time. Receivers can detect the loss of each secondary signal separately and display an alarm (usually one for each secondary) warning the user that a particular station is unuseable.

4. **Secondary Out of Tolerance.** When a secondary signal is out of tolerance, the secondary blinks its own first two pulses. More than one secondary can be out of tolerance at the same time, in which case each out of tolerance station would blink its first two pulses.

Receivers can separately detect blink in secondaries and display an alarm (usually one for each secondary) warning the user that a particular station is unuseable.

Occasionally a master or secondary signal may be off the air for less than one minute (due to very short term faults or when the station changes from primary to back up transmitter). These are called "momentaries." Some receivers can continue to operate normally during a momentary (especially when it lasts for only a few seconds) while other receivers may indicate an off the air condition.

Loran-C Geodetic Accuracy. Geodetic accuracy (also called Predictable or Absolute Accuracy) is the accuracy of a position with respect to the geographic or geodetic coordinates of the earth (i.e. latitude/longitude). The Coast Guard Loran-C Geodetic Accuracy requirement is plus or minus one quarter nautical mile (2 DRMS 95%) within the Coastal Confluence Zone of the United States. Two DRMS, a standard measure of accuracy, is the radius of a circle that contains at least 95% of all possible fixes that can be obtained with a system at any one place. Typical Loran-C position accuracies (for ground wave only) are indicated in Table 9-1. Actual Loran-C geodetic accuracy at a given location depends on the crossing angles or the lines of positions, the rate of change of each line of position (called the gradient) the stability of the Loran-C signals, and on how well one accounts for propagation delays as the signals travel over land.

Loran-C Repeatable Accuracy. Repeatable accuracy is the accuracy with which a user can return, again and again, to a position whose coordinates have been measured at a previous time with the same navigation system. Loran-C repeatability has been carefully measured in several locations and has been found to range from anywhere from plus or minus 75 feet, to plus or minus 3300 feet (2 DRMS 95%) depending on location. Actual Loran-C repeatability at a given location depends on the crossing angles, gradients and stability of the received signals. Repeatable accuracy is not affected by the amount of propagation delay along the transmission path, but it is affected by momentary changes to the delay, a factor that contributes to the stability of the received signal. A practical use of Loran-C in its repeatable mode is to measure the Loran-C Time Difference at, say, a favorite fishing hole and then at some later time maneuver the vessel so that the receiver reads the same TDs as were previously measured. At that point you are within the repeatable accuracy (for that area) of being at the same geodetic location as you were originally. This procedure can be done with any Loran-C Receiver, and does not involve the use of a nautical chart, nor a coordinate converter. The same Loran-C repeatable accuracy can be used to locate a distress vessel if the vessel's Loran-C TDs are known.

Loran-C Charts. Many navigational charts (except those with scales less than 1:80,000) are overprinted with lines of position (LOPs) for each master-secondary pair that is useful in the area covered by the chart. Lines of position are lines of constant time difference, and they appear on the chart spaced 2, 5, 10, 20 or 50 microseconds apart depending on the chart scale. The earliest Loran-C charts were drawn with LOPs that were predicted assuming that the signals travel over all seawater. Plotting measured TDs on these "all seawater" charts sometimes yielded fixes that were in error by more than one quarter mile.

The propagation delay due to Loran-C signals traveling over land, called the Additional Secondary Phase Factor, or ASF was not accounted for on the earliest charts. Loran-C Correction Tables were developed by Defense Mapping Agency that contained the ASF correction to be applied to measured Loran-C TDs before plotting on an "all seawater" chart, for improved accuracy. The LOPs printed on second generation Loran-C charts included predicted ASF correction alleviating the need for manually applying corrections from tables. A Loran-C chart verification program began in 1978 in which simultaneous Loran-C and independent reference position data were collected along the U.S. coasts. These data were used to adjust the predicted Loran-C correction tables and to adjust the LOPs printed on charts, further improving accuracy. A Loran-C Note on each chart describes the type of LOPs printed (all seawater, adjusted with predicted correction or verified with observed data). The separate Loran-C correction tables should only be used with charts that have "All Seawater" LOPs.

Use of the Loran-C System. The Loran-C receiver is extremely simple to use to obtain high quality navigational fixes. Although each receiver has its own specific procedures for its operation, care and maintenance, for which the manufacturer's instructions and manual should be consulted, the basic use of the system is uniform. The receiver is set for a specific GRI, and the best two secondary stations are selected for best accuracy and strongest signal. The TDs are read and recorded for the two master-secondary pairs. The TDs are then plotted on the chart and the Loran- C LOPs developed. Two or more crossed Loran-C LOPs provide an electronic fix. The specific details of the process will now be discussed, illustrated by figures and examples.

Loran-C Signal Selection and Acquisition.
Before setting the Loran-C receiver, the Loran-C chart of the area is consulted to determine which GRIs and secondary stations are available and suitable for use. A Loran-C chart will have the GRI lattice (as the GRI coordinate system is termed) overprinted on a small scale type chart of the area. Each master-secondary TD pair lattice is printed in a different color (i.e. purple, green, black, blue) to make it easier to differentiate it from other TD pairs on the chart.

The LOPs of the chosen TD pair should intersect at angles larger than 30 preferably as close to 90 and the rate of change of each LOP

(called the Gradient) in feet per microsecond should be as small as

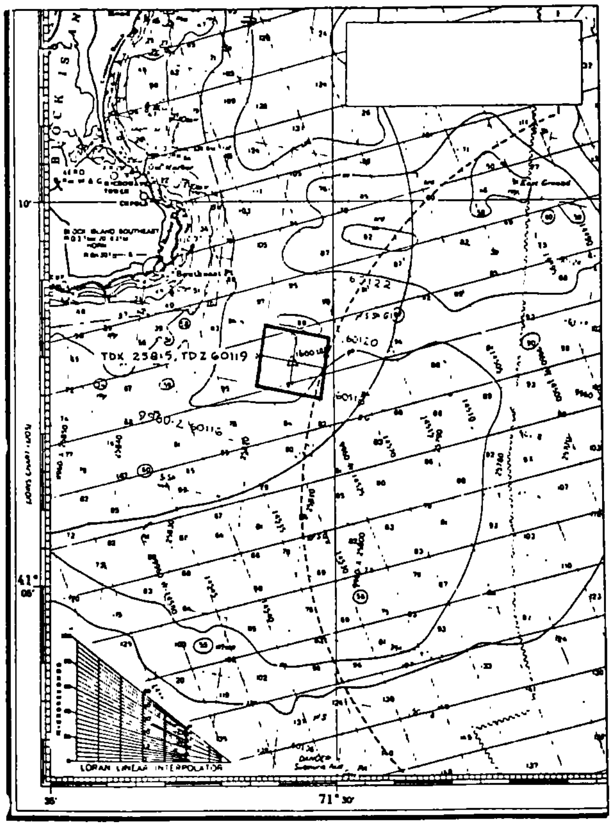
possible. Also, the strongest two secondary stations are preferred, although weaker ones can be used as long as the receiver can properly track the signal. When the Loran-C lines are selected, enter them into the receiver according to the manufacturer's directions. Depending on noise, signal strength, proximity to the transmitter, the equipment will take from a few seconds to several minutes (5 or more) to acquire and to begin to track the signal. Then, however, the receiver should track the signal continuously until it is turned off or reset to another GRI.
Near the transmitter, where the signal is strong and the signal to noise ratio is large, the signal is acquired quickly. Far away, at the limits of the system coverage, the receiver may take several minutes to acquire and track the signal.

When the instrument has acquired the signal and started to track it, the various alarm indicators (usually in the form of small lights) will be extinguished and the unit will be available for service. It is important to note that the Loran-C receiver is intended to be operated over extended periods of time, continually tracking and indicating the Loran-C TDs. It is not conductive to Loran-C navigation to "fire up the set, take the reading, and then shut down 'til the next position check." Keep the Loran-C set <u>on</u>.

Plotting the Loran-C Line of Position.
The Loran-C constant TD pair lattices are available in both tables and overprinted on charts. Since small craft usually operate within a few tens of miles from the shore, where the charts provide adequate coverage, plotting an LOP on the charts, with overprinted TD lattices (usually at 10 usec intervals) will be discussed rather than the tables, which are more useful to ships operating far out to sea.

Obtaining a Loran-C LOP is a relatively easy process. Simply take the readings off the Loran-C receiver and, using the overprinted chart, plot the position. Interpolation, if necessary, can be accomplished by "eyeball," mechanically, using the Loran Linear Interpolator, printed on the chart or by use of the Loran-C Plotter (a simple card with graduated scales on its edge). A single TD pair line constitutes a Loran-C LOP. Two or more crossing provide a Loran-C FIX. Once a Loran-C fix is plotted on a chart, the latitude/longitude coordinates of the fix can be determined from the chart using normal plotting techniques. Plotting is demonstrated by use of an example:

Figure 9-2 is a chart of Long Island Sound in the vicinity of Block Island. The Loran-C lattice is overprinted in 10 usec increments. The available GRIs and master-secondary pairs on the example chart are:



26th Ed. Jan 8, 83

13218

LORAN-C OVERPRINTED

CAUTION

This chart has been corrected from the Notice to Mariners published weekly by the Defense Mapping Agency Hydrographic/Topographic Center and the Local Notice to Mariners issued periodically by each U.S. Coast Guard district to the print date shown in the lower left hand corner.

9960 W
9960 X
9960 Z

Knowing the vessel is in the vicinity of Block Island, and because the lattices intersect clost to 90 pairs are chosen:

9960 X
9960 Z

The Loran-C receiver is set for these two pairs. The receiver is allowed to acquire the signals, stabilize and begin tracking them. All alarm indicators extinguishes indicating normal operation. Readings are now taken and recorded:

TDX 25815.0
TDZ 60119.0

A rough Loran-C position determination can be made simply by inspection of the chart. The position of the vessel lies in the parallelogram bounded by these TD constant lines:

9960-X-25810 and 9960-X-25820
9960-Z-60118 and 9960-Z-60120

This parallelogram is located SSE of Block Island.

TDZ 60119.0

A rough Loran-C position determination can be made simply by inspection of the chart. The position of the vessel lies in

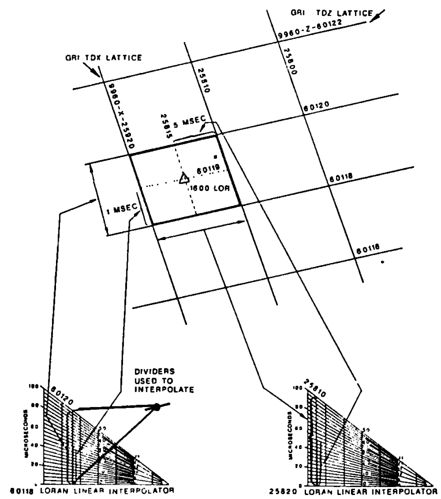


Fig. 9-3 9960-X-25815, 9960-Z-60119.

The position can be refined by "eyeball" interpolation or mechanically, using dividers and the Loran Linear Interpolator, printed on the chart. (See, also, Fig. 9-3.) The mechanical (or graphic interpolation will be demonstrated from which the "eyeball" interpolation technique should become readily apparent.

1. Set dividers along the 9960-Z-60118 TDZ to coincide with the distance between the TDX lines 9960-X-25810 and 9960-X-25820, which appear on the chart as 25810 and 25820. (The 9960-X-TD designator is only indicated every 10 usec.)

2. With dividers set, refer to the Loran Linear Interpolator. Holding the dividers with their "gap" vertically (i.e. in the north-south direction on the chart) move them until the gap coincides with the 0-usec baseline and the 100-50-usec upper lines on the chart. This establishes the "scale" for the GRI 9960 TDX lines on the chart.

3. Now, reduce the gap to the distance between the 0-usec baseline and the 25-50 usec line. This distance corresponds to a TDX of 5 usec on the chart.

4. Return to the chart (Fig. 9-2) and strike off two points, one on the 9960-Z-60118 line at the gap distance (5 usec) to the left the 25810 TDX line. Also strike off a point on the 60120 line in the same manner. Connect the two points with a light pencil line. This is the 9960-X-25815 Loran-C LOP.

5. Now, set the dividers between 9960- Z-60118 and 60120. Transfer this

9960-X-25815, 9960-Z-60119.

distance to the Loran Linear Interpolator, with the dividers on the zero-usec line and the 100-50-usec line. This, again, establishes the scale for the 9960 TDZ 2 usec difference lines.

6. Now, set the divider's gap for the distance between the zero-usec baseline and the 25-50-usec line. This corresponds to a TDZ of 1 usec.

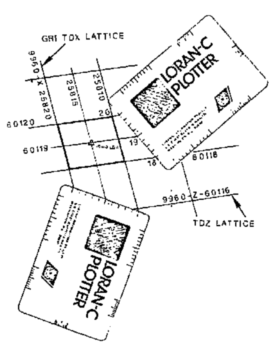
7. Return to the chart (Fig. 9-2), and along the 9960-X-25815 LOP from the 60118 TDZ, strike off the 1 usec. This point is on the 9960-Z-60119 Loran-C LOP. (With this technique there is no need to draw the LOP unless a third LOP is desired. However, this is an unnecessary refinement with Loran-C.)

8. The Loran-C position fix is the intersection of the 9960-X-25815 LOP with the 9960-Z-60119 LOP. Label this point with a triangle, the time, and the designator LOR for Loran-C fix. The Loran-C Plotter can also be used instead of the liner Interpolator. The plotter is simply a card (See Fig. 9-4) with graduations on each edge. These graduations are simply scales of ten equally spaced marks. There are one or two "scales" on each edge.

In use, the card is simply held on the lattice. One of the scales is chosen, depending on the spacing between TD lines, and laid at an angle between them such that the edge scale touches the TD lines at each end. Now, the distance between the TD lines is divided into ten equal spaces by the graduations on the scale. The specific Loran-C LOP, for example 9960-Z-60119, would cross the edge scale at the halfway (or .5) mark. A small dot would be made on the chart at this point. The card would then be slid further to the left or right, and another mark at the 1 usec interval. The two dots would be connected by a light pencil line, and the 60119 LOP would be established.

The process would be repeated between the 9960-X-25810 and 9960-X-25820 TD lines. Now, however, the scale would be in 1 usec interval between the 10 usec spaced TDX lines. The LOP on the 9960-X-25815 TDX would be again "ticked" off of the .5 mark on the edge scale of the plotter. Although these cards, printed on plastic, are available from the Coast Guard, they can easily be made up on card stock and graduated on the edges using rules of different scales.

Although most Loran-C functions are beyond the control of the navigator, there are important decisions to be made by the individual. Selection of the best secondaries is such a decision. In general, the experienced operator will choose the secondary which is close to his position and which has a mostly over water path. This ensures the highest signal reception to maintain tracing in unfavorable conditions such as interfering radio transmissions or locally generated electrical noise. For example, in Fig. 9-1 the navigator



Use of Loran-C Plotter To Locate Loran-C Fix on 9960 TDX 25815, TDZ 60119.

has elected to use secondaries "W" and "Y" which have good crossing angles at his location. Note that secondary "X" is a direct over water path and is nearer to his position. In marginal conditions the receiver would maintain lock-on to "X" under circumstances that could cause loss of lock on "W." In Fig. 9-2 the navigator has chosen "X" and "Z." The "Z" signal comes from Dana, Indiana more than 736 nautical miles inland from his location. It is a tribute to the receiver manufacturer that he will probably get an adequate position fix in spite of choosing "Z." A more experienced navigator would have selected "X" and "Y."

There are circumstances which will force you to select a secondary giving less than optimum signal to noise results. This is when you find a shallow, less than 30 degrees, crossing angle between lines on the strongest secondary or when you are operating near a station base-line extension.

Recommended Loran-C Receiver Characteristics.

Prior to further discussion on the Loran-C system, it is important to point out the features of a minimally adequate Loran-C receiver.

Standard Features. Such a receiver should, at the very least:

- acquire Loran-C signals <u>automatically</u>, without the need for an oscilloscope,

- cycle match on <u>all</u> pulses to provide maximum accuracy,

- automatically track signals once they have been acquired, and

- display two time-difference (TD) readings.

Optional Feature. With the advent of the microchip and the microprocessor, Loran-C receivers on today's market often perform amazing feats of navigation CC depending on the <u>cost</u>. Some units, in addition to providing the minimum features indicated above, also provide course and speed made good; distance off course to port or starboard; direction and distance to a previously entered position; time to go to reach destination at present speed, change-of-course point, and other useful features.

Automatic Coordinate Converters. Many Loran-C receivers now have a built-in Loran-C TD to Latitude/Longitude converter. These converters, in a sense, do exactly what the navigator does with a nautical chart, only automatically. The converter uses measured Loran-C TDs (usually from a receiver packaged together with the converter) and mathematically computes the Latitude/Longitude position with equations similar to those used to compute the locations of the LOPs on charts. You should be aware that each brand of receiver may use slightly different equations and ASF corrections, resulting in a slightly different latitude/longitude position given the same measured Loran-C TDs. On some receivers a "delta" correction can be entered to correct for local variations not taken into account automatically by the receiver.

Radio Direction-Finding.
Radio direction-finding receiver sets on board vessels enable bearings to be taken of transmissions from other vessels, aircraft, and shore stations, marine radiobeacons, and the coastal stations of the radio communication network. Due to the great value of radio bearings, particularly when visibility is poor, the radio direction-finder on board the vessel deserves the same care as is given to other radios, radar and compass. The radio direction-finder (RDF) has some characteristics in common with other important navigational instruments: the readings are subject to certain errors; these errors may be reduced by skillful and intelligent operation; the dangers of using erroneous readings may be greatly reduced by the intelligence and good

judgement of the navigator. In order to acquire experienced judgement in the operation of the instrument, it is essential that the navigator use it as much as practicable, especially in conditions of good visibility, where bearings can also be checked visually.

Trouble from interference and weak signals are greatly reduced by the use of radio direction-finder receivers of proper selectivity. The bearings provided by the receiver are relative bearings and the true bearings are obtained by applying the vessel's heading to the bearings taken. On some boats the receiver is mounted over the compass so as to permit the bearings to be read directly from the compass card. In either case, the bearings must be corrected for RADIO DEVIATION as shown by the calibration curve of the set. (Radio deviation is determined in the same manner as compass deviation, using observations made simultaneously by radio and visual means.)

Types of Radiobeacons. There are two main types of radiobeacons (RBn) used in navigation:

1. Directional radiobeacons which transmit radio waves in beams along fixed bearings, and

2. Circular radiobeacons which send out waves of approximately uniform strength in all directions so that vessels may take radio bearings on them by means of the direction-finder set. This is the most common type of radiobeacon.

Aeronautical Radio Aids. Aeronautical radiobeacons and radio ranges may occasionally be used by navigators of marine craft in the same manner as marine radiobeacons for determining lines of position. They are particularly useful along coasts where marine broadcast coverage is inadequate. Aeronautical aids situated inland become less trustworthy, so far as vessels are concerned, when high land intervenes between them and the coast. They are established to be of primary usefulness to aircraft, and surface craft should use these aids with caution.

Accuracy of Bearings Taken Aboard Vessels. No exact rules can be provided as to the accuracy to be expected in radio bearings taken by a vessel as the accuracy depends to a large extent upon the skill of the operator of the receiver set, the condition of the equipment, and the accuracy of the calibration curve. Navigators are urged to obtain this information by taking frequent radio bearings when their vessel's position is accurately known and by recording the results.

Skill of the Operator. Skill in the operation of the radio direction-finder can be obtained only by practice and by observing the technical instructions for the receiver in question. For these reasons, the operator should carefully study the instructions issued with the equipment and should practice taking bearings frequently.

Operator's Error. Radio direction bearings are taken as the coil or circular antenna is rotated, at the point when the signal is weakest or fades away completely. This point is called the NULL point. The human ear is much more sensitive in detecting a null than the point at which the maximum signal is received. Thus, only the null point should be measured. This will occur when the antenna is perpendicular to the direction of the transmitting station.

Some receivers are equipped with a null meter which can greatly simplify this measurement. As the operator obtains bearings by revolving the direction-finder coil until the signal disappears or becomes a minimum, the operator can tell by the size of the are of silence (the width of the null "point") or of minimum strength approximately how accurately the bearing has been taken. For example, if the minimum is broad and the residual signal covers about 10 strength, it is doubtful if the bearing can be accurately estimated. However, if a sharp minimum, or null, can be obtained, the operator can determine the bearing to within, perhaps, two or three degrees in azimuth. CAUTION: This error is in addition to those due to other causes. A properly operating and correctly adjusted direction-finder should, in no case, produce other than a point or are of absolute silence. There should be no "residual" signal at the point or are of observation. The sharpness and completeness of the arc of silence are the best indications of a properly operating direction-finder receiver, and their absence is the best indication of the presence of "night effect."

Sunrise, Sunset or Night Effect. Bearings obtained from about half an hour before sunset to about half an hour after sunrise may be subject to errors due to night effect. On some nights this effect is more pronounced than on others and the effect is usually greatest during the hours of twilight. Night effect may be detected by a broadening of the arc of minimum signals and by a fluctuation in the strength of the signals. It may also be indicated by difficulty in obtaining a minimum or by a rapidly shifting minimum. It is sometimes accompanied by an actual shift in the direction of the bearings. If it is essential to obtain a bearing when the night effect is pronounced, several bearings should be taken over a short period of time and an average taken of them.

Vessel's Compass. Since RDF bearings are relative bearings, the vessel's compass must be read at the instant that the bearing is taken or an error may be introduced equal to the amount the vessel has yawed in the interval between taking the bearing and reading the compass. Any error in the compass must be applied to the bearing.

Reciprocal Bearings. In some direction-finder receivers, the operator cannot tell from which side of the boat the signals are coming. With these receivers the operator should correct both the bearings for their respective deviations and give both corrected bearings to the person who is plotting the bearings on the chart. If there is a doubt as to the side of the boat from which the bearings are coming, this can be overcome by taking another bearing after running a short distance and noting in which direction the bearing is changing.

Coastal Refraction (Land Effect). In the case of bearings which cut an intervening coastline at an oblique angle or cross high intervening land, errors of from 4 to 5 many observations seem to indicate that such errors are negligible when the observing vessel is well out from the shore. Bearings secured entirely over water areas are to be preferred, since "land effect" is eliminated.

Program Broadcasting Stations. Before taking bearings on a station broadcasting entertainment programs, be aware that its frequency may differ widely from the frequency for which the direction-finding elements of the receiver are calibrated, that the published location of the station may be that of its studio and not that of its transmitting antenna, that if the station is synchronized with other stations it may be impossible to tell on which station the bearing was taken, and that as the majority of these stations are inland, the coastal refraction may be excessive. However, suitable broadcast station antennas are indicated on NOS charts.

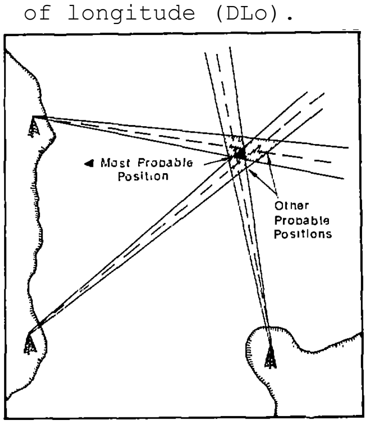
Strength of Signals. The best bearings can be taken on signals that are steady, clear and strong. If the signals are too weak, accurate bearings cannot be taken.

Plotting Radio Bearings.

Radio bearings may be used in the same manner as other lines of position to obtain a fix if you remember that radio bearings are subject to possible errors. Some of the uses of radio bearings in obtaining a fix are: cross bearings taken on two or more stations, a single bearing crossed with a line of position obtained from another means, a bearing and a sounding, and two bearings on the same station and the distance run between bearings.

Transmitters and Receivers. Bearings reported by a direction-finder station ashore must be plotted from the geographic position of the receiving antenna of the station. Bearings taken by a vessel on a shore station must be plotted from the geographic position of the station's transmitting antenna. CAUTION: These two positions are seldom the same for all stations.

Track of Radio Waves. The track of a radio wave is on a great circle. The radio bearing is the angle between the meridian of the vessel or station taking the bearing and the great circle, not the rhumb line. Radio bearings cannot always be plotted on a Mercator chart without first being corrected. The amount of correction depends on the latitude and the difference of longitude (DLo).



PLOTTING INTERSECTING RADIO BEARINGS.

A bearing from a transmitter several hundred miles away in low latitudes (near the equator) or in a nearly north-south direction from the receiver may require a smaller correction than if the distance is a few miles in an east-west direction in high latitudes. The best way to be sure is to determine the magnitude of the correction using the correction table. This is a very easy process, which will be indicated shortly.

Vessel's Probable Position. As radio bearings are not absolutely accurate, it is suggested that lines be drawn on both sides of each radio bearing at an angular distance from the bearing equal to the estimated probable error. In the case of intersecting radio bearings, the vessel's most probable position is the area enclosed by these outer lines. This is demonstrated by example. Radio bearings are plotted like other bearings, from the object observed (i.e. the transmitter, or receiving antenna).
In Fig. 9-5, the broken lines represent radio bearings obtained by a vessel on three radio stations. The solid lines are drawn at angles of ± 2 bearings (it is assumed that all the bearings are accurate within 2 black area in the illustration lies within the 2 consequently the most probable position of the vessel, assuming that none of the bearings are more than 2

Note: It is sometimes advantageous to plot radio bearings on plotting sheets, to avoid marking the chart excessively. In this case, the coordinates of the position so determined can then be transferred to the chart being used to keep the plot. The radio bearing fix is designated with a triangle, the time and if the fix was determined using a radio beacon, the designator "RDF."
If, in the example above, there is a

possibility that one of the bearings may be out more than 2 with parallel lines give other probable positions. If it is known which of the bearings is probably the least accurate, the outer lines should be offset from this bearing the same number of degrees as the estimated error and the area or areas partially enclosed by these lines should be given less weight than the other areas.

Running Fixes. If it is necessary to obtain the vessel's position by two radio bearings and the distance run between the bearings, it is desirable to solve the problem by graphic means rather than by some mathematical rule such as doubling the angle on the bow, as in the graphic method, allowance can be made for possible inaccuracies in the bearings.

Radio Bearing Conversion. Table 9-3 is used to convert radio or great circle bearings into Mercator bearings when bearings on a Mercator chart. (The conversion is unnecessary when plotting the bearings on a Lambert, or polyconic chart.) It should be used when the distance between the ship and the station is over 50 miles. The arguments used to find the correction are the middle latitude and the difference of longitude between the position of the radio station transmitting antenna and the DR position of the vessel. An example is provided for the use of the table.

1. Assume the vessel is at a DR position of Lat. 56 43' W. A bearing is taken on the Station Lat. 58 38'3 W. The bearing observed is 057 bearing that would be plotted on a Mercator chart) is to be determined.

   Mil-latitude = 57 (to the nearest whole degree)
   DLo = 6 (to nearest half degree)

2. With Mid-Lat. 57 the conversion table and extract the correction 2.5 degree). The receiver (vessel) is in North latitude, the transmitter is eastward. Following the rule given at the bottom of the table, the correction is to be added:

   Great circle (radio bearing) bearing 57.6
   Correction 03
   Mercator bearing 60.0
   Plot this bearing from the transmitting antenna using the plotter and its protractor or compass rose.

RADAR - Introduction

Although many of the features of radar

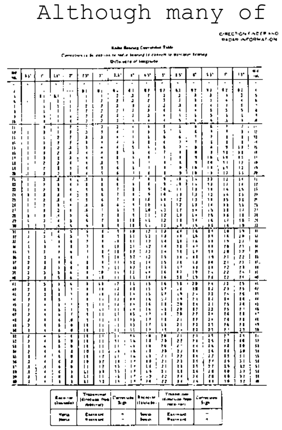


Table 9-3 Radio Bearing Conversion Table.

RADIO BEARING CONVERSION TABLE

systems are not available on all types of small craft radar sets, they are discussed here in order to develop a firm foundation in radar technique and interpretation. Thus, even though the radar installation owned by a particular Auxiliarist or pleasure boater may not have all of the features treated in this chapter, they will be at least known, and for those which are available, some understanding will be gained.

Radar is a pulse modulated, Super High Frequency (SHF), 3-10 GHz, radio ranging system which is used for navigation aboard vessels and aircraft. The word stems from RAdio Detection AndRnging.

In radar, energy is emitted from a directional antenna in the form of SHF radio waves in very sharp pulses, directed outward in a well-defined beam. When this energy contacts an object (termed a TARGET in radar language) some of the energy is reflected (an ECHO) back to the antenna, where it is received, and then processed by a special receiver-display system. The distance from the transmitter/receiver antenna to the target is determined by measurement of the time between transmission of the pulse and reception of the echo. This time interval is converted to a distance measurement and displayed on a Cathode Ray Tube (CRT) screen display termed a PLAN POSITION INDICATOR (PPI). Direction, or bearing of the target is determined by the direction of the antenna which may be rotated (SCANNED) rapidly, in full circles, arcs, or slowly, manually. Information is displayed on the PPI in such a manner that direction and distance can be indicated as well as a reasonable (within limits) representation of various features of the target, including size and shape.

The makeup of the target determines the strength of the echo and its representation on the PPI. Electrical conductors, such as metal objects, reflect the radio energy very well, and give strong, clear indications on the PPI.

Non-conductors, such as dry wood, or relatively poor conductors, such as fiber glass boat hulls, moist soil, rocks, sand, trees, and other vegetation, return the radiation poorly and provide weak, blurred representations on the PPI. Other objects reflect or scatter the radio energy in various ways and produce characteristic representations on the PPI, as well. Such objects are precipitation (rain, snow, sleet), and rough seas, where wave tops return echoes. Adjustment of the receiver, transmitter and display apparatus can improve the information available to the navigator.

Although radar has come a long way since its primitive beginnings prior to World War II, and has become a very sophisticated system capable of providing a tremendous amount of critical information, it still is a system that requires considerable interpretation, skill in which can only be gained by familiarization with the equipment and frequent practice under good and bad conditions. Wise use of the system includes the ability to recognized its limitations and idiosyncrasies. This requires some (but not extensive) understanding of the basics of the system, the mechanisms involved, certain interactions between the radio radiation, the atmosphere and the targets, and techniques of manipulating the display to enhance desirable information and suppress or reject unwanted interference.

This section will address these subjects in sufficient detail to provide a working understanding of the subject, but no more. And, a working knowledge is necessary to safely operate and interpret radar. The reader is urged to consult more detailed publications, such as DMAHTC publication 1310, Radar Navigation Manual, form which much of the material in this section is drawn, to gain greater understanding of radar and its many uses. Publication 1310 is an excellent reference, well written and illustrated, for a general audience, and conveys the elements of basic radar theory, radar systems, radar aids to navigation, plotting and standard radar collision avoidance techniques.

Radar Fundamentals.
The radio frequency energy transmitted by the radar system consists of a series of equally spaced pulses, usually of two microsecond (2 usec) or less, separated by relatively longer periods in which no energy is emitted. The cycle of pulses is repeated after sufficient time has elapsed for the previous signal to go out and return (through the same antenna) in marine radars as an echo from a target. This radio energy travels at the speed of light, 161,829 nautical miles per second (or 300,000,000 meters per second).

The basic components of the radar system and their functions are:

- **Power Supply.** Provides AC and DC voltages. This is a source of HIGH VOLTAGE HAZARD and should be treated with due respect.

- **Modulator.** Produces the synchronizing signals which, regulate the transmitter to produce the required number of pulses per second, and also triggers the indicator sweep.

- **Transmitter.** Generates the SHF radio energy as very short, powerful pulses.

- **Antenna System.** Radiates the energy in a highly directional, well-defined beam, receives returning echoes, and passes the energy back into the receiver.

- **Reciever.** Aplifies the echoes and processes them into video pulses for the indicator.

- **Indicator.** A display system which provides a visual indication of the desired information.

Some Important Radar System Constants.
There are several system constants which must be discussed in order to explain system limitations, later. These constants are:

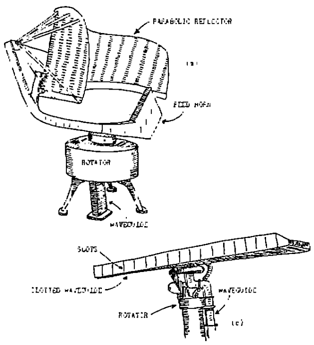
Carrier Frequency. The frequency at which the radio energy is generated. Marine radars operate on the SHF band, between 3,000 and 10,000 MHz (3-10 GHz). The frequency is chosen to provide maximum directibility of the beam and optimum resolution of the target.

Pulse Repetition Rate (PRR). The number of pulses per second. This rate must be such that the pulses can travel to the target and return without interferring with the next train of pulses, and also be sufficient to accommodate for rotation of the antenna to provide scanning over 360 measurable range for the system is dependent of the PRR and can be determined by dividing 80,915 radar nautical miles per second, by the PRR. Remember, the speed of light is 161,829 nautical miles per second, but for radar, the pulse goes out and comes back, going a total of 161,829 nautical miles in one second, but reaching out only <u>one-half</u> the distance for a target. Thus, the term 80,915 radar miles per second.

An antenna rotating at 10 revolutions per minute (once each six seconds) (RPM), transmitting a signal with a PRR of 800 pulses per second will produce 13 pulses for each degree of rotation. The PERSISTENCE of the CRT (i.e. the time its phosphors retain the image of the echoes) and the antenna rotational speed determine the lowest usable PRR.

Pulse Length. The transmission time of a single pulse of SHF energy. The pulse length determines the MINIMUM RANGE at which a target can be detected. If the target is too close to the transmitter, the echo could be returned to the receiver before the transmission of the pulse is completed, and be masked by the transmitted pulse. For a pulse length of 1 usec, the minimum range will be 0.81 M, or about 1645 yards, or half the distance the pulse would travel in 1 usec.

(The pulse would go to the target and return in one usec. The minimum range would be one half the distance the pulse traveled during that time.)
If close-in ranging is desired, the pulse length must be short, on the order of 0.1 usec. Longer pulses are appropriate for greater distance, when more energy can be transmitted in the pulse, enhancing the returned signal.



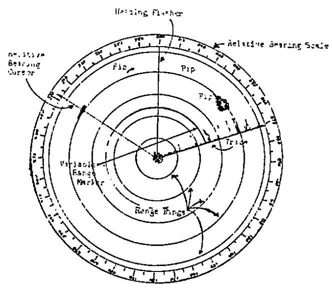
Two Marine Radar Antenna Systems: a) Parabolic Reflector b) Slotted Waveguide.

Transmitting and Receiving Antenna System. The function of the radar antenna system is to radiate the SHF energy in a narrow, highly directional beam, then receive the returning echoes, and then pass them to the receiver. The the antenna via a hollow waveguide tube, usually of rectangular cross-section, the dimensions of which are dependent upon the carrier frequency.

There is a considerable flux of energy traveling within this tube. Energy leaks should be repaired promptly, by qualified personnel. Care should be taken to avoid damage to the waveguide, or the efficiency of its ability to conduct the radio energy to and from the antenna will be greatly degraded.
The actual radar antenna may take several forms. Two of the most common forms of antennas used in marine radar are the PARABOLIC REFLECTOR and the SLOTTED WAVEGUIDE antenna, both of which may be enclosed in a RADOME.
The parabolic reflector antenna has a curved reflector (in the form of a parabola) which focuses the radio energy fed to it by the FEEDHORN (at the end of the waveguide) into a tight, directional beam. Returning echoes are focused by the reflector back into the feedhorn, and then to the waveguide.
The slotted waveguide antenna is a compact antenna which resembles a flat, rectangular bar. Under its plastic cover is a section of waveguide with slots in one of the long sides. The radio energy exits these slots in a beam. The returning echoes reenter the antenna through the same slots which have been arranged to enhance constructive interference of the pulses to obtain some measure of gain. This type of antenna is often enclosed in a disc-shaped radome.

Both types of antennas are usually mounted on a rotator to allow the antenna to scan in a full circle arc. Fig. 9-6 illustrates the two types of marine antenna.

The indicator provides a visual display of the ranges and bearings of the targets from which the echoes are returned. The display uses a CRT mounted so that the information is displayed as polar diagram, with the vessel in the center of the plot and a luminous line sweeping outward from the center termed a TRACE, which is rotated (SCANNED) in a clockwise direction through 360 called a Plan Position Indicator (PPI). The targets appear as bright spots (called PIPS) or broad lines, as the trace sweeps outward (so fast that it appears as a



THE PLAN POSITION INDICATOR \ (PPR) RADAR DISPLAY

continuous line, except where the target spot appears brighter) and scans around the screen.

Range scales (called RANGE RINGS or RANGE MARKERS) are provided in the form of pre-marked concentric circles,and /or by means of a movable VARIABLE RANGE MARKER (VRM) which appears as a small bright spot on the trace, but can be moved in and out by means of a calibrated dial, which indicates the range to the marker. The VRM also may create a ring as it sweeps around with the trace.

An electronic or mechanical BEARING CURSOR may be provided to align with a target to determine its <u>relative</u> bearing. The electronic cursor appears as a solid, dashed or dotted line on the screen emanating from the center, outward. The bearing would be read from the scale provided. The mechanical bearing cursor would be a rule or line etched on a screen cover which would be rotated. The bearing is then read off the scale located in the ring around the screen. Thus, range may be measured to the pips by means of fixed range rings or by VRM, and bearing may be determined by means of the bearing cursor. The PPI is illustrated in Fig. 9-7.

A HEADING FLASHER may also be provided to indicate the vessel's heading on the screen. This is usually a bright flash line from the center of the PPI to the top of the screen.

Radar Wave Propagation. A little understanding of the propagation of radar SHF energy is necessary in order to be able to interpret the information displayed on the PPI and to make adjustments in the set to enhance desired information and suppress interference.

The radar SHF energy travels outward, from the transmitter antenna in a tight beam, in wave form. The basic parameters of this wave form are:

- **Wave Length (L).** The distance along the direction of propagation between successive crests or troughts of the wave form.

- **Cycle.** One complete oscillation or one complete wave form.

- **Frequency (F).** The number of cycles completed in one second. One cycle per second is termed on Hertz, (Hz), one thousand cycles per second, a kilohertz (kHz), one million cycles per second, a megahertz (MHz), one trillion cycles per second, a gigahertz (GHz).

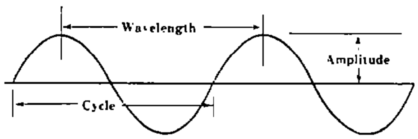
- **Amplituted.** The maximum displacement of the wave from its mean or zero value.

These parameter are shown in Fig. 9-8. SHF energy propagates at the speed of light, the relationship between wavelength (L) to frequency (f), can be stated:

$$f = \frac{300,000\ m/s}{L}$$

f in Hz, L in meters. m

Refraction of Radar Waves. Like light rays, rader waves are subject to bending



The Radar Wave Form and Parameters, Wave Length (L), Amplitude, Cycle.

or REFRACTION as they propagate through regions of varying air density existing in the atmosphere. Also, like light rays, radar waves are refracted slightly downward, following the curvature of the earth.

Normal Refraction. Under normal atmospheric conditions the radar can detect targets farther away than the eye, at the same height, even with optical assistance (telescope or binocular). Just as the eye has an optical horizon (the distance seen from the eye of the observer to the horizon), which is greater than the geometrical horizon (the distance to the tangent to the earth's surface), because of light refraction, the radar has its RADAR HORIZON, which is even greater than the optical horizon. It is important to be able to determine the various horizons. If the height of the eye of the observer or the height of the active part of the radar antenna is h, in feet, then the distance to the respective horizon, d, in nautical miles would be:

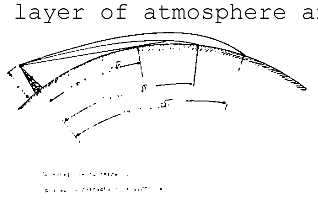
geometric horizon (no refraction) d = 1.06
optical horizon (light refraction) d = 1.15
radar horizon (radio refraction) d = 1.22

These various horizons are illustrated in Fig. 9-9.

Super-Refraction. When the weather is calm and stable, and there is an upper layer of warm, dry air over a colder, denser, surface layer of moist air, SUPER-REFRACTION may occur. In super-refraction, the radar waves bend more downward, and thus, increase the range in which targets may be detected. This condition often occurs in the tropics when a warm, dry, land breeze blows over cooler ocean water, especially over cooler ocean currents and areas of cold water upwelling.

Sub-Refraction. If the upper layers of air are more dense than lower ones, such as when a layer of cooler, moist air exists over a lower layer of warm, dry air, SUB-REFRACTION may occur. The opposite of super-refraction, in sub-refraction, the radar waves bend upward, away from the earth, shortening the effective range at which targets can be detected. This condition also affects minimum ranges, lifting the radar beam above low lying targets at short ranges. Sub-refraction may occur in polar regions when cold, dry air masses move over the warmer water or warmer ocean currents.

Ducting. Radar operators with experience over the world are usually aware that, at certain times, they are able to detect targets at extremely long ranges, while at other times they are unable to detect targets clearly within visual range. Such occurrences are caused by ducting, when, during extreme cases of super-refraction, the radio energy is trapped within a shallow layer of atmosphere and refracted and reflected upward, downward, upward,



Geometric, Optical, and RADAR Horizons.

etc., continuously.

This may occur when the energy is radiated at angles of 1 targets have been detected at ranges in excess of 1400 nautical miles with common marine radar equipment. (The extreme range targets appear on the PPI as pips at much closer ranges as their echoes mingle with those of more appropriate range targets.) In instances of extremely low-level ducts - when the antenna is above the duct, surface targets lying below the duct may not be detected, as the radio energy passes over them. (This is rare!)
Ducting is common in the summer along the northern part of the Atlantic coast of the United States. In the Florida region, the seasonal trend is reversed, with ducting a maximum in the winter.

Factors Affecting Detection, Display and Measurement of Radar Targets.
Many of the characteristics and phenomena discussed above affect the detection and presentation of targets on the radar set. It is very important that radar operators understand these factors and be able to recognize them when they occur. This recognition must be positive, and timely. It can only be developed and maintained through frequent use of the radar, not only in conditions of restricted visibility, but also during clear weather, when radar images can be compared with visual ones. The factors affecting maximum and minimum range, range accuracy, range resolution, bearing accuracy and resolution, as well as the effects of weather, and target characteristics will be discussed.

Factors Affecting Maximum Range. Maximum range is affected by: Frequency, Peak Power, Pulse Length, Pulse Repetition Rate, Beam Width, Target Characteristics, Receiver Sensitivity, and Antenna Rotation Rate.

- Frequency. The higher the frequency of the radar the greater is the attenuation (loss in power), regardless of weather. Lower radar frequencies (longer wavelengths) therefore, have been ranges.

- Peak Power. The peak power of a radar is its useful power. Range capabilities of the radar increase with peak power. Doubling the peak power increases the range capabilities by about 25 percent.

- Pulse Length. The longer the pulse length, the greater is the range capability of the radar because of the greater amount of energy transmitted per pulse.

- Pulse Repetition Rate. The pulse repetition rate (PRR) determines the maximum measurable range of the radar. Ample time must be allowed between pulses for an echo to return from any target located within the maximum workable range of the system. Otherwise, echoes returning from the more distant targets are blocked by succeeding transmitted pulses. This necessary time interval determines the highest PRR that can be used. The PRR must be high enough, however, that sufficient pulses hit the target and enough echoes are returned to the radar. The maximum measurable range can be determined approximately by dividing 81,000 by the PRR.

- Beam Width. The more concentrated the beam, the greater is the detection range of the radar.

- Target Characteristics. Targets that are larger can be seen on the scope at greater ranges, provided line-of-sight exists between the radar antenna and the target. Conducting materials (a ship's steel hull, for example) return relatively strong echoes while nonconducting materials (a wood hull of a fishing boat or a fiber glass hull, for example) return much weaker echoes.

- Receiver Sensitivity. The more sensitive receivers provide greater detection ranges but are more subject to jamming.

- Antenna Rotation Rate. The more slowly the antenna rotates, the greater is the detection range of the radar.

Factors Affecting Minimum Range. Minimum range is affected by Pulse Length, Sea Return, and Side-Lobe Echo.

- Pulse Length. The minimum range capability of a radar is determined primarily by the pulse length. It is equal to half the pulse length of the radar (164 yards per microsecond of pulse length). Electronic considerations such as the recovery time of the receiver and the duplexer (TR and anti-TR tubes assembly) extend the minimum range at which a target can be detected beyond the range determined by the pulse length.

- Sea Return. Sea return or echoes from waves may clutter the indicator within and beyond the minimum range established by the pulse length and recovery time.

- Side-Lobe Echoes. Targets detected by the side-lobes of the antenna beam pattern are called side-lobe echoes (the beam radiated from the antenna consists of the main lobe, which is the useful part of the beam, and slide lobes - a result of antenna imperfection - (which can be a nuisance). When operating near land or large targets, side-lobe echoes may clutter the indicator and prevent detection of close targets, without regard to the direction in which the antenna is trained.

Factors Affecting Range Accuracy. There are many factors which affect range accuracy. Some factors concern equipment condition and can be minimized by adequate maintenance and care, while others are characteristic of the particular equipment and the expertise of the operator. Among the factors affecting range accuracy of radar systems are: Fixed Error, Line Voltage, Frequency Drift, Calibration, Pip and VRM alignment, Range Scale, PPI Curvature and Radarscope Interpretation. Some will be discussed below:

- Calibration. The range to a target can be measured most accurately on the PPI when the leading edge of its pip just touches a fixed range ring. The accuracy of this measurement is dependent upon the maximum range of the scale in use. Representative maximum error in the calibration of the fixed range rings is 75 yards or 1-1/2 percent of the maximum range of the range scale in use, whichever is greater. With the indicator set on the 6-mile range scale, the error in the range of a pip just touching a range ring may be about 180 yards or about 0.1 nautical mile because of calibration error alone when the range calibration is within acceptable limits.
On some PPI's range can only be estimated by reference to the fixed range rings.

Many radar indicators usually have a variable range marker (VRM) or adjustable range ring which is the normal means for range measurements. With the VRM calibrated with respect to the fixed range rings within a tolerance of 1 percent of the maximum range of the scale in use, ranges as measured by the VRM may be in error by as much as 2-1/2 percent of the maximum range of the scale in use. With the indicator set on the 8-mile range scale, the error in a range as measured by the VRM may be in error by as much as 0.2 nautical miles.

- Pip and VRM Alignment. The accuracy of measuring ranges with the VRM is dependent upon the ability of the radar observer to align the VRM with the leading edge of the pip on the PPI. On the longer range scales it is more difficult to align the VRM with the pip because small changes in the reading of the VRM range counter do not result in appreciable changes in the position of the VRM on the PPI.

- Range Scale. The higher range scale settings result in reduced accuracy of fixed range ring and VRM measurements because of greater calibration errors and the greater difficulty of pip and VRM alignment associated with the higher settings.

- **PPI Curvature.** Because of the curvature of the PPI, particularly in the area near its periphery, range measurements of pips near the edge are of lesser accuracy than the measurement nearer the center of the PPI.

- **Radarscope Interpretation.** Relatively large range errors can result from incorrect interpretation of a landmass image on the PPI. The difficulty of radarscope interpretation can be reduced through more extensive use of height contours on charts.

- For reliable interpretation it is essential that the radar operating controls be adjusted properly. If the receiver gain is too low, features at or near the shoreline, which would reflect echoes at a higher gain setting, will not appear as part of the landmass image. If the receiver gain is too high, the landmass image on the PPI will "bloom." With blooming the shoreline will appear closer than it actually is.

- A fine focus adjustment is necessary to obtain a sharp landmass image on the PPI.

- Because of the various factors introducing errors in radar range measurements, one should not expect the accuracy of navigational radar to be better than + or - 50 yards under the best conditions.

Factors Affecting Range Resolution. Range rsolution is a measure of the capability of a radar to display as separate pips the echoes received from two targets which are on the same bearing and are close together. The principal factors that affect the range resolution of a radar are the length of the transmitted pulse, receiver gain, CRT spot size, and the range scale. A high degree of range resolution requires a short pulse, low receiver gain, and a short range scale.

- **Pulse Length.** Two targets on the same bearing, close together, cannot be seen as two distinct pips on the PPI unless they are separated by a distance greater than one-half the pulse length (164 yards per microsecond of pulse length). If a radar has a pulse length of 1-microsecond duration, the targets would have to be separated by more than 164 yards before they would appear as two pips on the PPI.

- **Receiver Gain.** Range resolution can be improved by proper adjustment of the receiver gain control. The echoes from two targets on the same bearing may appear as a single pip on the PPI if the receiver gain setting is too high. With reduction in the receiver gain setting, the echoes may appear as separate pips on the PPI.

- **CRT Spot Size.** The range separation required for resolution is increased because the spot formed by the electron beam on the screen of the CRT cannot be focused into a point of light. The increase in echo image (pip) length and width varies with the size of the CRT and the range scale in use. This is illustrated below:

CRT Diameter (inches		Range Scale (nautical mi)	Spot Length or Width (yards)
Nominal	Effective		
9	7.5	0.5	5
		24	250
12	10.5	0.5	4
		24	185
16	14.4	0.5	3
		24	134

On the longer range scales, the increase in echo size because of spot size is appreciable.

- Range Scale. The pips of two targets separated by a few hundred yards may merge on the PPI when one of the longer range scale is used. The use of the shortest range scale possible and proper adjustment of the receiver gain may enable their detection as separate targets. If the display can be off-centered, this may permit display of the targets on a shorter range scale than would be possible otherwise.

Factors Affecting Bearing Accuracy. Bearing accuracy, how close the radar measures the actual bearing, is affected by: Horizontal Beam Width, Target Size, Target Rate of Movement, Sweep Centering Error, Paralax Error, and Heading Flash Alignment.

- Horizontal Beam Width. Bearing measurements can be made more accurately with the narrower horizontal beam widths. The narrower beam widths afford better definition of the target and, thus, more accurate identification of the center of the target. Several targets close together may return echoes which produce pips on the PPI which merge, thus preventing accurate determination of the bearing of a single target within the group. The effective beam width can be reduced through lowering the receiver gain setting. In reducing the sensitivity of the receiver, the maximum detection range is reduced, but the narrower effective beam width provides better bearing accuracy.

- Target Size. For a specific beam width, bearing measurements of small targets are more accurate than large targets because the centers of the smaller pips of the small targets can be identified more accurately.

- Target Rate of Movement. The bearings of stationary or slowly moving targets can be measured more accurately than the bearings of faster moving targets.

- Sweep Centering Error. If the origin of the sweep is not accurately centered on the PPI, bearing measurements will be in error. Greater bearing errors are incurred when the pip is near the center of the PPI than when the pip is near the edge of the PPI. Since there is normally some centering error, more accurate bearing measurements can be made by changing the range scale to shift the pip positon away from the center of the PPI.

- Parallax Error. Improper use of the mechanical bearing cursor will introduce bearing errors. On setting the cursor to bisect the pip, the cursor should be viewed from a position directly in front of it. Electronic bearing cursors used with some stabilized displays provide more accurate bearing measurements than mechanical bearing cursors because measurements made with the electronic cursor are not affected by parallax or centering errors.

- Heading Flash Alignment. For accurate bearing measurements, the alignment of the heading flash with the PPI display must be such that radar bearings are in close agreement with relatively accurate visual bearings observed from near the radar antenna.

Factors Affecting Bearing Resolution. Bearing resolution is a measure of the capability of a radar to display as separate pips the echoes received from two targets which are at the same range and are close together.
The principal factors that affect the bearing resolution of a radar are horizontal beam width, the range to the targets, and CRT spot size.
- As the radar beam is rotated, the painting of a pip on the PPI begins as soon as the leading edge of the radar beam stikes the target. The painting of the pip is continued until the trailing edge of the beam is rotated beyond the target. Therefore, the pip is distorted angularly by an amount equal to the effective horizontal beam width. The bearing must be read at the center of the pip.

- Since the pip of a single target as painted on the PPI is elongated angularly an amount equal to beam width, two targets at the same range must be separated by more than one beam width to appear as separate pips on the PPI. Inasmuch as bearing resolution is determined primarily by horizontal beam width, a radar with a narrow horizontal beam width provides better bearing resolution than one with a wide beam.

- CRT Spot Size. The bearing separation required for resolution is increased because the spot formed by the electron beam on the screen of the CRT cannot be focused into a point of light. The increase in the pip width because of CRT spot size varies with the size of the CRT and the range scale in use.

Weather Effects. The usual effects of weather are to reduce the ranges at which targets can be detected and to produce unwanted echoes on the radar scope which may obscure the returns from important targets or from targets which may be dangerous to one's vessel.

- Wind. The wind produces waves which reflect unwanted echoes which appear on the PPI as sea return. Sea return is normally greater in the direction from which the wind and seas are coming. Sea return effects may be reduced by the proper use of the gain, STC and anticlutter controls; however care must be taken not to lose any valid targets in the process (STC, sensitivity time control, suppresses echoes on PPI).

- Precipitation. Rain, hail, and snow storms all may return echoes which appear on the PPI as a blurred or cluttered area. The FTC switch is used to minimize precipitation returns so as to reveal any targets which may be hidden in the clutter. (FTC, fast time constant, shortens echoes on PPI). In addition to masking targets which are within the storm area, heavy precipitation may absorb some of the strength of the pulse and decrease maximum detection range.

Target Characteristics. There are several target characteristics which will enable one target to be detected at a greater range than another, or for one target to produce a stronger echo than another target of similar size.

- Height. Since radar wave propagation is almost line of sight, the height of the target is of prime importance. If the target does not rise above the radar horizon, the radar beam cannot be reflected from the target. Because of the interference pattern, the target must be somewhat above the radar horizon.

- Size. Up to certain limits, targets having larger reflecting areas will return stronger echoes than targets having smaller reflecting areas. Should a target be wider than the horizontal beam width, the strength of the echoes will not be increased on account of the greater width of the target because the area not exposed to the radar beam at any instant cannot, of course, reflect an echo.

Since the vertical dimensions of most targets are small compared to the vertical beam width of marine navigational radars, the beam width limitation is not normally applicable to the vertical dimensions. However, there is a vertical dimension limitation in the case of sloping surface or stepped surfaces. In this case, only the projected vertical area lying with the distance equivalent of the pulse length can return echoes at any instant.

- Aspect. The aspect of a target is its orientation to the axis of the radar beam. With change in aspect, the effective reflecting area may change, depending upon the shape of the target. The nearer the angle between the reflecting area and the beam axis is to 90 the strength of the echo returned to the antenna.

- Shape. Targets of identical shape may give echoes of varying strength, depending on aspect. Thus a flat surface at right angles to the radar beam, such as the side of a steel ship or a steep cliff along the shore, will reflect very strong echoes. As the aspect changes, this flat surface will tend to reflect more of the energy of the beam away from the antenna, and may give rather weak echoes. A concave surface will tend to focus the radar beam back to the antenna while a convex surface will tend to scatter the energy. A smooth conical surface will not reflect energy back to the antenna. However, echoes may be reflected to the antenna if the conical surface is rough.

- Texture. The texture of the target may modify the effects of shape and aspect. A smooth texture tends to increase the reflection qualities, and will increase the strength of the reflection, but unless the aspect and shape of the target are such that the reflection is focused directly back to the antenna, the smooth surface will give a poor radar echo because most of the energy is reflected in another direction. On the other hand, a rough surface will tend to break up the reflection, and will improve the strength of echoes returned from those targets whose shape and aspect normally give weak echoes.

- Composition. The ability of various substances to reflect radar pulses depends on the intrinsic electrical properties of those substances. Thus metal and water are good reflectors. Ice is a fair reflector, depending on aspect. Land areas vary in their reflection qualities depending on the amount and type of vegetation and the rock and mineral content. Wood and fiber glass boats are poor reflectors. All of the characteristics interact with each other to determine the strength of the radar echo, and no factor can be singled out without considering the effects of the others.

Radar Operating Controls.
Although each radar unit has controls specific to its manufacturer and model, the majority of the controls are common to all sets with a few minor modifications and are discussed below. However you should consult your set's manufacturers guide for details.

Power Controls. The basic power controls common to nearly all radar sets are the Indicator Power Switch, the Antenna (Scanner) Power Switch, and various Special Switches.

- Indicator Power Switch. This switch on the indicator has OFF, STANDBY, and OPERATE (ON) positions. If the switch is turned directly from the OFF to OPERATE positions, there is a warmup period of about three minutes before the radar set is in full operation. During the warmup period the cathodes of the tubes are heated, this heating being necessary prior to applying high voltages. If the switch is in the STANDBY position for a period longer than that required for warmup, the radar set is placed in full operation immediately upon turning the switch to the OPERATE position. Keeping the radar set in STANDBY when not in use tends to lessen maintenance problems. Frequent switching from OFF to OPERATE tends to cause tube failures.

- Antenna (Scanner) Power Switch. For reasons of safety, a radar set should have a separate switch for starting and stopping the rotation of the antenna. Separate switching permits antenna rotation for deicing purposes when the radar set is either off or in standby operation. Separate switching permits work on the antenna platform when power is applied to other components without danger attendant to a rotating antenna.

- Special Switches. Even when the radar set is off, provision may be made for applying power to heaters designed for keeping the set dry. In such case, a special switch is provided for turning this power on and off. NOTE: Prior to placing the indicator power switch in the OPERATE position, the brilliance control, the receiver gain control, the sensitivity time control, and the fast time constant switch should be placed at their minimum or off positions. The setting of the brilliance control avoids excessive brilliance harmful to the CRT on applying power. The other settings are required prior to making initial adjustments of the performance controls.

Performance Controls - Initial Adjustments. Prior to operating the radar set initial adjustments are made using the Brilliance Control, the Receiver Gain Control, and the Tuning Control.

- Brilliance Control. Also called INTENSITY, BRIGHTNESS. The brilliance control, which determines the overall brightness of the PPI display, is first adjusted to make the trace of the rotating sweep visible but not too bright. Then it is adjusted so that the trace just fades. This adjustment should be made with the receiver gain control at its minimum setting because it is difficult to judge the right degree of brilliance when there is a speckled background on the PPI. With too little brilliance, the PPI display is difficult to see; with excessive brilliance the display is defocused.

- Receiver Gain Control. The receiver gain control is adjusted until a speckled background just appears on the PPI. With too little gain, weak echoes may not be detected; with excessive gain, strong echoes may not be detected because of the poor contrast between echoes and the background of the PPI display. In adjusting the receiver gain control to obtain the speckled background, the indicator should be set on one of the longer range scales because the speckled background is more apparent on these scales. On shifting to a different range scale, the brightness may change. Generally, the required readjustment may be effected through use of the receiver gain control alone, although the brightness of the PPI display is dependent upon the setting of the receiver gain and brilliance controls. In some radar indicator designs, the brilliance control is preset at the factory. Even so, the brilliance control may have to be readjusted at times during the life of the cathode-ray tube. Also the preset brilliance control may have to be readjusted because of large changes in ambient light levels.

- Tuning Control. Without ship or land targets, a performance monitor, or a tuning indicator, the receiver may be tuned by adjusting the manual tuning control for maximum sea clutter. An alternative to the use of normal sea clutter which is usually present out to a few hundred yards even when the sea is calm, is the use of echoes from the ship's wake during a turn. When sea clutter is used for manual tuning adjustment, all anti-clutter controls should be either off or placed at their minimum settings. Also, one of the shorter range scales should be used.

Performance Controls. Adjustments According to Operating Conditions - In order to optimize the presentation of information during radar set operation, adjustments are made according to the operating conditions being experienced at the time. Among the controls adjusted according to operating conditions are: Receiver Gain Control, Fast Time Constant (FTC) Switch, Rain Clutter Control, Sensitivity Time Control (STC), Heading Flash, Electronic Bearing Cursor, Fixed Range Markers, Variable Range Marker (VRM), and Panel Lighting.

- Receiver Gain Control. This control is adjusted in accordance with the range scale being used. Particular caution must be exercised so that while varying its adjustment for better detection of more distant targets, the area near the center of the PPI is not subjected to excessive brightness within which close targets may not be detected. When detection at the maximum possible range is the primary objective, the receiver gain control should be adjusted so that a speckled background is just visible on the PPI. However, a temporary reduction of the gain setting may prove useful for detecting strong echoes from among weaker ones.

- **Fast Time Constant (FTC) Switch**. Also called DIFFERENTIATOR. With the FTC switch in the ON position, the FTC circuit, through shortening the echoes on the display, reduces clutter on the PPI which might be caused by rain, snow or hail. When used, this circuit has an effect over the entire PPI and generally tends to reduce receiver sensitivity and, thus, the strengths of the echoes as seen on the display.

- **Rain Clutter Control.** The rain clutter control provides a variable fast time constant. Thus, it provides greater flexibility in the use of FTC according to the operating conditions. Whether the FTC is fixed or variable, it provides the means for breaking up clutter which otherwise could obscure the echo of a target of interest. When navigating in confined waters, the FTC feature provides better definition of the PPI display through better range resolution. Also, the use of FTC provides lower minimum range capability.

- **Sensitivity Time Control (STC).** Also called SEA CLUTTER CONTROL, ANTI-CLUTTER CONTROL, SWEEP GAIN, SUPPRESSOR. Normally, the STC should be placed at the minimum setting in calm seas. This control is used with a circuit which is designed to suppress sea clutter out to a limited distance from the ship. Its purpose is to enable the detection of close targets which otherwise might be obscured by sea clutter. This control must be used judiciously in conjunction with the receiver gain control. Generally, one should not attempt to eliminate all sea clutter with this control. Otherwise, echoes from small close targets may be suppressed also.

- **Heading Flash.** The brightness of the heading flash is adjusted by control, labeled FLASHER INTENSITY CONTROL. The brightness should be kept at a low level to avoid masking a small pip on the PPI. The heading flash should be turned off periodically for the same reason.

- **Electronic Bearing.** The brightness of the electronic bearing cursor is adjusted by a control for this purpose. Unless the electronic bearing cursor appears as a dashed or dotted line, the brightness levels of the electronic bearing cursor and the heading flash should be different to serve as an aid to their identification.

- **Fixed Range Markers.** The brightness of the fixed range marker is adjusted by a control, labeled FIXED RANGE MARK INTENSITY CONTROL. The fixed range markers should be turned off periodically to avoid the possibility of their masking a small pip on the PPI.

- **Variable Range Marker.** The brightness of the variable range marker is adjusted by the control labeled VARIABLE RANGE MARKER INTENSITY CONTROL. This control is adjusted so that the ring described by the VRM is sharp and clear but not too bright.

- **Panel Lighting**. The illumination of the panel is adjusted by the control labeled PANEL CONTROL.

Radarscope Interpretation.

General. In its position-finding or navigational application, radar may serve the navigator as a very valuable tool if its characteristics and limitations are understood. While determining position through observation of the range and bearing of a charted, isolated, and well defined object having good reflecting properties is relativly simple, this task still required that the navigator have an understanding of the characteristics and limitations of the radar. The more general task of using radar in observing a shoreline where the radar targets are not so obvious or well defined requires considerable expertise which may be gained only through an adequate understanding of the characteristics and limitations of the radar being used. While the plan position indicator does provide a chartlike presentation when a landmass is being scanned, the image painted by the sweep is not a true representation of the shoreline. The width of the radar beam and the length of the transmitted pulse are factors which act to distort the image painted on the scope. Briefly, the width of the radar beam acts to distort the shoreline features in bearing; the pulse length may act to cause offshore features to appear as part of the landmass. The major problem is that of determining which features in the vicinity of the shoreline are actually reflecting the echoes painted on the scope. Particularly in cases where a low lying shore is being scanned, there may be considerable uncertainty.

An associated problem is the fact that certain features on the shore will not return echoes, even if they have good reflecting properties, simply because they are blocked from the radar beam by other physical features or obstructions. This factor in turn causes the chart-like image painted on the scope to differ from the chart of the area.

If the navigator is to be able to interpret the chart-like presentation on the radarscope, there must be at least an elementary understanding of the characteristics of radar propagation, the characteristics of the radar set, the reflecting properties of different types of radar targets, and the ability to analyze the chart to make an estimate of just which charted features are most likely to reflect the transmitted pulses or to be blocked from the radar beam. While contour lines on the chart topography aid the navigator materially in the latter task, experience gained during clear weather comparison of the visual cross-bearing plot and the radarscope presentation is invaluable.

Land Targets. Landmasses are readily recognizable because of the generally steady brilliance of the relatively large areas painted on the PPI. Also land should be at positions expected from knowledge of the vessel's navigational position. On relative motion displays, landmasses move in directions and at rates opposite and equal to the actual motion of the observer's ship. Individual pips do not move relative to one another. While landmasses are readily recognizable, the primary problem is the identification of specific features so that such features can be used for fixing the position of the observer's vessel. Identification of specific features can be quite difficult because of various factors, including distortion resulting from beam width and pulse length and uncertainty as to just which charted features are reflecting the echoes. The following hints may be used as an aid in identification:

- Sandspits and smooth, clear beaches normally do not appear on the PPI at ranges beyond 1 or 2 miles because these targets have almost no area that can reflect energy back to the radar antenna. Ranges determined from these targets are not reliable. If waves are breaking over a sandbar, echoes may be returned from the surf. Waves may, however, break well out from the actual shoreline, so that ranging on the surf may be misleading when a radar position is being determined relative to the shoreline.

- Mud flats and marshes normally reflect radar pulses only a little better than a sandspit. The weak echoes received at low tide disappear at high tide. Mangroves and other thick growth may produce a strong echo. Areas that are indicated as swamps on a chart, therefore, may return either strong or weak echoes, depending on the density and size of the vegetation growing in the area.

- When sand dunes are covered with vegetation and are well back from a low, smooth beach, the apparent shoreline determined by radar appears as the line of the dunes rather than the true shoreline. Under some conditions, sand dunes may return strong echo signals because the combination of the vertical surface of the vegetation and the horizontal beach may form a sort of corner reflector.

- Lagoons and inland lakes usually appear as blank areas on a PPI because the smooth water surface returns no energy to the radar antenna. In some instances, the sandbar or reef surrounding the lagoon may not appear on the PPI because it lies too low in the water.

- Coral atolls and long chains of islands may produce long lines of echoes when the radar beam is directed perpendicular to the line of the islands. This indication is especially true when the islands are closely spaced. The reason is that the spreading resulting from the width of the radar beam causes the echoes to blend into continuous lines. When the chain of islands is viewed lengthwise, or obliquely, however, each island may produce a separate pip. Surf breaking on a reef around an atoll produces a ragged, variable line of echoes.

- Submerged objects do not produce radar echoes. One or two rocks projecting above the surface of the water, or waves breaking over a reef, may appear on the PPI. When an object is submerged entirely and the sea is smooth over it, no indication is seen on the PPI.

- If the land rises in a gradual, regular manner from the shoreline, no part of the terrain produces an echo that is stronger than the echo from any other part. As a result, a general haze of echoes appears on the PPI, and it is difficult to ascertain the range to any particular part of the land. Land can be recognized by plotting the contact. Care must be exercised when plotting because, as a vessel approaches or goes away from a shore behind which the land rises gradually, a plot of the ranges and bearings to the land may show an "apparent" course and speed.

- Blotchy signals are returned from hilly ground because the crest of each hill returns a good echo although the valley beyond is in a shadow. If high receiver gain is used, the pattern may become solid except for the very deep shadows.

- Low islands ordinarily produce small echoes. When thick palm trees or other foliage grow on the island, strong echoes often are produced because the horizontal surface of the water around the island forms a sort of corner reflector with the vertical surfaces of the trees. As a result, wooded islands give good echoes and can be detected at a much greater range than barren islands.

Ship Targets. With the appearance of a small pip on the PPI, its identification as a ship can be aided by a process of elimination. A check of the navigational position can overrule the possibility of land. The size of the pip can be used to overrule the possibility of land or precipitation, both usually having a massive appearance on the PPI. The rate of movement of the pip on the PPI can overrule the possibility of aircraft.
Having eliminated the foregoing possibilities, the appearance of the pip at a medium range as a bright, steady and clearly defined image on the PPI indicates a high probability that the target is a steel ship.
The pip of a ship target may brighten at times and then slowly decrease in brightness. Normally, the pip of a ship target fades from the PPI only when the range becomes too great.

Radar Shadow. While PPI displays are approximately chart-like when landmasses are being scanned by the radar beam, there may be sizable areas missing from the display because of certain features being blocked from the radar beam by other features. A shoreline which is continuous when the ship is at one position may not be continuous when the ship is at another position and scanning the same shoreline.
The radar beam may be blocked from a segment of this shoreline by an obstruction such as a promontory. An

indentation in the shoreline, such as a cove or bay, appearing on the PPI when the ship is at one position may not appear when the ship is at another position nearby. Thus, radar shadow alone can cause considerable differences between the PPI display and the chart presentation. This effect in conjunction with beam width and pulse length distortion of the PPI display can cause even greater differences.

Beam Width and Pulse Length Distortion.
The pips of ships, rocks, and other targets close to shore may merge with the shoreline image on the PPI. This merging is due to the distortion effects of horizontal beam width and pulse length. Target images on the PPI always are distorted angularly by an amount equal to the effective horizontal beam width. Also, the target images always are distorted radially by an amount at least equal to one-half the pulse length (164 yards per microsecond of pulse length).

Aids to Radar Navigation.
Various aids to radar navigation have been developed to aid the navigator in identifying radar targets and for increasing the strength of the echoes received from objects which otherwise are poor radar targets.

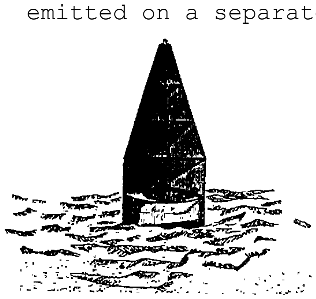
Radar Reflectors. Buoys and small boats, particularly those boats constructed of wood, are poor radar targets. Weak fluctuating echoes received from these targets are easily lost in the sea clutter on the radarscope. To aid in the detection of these targets, radar reflectors, of the corner reflector type, may be used. The corner reflectors may be mounted on the tops of buoys or the body of the buoy may be shaped as a corner reflector, as illustrated in Fig. 9-10.

Each corner reflector illustrated in this figure consists of three mutually perpendicular flat metal surfaces.

A radar wave on striking any of the metal surfaces or plates will be reflected back in the direction of its source, i.e., the radar antenna. Maximum energy will be reflected back to the antenna if the axis of the radar beam makes equal angles with all the metal surfaces. Frequently corner reflectors are assembled in clusters to insure receiving strong echoes at the antenna.

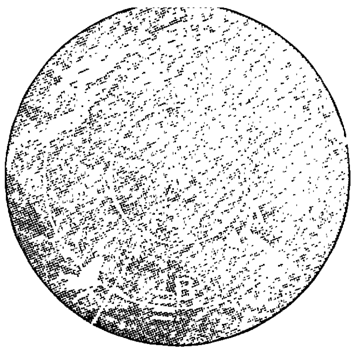
Radar Beacon. While radar reflectors are used to obtain stronger echoes from radar targets, other means are required for more positive identification of radar targets. Radar beacons are transmitters operating in the marine radar frequency band which produce distinctive indications on the radarscopes of ships within range of these beacons. There are two general classes of these beacons: Racon which provides both bearing and range information to the target and Ramark which provides bearing information only. However, if the ramark installation is detected as an echo on the radarscope, the range will be available also.

RACON. Racon is a radar transponder which emits a characteristic signal when triggered by a ship's radar. The signal may be emitted on the same frequency as that of the triggering radar, in which case it is superimposed on the ship's radar display automatically. The signal may be emitted on a separate frequency,



Radar Reflector Buoy.

in which case to receive the signal the ship's radar receiver must be capable of being tuned to the beacon frequency or a special receiver must be used. In either case, the PPI will be blank except for the beacon signal. However, the only racons in service are "in band" beacons which transmit in one of the marine radar bands, usually only the 3-centimeter band. The racon signal appears on the PPI as a radial line originating at a point just beyond the position of the radar beacon or as a Morse code signal displayed radially from just beyond the beacon. (See Fig. 9-11.)



The Racon Signal: (A) Uncoded, (B) Coded.

Ramark, not currently used in U. S. waters, is a radar beacon which transmits either continuously or at intervals. The latter method of a transmission is used so that the PPI can be inspected without clutter introduced by the ramark signal on the scope. The ramark signal as it appears on the PPI is a radial line from the center. The radial line may be a continuous narrow line, a series of dashes, a series of dots, or a series of dots and dashes.

Collision Avoidance.
Marine radar is a powerful tool in the practice of collision avoidance, and should be used, if so equipped, whenever navigating in restricted visibility, to avoid or be avoided. Although there are many techniques for using radar for collision avoidance, their discussion is lengthy and beyond the scope of this book. Publication 1310 covers this aspect of radar navigation thoroughly. The reader is referred to this source for treatment of the subject in depth. However, several simple examples will be provided here to illustrate some of the basic methods. It should be noted that the Navigation Rules <u>require</u> the use of radar and radar <u>plotting</u>, if operational radar is onboard, in conditions of restricted visibility for the purpose of collision avoidance. In order for this to be possible, operators of such radar must be familiar with at least the techniques shown here. In addition, all vessel operators are cautioned that course changes made during conditions of restricted visibility should be made at angles of at least 60 clearly recognized on even stabilized radar. Course changes of less than this amount are difficult to detect on radar and often go unnoticed until it is too late.

Relative Motion. The actual or true motion of an object usually is defined in terms of its direction and rate of movement relative to the earth. If the object is a vessel, this motion is defined in terms of the true course and speed. The motion of an object also may be defined in terms of its direction and rate of movement relative to another object also in motion. The relative motion of a vessel or the motion of another one, is defined in terms of the Direction of Relative Movement (DRM) and the Speed of Relative Movement (SRM). Each form of motion may be depicted by a velocity vector, a line segment representing direction and rate of movement. Before further discussion of velocity vectors and their application, a situation involving relative motion between two vessels will be examined.

In Fig. 9-12, vessel A, at geographic position A1, on true course 000
knots initially observes vessel B on the PPI bearing 180 and distance to
vessel B changes as vessel A proceeds from geographic position A1 to A3.
The changes in the positions of vessel B relative to vessel A are illustrated
in the successive PPI presentation corresponding to the geographic positions
of vessels A and B. Likewise vessel B, at geographic position B1, on true
course 026 initially observes vessel A on the PPI bearing 000 distance to
vessel A changes as vessel B proceeds from geographic position B1 to B3.
The changes in the positions of vessel A relative to vessel B are illustrated
in the successive PPI presentations corresponding to the geographic positions
of vessel A and B.

Of primary significance at this point is relative plot on each PPI is not
course and speed of another vessel. Figure 9-15 illustrates the actual
heading of vessel B superimposed upon the relative plot obtained by vessel
A. Relative motion displays do not indicated the aspects of vessel targets.
For either radar observer to determine the tru course and speed of the other
vessel, relative and true vectors are required.

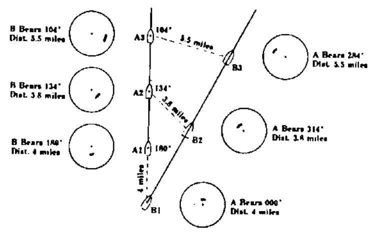
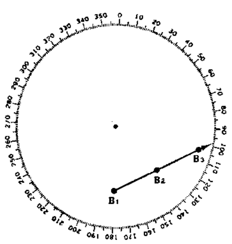
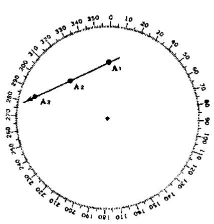


Fig. 9-12 Relative Motion Between Two Vessels.



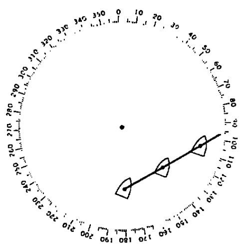
Motion of Vessel B relative to Vessel A on Radarscope of Vessel A.



Motion of Vessel A Relative to Vessel B on Radar Scope of Vessel B.

If the radar observer aboard vessel A plots the successive positions of
vessel B relative to his position fixed at the center of the PPI, he will
obtain a plot called the RELATIVE PLOT or RELATIVE MOTION PLOT as illustrated
in Fig. 9-13. If the radar observer aboard vessel B plots the successive
positions of vessel A relative to his position fixed at the center of the
PPI, he will obtain a relative plot as illustrated in Fig. 9-14. The radar
observer aboard vessel A will determine that the Direction of Relative
Movement (DRM) of vessel B is 063 whereas the radar observer aboard vessel
B will determine that the DRM of vessel A is 243

distances between plots coordinated in time, the geographical plot does not provide a direct presentation of the relative movement.
Figure 9-17 illustrates a modification of Figure 9-16 in which the true bearing lines and ranges of other boat M from own boat R are shown at equal time intervals. On plotting these ranges and bearings from a fixed point R, the movement of M relative to own boat R is directly illustrated. The lines between the equally spaced plots at equal time intervals provide direction and rate of movement of M relative to R and thus are relative velocity vectors.



The Actual Heading of Vessel B Superimposed Upon the Relative Plot Obtained by Vessel A.

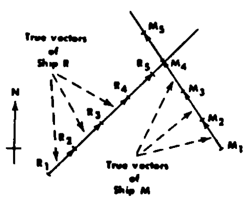


Fig. 9-16 True Velocity Vectors.

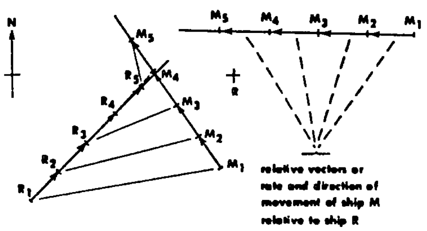
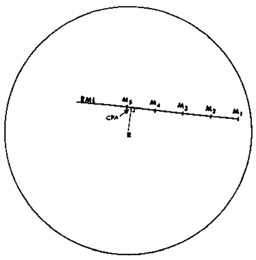


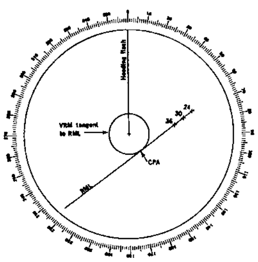
Figure 9-16 illustrates the timed movements of two boats R and M with respect to the earth. This plot, similar to the plot made in ordinary chart navigation work, is called a geographical (navigational) plot. Boat R proceeding on course 045 passes through successive positions R(1), R(2), R(3), R(4)...equally spaced at equal time intervals. Therefore, the line segments connecting successive positions represent direction and rate of movement with respect to the earth. Thus, they are true velocity vectors. Likewise, for boat M on course 325 connecting the equally spaced plots for equal time intervals represent true velocity vectors of boat M. Although the movement of R relative to M or M relative to R may be obtained by additional graphic construction or by visualizing the changes in bearing and

Of primary significance at this point is relative plot on each PPI is not course and speed of the other vessel. Fig. 9-15 illustrates the actual heading of vessel B superimposed upon the relative plot obtained by vessel A. Relative motion displays do not indicate the aspects of vessel targets. For either radar observer to determine the true course and speed of the other vessel, relative and true vectors are required.
The true velocity vector depicting own vessel's true motion is called own boat

on a relative motion display on the PPI of the radar set aboard own vessel R would appear as in Fig. 9-18. With a Relative Movement Line (RML) drawn through the plot, the individual segments of the plot corresponding to relative distances traveled per elapsed time are relative (DRM-SRM) vectors, although the arrowheads are not shown. The plot, called the RELATIVE PLOT or RELATIVE MOTION PLOT, is the plot of the true bearings and distances of boat M from own boat R.



Relative Plot Showing Closest Point of Approach, CPA.



Closest Point of approach Graphical Solution.

If the plots were not times, vector magnitude would not be indicated. In such cases the relative plot would be related to the (DRM-SRM) vector in direction only.

Figure 9-18 illustrates that the relative plot provides an almost direct indication of the CLOSEST POINT OF APPROACH (CPA). The CPA is the true bearing and distance of the closest approach of one ship to another.

Graphical Solutions by Rapid Plotting on the PPL.
On some radar equipment, the PPI is equipped with a curved, clear plastic sheet over the CRT screen upon which plotting, using a common grease pencil, can be done. Several easy techniques using this rapid plotting method will be illustrated.

Closest Point of Approach (CPA). To determine the closest point of approach of a contact by graphical solution on the reflection plotter, follow the procedure shown below, and illustrated in Fig. 9-19:

1. Plot at least three relative positions of the contact. If the relative positions lie in a straight or nearly straight line, fair a line through the relative positions. Extend this relative movement line (RML) past the center of the PPI.

2. Crank out the variable range marker (VRM) until the ring described by it is tangent to the RML as shown in Fig. 9-19. The point of tangency is the CPA.

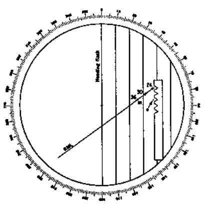
3. The range at CPA is the reading of the VRM counter; the bearing at CPA is determined by means of the mechanical bearing cursor, parallel-line cursor, or other means for bearing measurement from the center of the PPI.

NOTE: The RML should be reconstructed if the contact does not continue to plot on the RML as originally constructed.

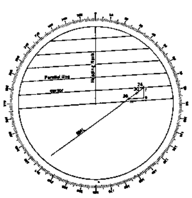
True Course and Speed of Contact. To determine the true course and speed of a contact by graphical solution on the reflection plotter, follow the procedure given below.

1. As soon as possible after a contact appears on the PPI, plot its relative position on the reflection plotter. Label the position with the time of the observation as shown in Fig. 9-19. When there is no doubt with respect to the hour of the plot, it is only necessary to show the last two digits, i.e., the minutes after the hour. In those instances where an unduly long wait would be required it might be advantageous to delay starting the timed plot until the time is one tenth of an hour, ... 6 minutes, 12 minutes, 18 minutes, etc., after the hour. This timing could simplify the use of the 6 minute plotting interval normally used with the rapid radar plotting technique.

2. Examine the relative plot to determine whether the contact is on a steady



Use of The Notched Rule.



Use of Parallel-Line Cursor to Determine True Course of Contact.

course at constant speed. If so, the relative positions plot in a straight or nearly straight line; the relative positions are equally spaced for equa time intervals as shown in Fig. 9-19.

3. With the contact on a steady course at constant speed, select a suitable relative position as the origin of the relative speed (DRM-SRM) vector; label this plot r as shown in Fig. 9-20.

4. Crank the parallel-line cursor until its lines are parallel to the heading flash. As shown in Fig. 9-20, place the appropriate plastic rule so that one notch is at r and its straightedge is parallel to the lines of the cursor and the heading flash. The rule is scaled for a 6-minute run between notches.

5. Select the time interval for the solution, 12 minutes for example. Accordingly, the origin, e, of own ship's true (course-speed) vector er is at the second notch from rm, the head of the contact's true (course-speed) vector is at the plot 12 minutes beyond r in the direction of relative movement.

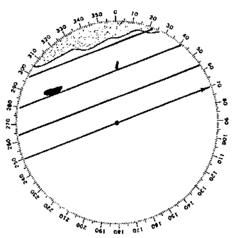
6. Construct the contact's true (course-speed) vector em.

7. Crank the parallel-line cursor so that its lines are parallel to vector em as shown in Fig. 9-21. The contact's true course is read on the true bearing dial using the radial line of the parallel-line cursor; the contact's true speed is esstimated by visual comparison with own ship's true vector er. For example, if em is about two-thirds the length of er, the contact's speed is about two-thirds own ship's speed. Or, the notched rule can be used to determine the speed corrresponding to the length of em.

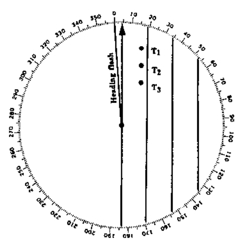
Identifying Radar-Inconspicuous Object. If there is doubt that a pip on the PPI represents the echo from a buoy, a radar-inconspicuous object, the technique shown here can be used to identify the pip which is in doubt. On the chart there is a radar-conspicuous object, a rock, in the vicinity of the buoy. The pip of the rock is identified readily on the PPI.

1. Measure the bearing and distance of the buoy from the rock on the chart.

2. Determine the length of this distance



Use of Parallel-line Cursor to Identify Radar-Inconspicuous Object.



Use of Parallel-Line Cursor to Find Course and Speed Made Good.

on the PPI according to the range scale setting.

3. Rotate the parallel-line cursor to the bearing of the buoy from the rock (see Fig. 9-22).

4. With rubber-tipped diveders set to the appropriate PPI length, set one point over the pip of the rock; using the parallel lines of the cursor as a guide, set the second point int he direction of the bearing of the buoy from the rock.

5. With the dividers so set, the second point lies over the unidentified pip. Subject to the accuracy limitations of the measurements and normal prudence, the pip may be evaluated as the echo received from the buoy.

NOTE: During low visibility a radar-conspicuous object can be used similarly to determine whether another ship is fouling an anchorage berth.

Finding Course and Speed Made Good by Parallel-Line Cursor. A ship steaming in fog detects a prominent rock by radar. Because of the unknown effects of current and other factors the navigator is uncertain of the course and speed being made good. This can be determined as follows:

1. Make a timed plot of the rock on the reflection plotter.

2. Align the parallel-line cursor with the plot to determine the course being made good, which is in a direction opposite to the relative movement (see Fig. 9-23).

3. Measure the distance between the first and last plots and using the time interval, determine the speed of relative movement. Since the rock is stationary, the relative speed is equal to that of the vessel.

NOTE: This basic technique is useful for determining whether the vessel is being set off the intended track in pilot waters. Observing a radar-conspicuous object and using the parallel-line cursor, a line is drawn through the radar conspicuous object in a direction opposite to own vessel course. By observing the successive positions of the radar-conspicuous object relative to this line, the navigator can determine whether the vessel is being set to the left or right of the intended track.

Chapter 10

Navigation Reference Publications

Knowledge in piloting required familiarity with the various publications available to assist the mariner in the safe navigation of a vessel. Those normally used by Coast Guard Auxiliarists and other small craft operators include:

Coast Pilots.
The amount of information that can be printed on a nautical chart is limited by available space and the system of symbols that are used. Additional information is often needed for safe and convenient navigation. The National Ocean Service publishes such information in the Coast Pilot series. These are printed in book form. Nine separate volumes cover the coastline of the United States and the Great Lakes.
Each Coast Pilot contains sailing directions between points in its respective area, including recommended true courses and distances. Channels with their controlling depths and all dangers and obstructions are fully described. Harbors and anchorages are listed with information on those points at which facilities are available for boat supplies and marine repairs. Information on canals, bridges, docks, etc., is also included.

Light Lists.
Light Lists provide more complete information concerning aids to navigation than can be shown on charts. They are published annually in five volumes:
Volume I: Atlantic Coast from St. Croix River Maine to Little River, S. C.
Volume II: Atlantic and Gulf Coasts from Little River, S. C. to Rio Grande, Texas.
Volume III: Pacific Coast and Pacific Islands.
Volume IV: Great Lakes.
Volume V: Mississippi River System.

Notices to Mariners.
Nautical charts and publications are kept up-to-date through use of the Notice to Mariners, prepared jointly by the National Ocean Service and the U. S. Coast Guard. The notice is published weekly, and is available free of charge from the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) through the Office of Distribution Services (IMA), Defense Mapping Agency, Washington, D.C. 20315.

This pamphlet contains the latest information on navigational safety, changes in aids to navigation, channels, and chart information over a broad area useful to the ocean going vessel. The Coast Pilots are kept current through the navigator's incorporating into them the information supplied by the weekly Notice to Mariners.

Local Notice to Mariners.
The Commander (oan) of the local U. S. Coast Guard district issues the Local Notice to Mariners on a weekly basis.

There is no charge for this publication, which may be obtained upon request to the local Coast Guard District Commander. The Local Notice to Mariners contains the very latest navigational safety information pertinent to all craft within the area of the district. Notices of marine regattas and other important marine events are also announced through the Local Notice to Mariners.

One of the most important purposes of the Local Notice to Mariners (LNM) is the dissemination of information on changes to aids to navigation. In this process, some districts use the abbreviations listed below to convey this information:

BY - Buoy
CH - Channel
DBD - Dayboard
DBN - Daybeacon
DISC - Discontinued
EMER CHAR - Emergency Characteristics
FOG SIG INOP - Sound Signal Inoperative
IMP CHAR - Aid not displaying characteristics as advertised in Light List or Chart
LB - Lighted Buoy
LBB - Lighted Bell Buoy
LGB - Lighted Gong Buoy
LHB - Lighted Horn Buoy
LNB - Large Navigational Buoy
LWB - Lighted Whistle Buoy
LLNR/LLP - Light List Number/Light List Page
NM - Nautical miles
OP CONSTSLY - Signal is on throughout 24 hours.
RBN - Radiobeacon
RED INT - Aid operating at a lesser range/intensity than stated in Light List.
REMOVED - Old structure located and removed.
REMAINS - Structure remains in area, possibly still standing, and the search for the structure was unsuccessful or search is yet to be made.
TEMP DISC - Temporarily Discontinued
TRLB - Temporarily replaced with a lighted buoy.
TRSB - Temporarily replaced by a smaller buoy.
TRUB - Temporarily replaced by an unlighted buoy.
UNKNOWN - Failed to locate structure during a search of the area.
W/F - Watching properly

Chapter 11

Seaman's Eye

When the mariner has learned navigation skills thoroughly, he or she will know when use of the formal techniques (such as plotting) is necessary and when departures from the formal processes are appropriate and can be made safely. In areas where the navigator is very familiar, such as on a particularly frequented embayment or sound, river or coastal area, and the charted hazards, aids to navigation, currents, tides and other essential navigational information are well known, it may be sufficient only to keep the chart handy for marking positions when desired (at the approach of a fog bank or other period of restricted visibility, for example) but not carry on a DR plot or take frequent fixes.

Such a time may be when proceeding from the dock out to a rendezvous point at the beginning of a boating outing.

Informal navigation is appropriate under these circumstances, and is termed navigation by SEAMAN'S EYE. Its proper and safe use comes only after the mariner has learned the navigation skills and techniques sufficiently, and has gained sufficient experience to make sound judgements regarding the use of the various techniques available for navigation of the vessel.
Thus, Seaman's Eye navigation is applied after sufficient knowledge of the area is obtained through study of the available charts, Tide Tables, Current Tables, Coast Pilots, and other navigation publications and combined with local knowledge of the area. A thorough mastering of the navigational skills and techniques offered in the material in this textbook should provide a firm foundation for the navigator to know when to apply Seaman's Eye.

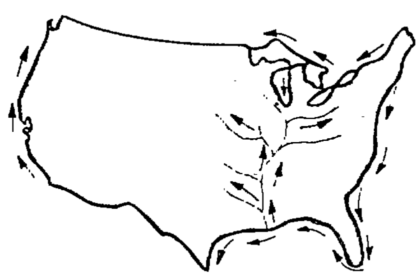
Aids to Navigation (ATON)

Buoyage Systems.
Four buoyage systems are used on waters of the United States. They are: Navigable Waters; Intracoastal; Western Rivers; and Uniform State Waterway Marking System. The basic structure for these systems is called the Lateral System of Buoyage - now called Lateral (modified). This system is based upon channels determined as "proceeding from seaward" in which vessels returning from sea are to leave red markers to the starboard side. (RED, RIGHT, RETURNING).

The term "PROCEEDING FROM SEAWARD" means following the Atlantic coast in a southerly direction, northerly and westerly along the Gulf coast, and in a northerly direction on the Pacific coast. On the Great Lakes, "proceeding from seaward" follows a generally westerly and northerly direction, except on Lake Michigan where the direction is southerly.

On the Mississippi and Ohio Rivers and their tributaries, "proceeding from seaward" is from the Gulf of Mexico toward the headwaters of the rivers (upstream). The local terminology, "left bank" and "right bank" has as a reference the direction of the current when it is flowing downstream, that is, proceeding with the flow of the river. U. S. maintained aids to navigation are to be modified in a 6-year period that began in 1983. The major changes are green on buoys and daymarks instead of black, vertical red and white stripes on fairway and mid-channel buoys instead of black and white vertical stripes, and yellow used on all special purpose buoys.

Navigable Waters.
Navigable Waters are defined as coastal waters that include bays, sounds, rivers and lakes that are navigable from the sea. The buoyage system used on navigable waters follows the lateral (modified) system of buoyage, as entering from seaward. This system employs a simple arrangement of shapes, colors, numbers/letters and light characteristics to show the side on which a buoy should be passed, when proceeding in a given direction. In order to provide ready identification of aids to navigation in the system, certain buoys and daymarks have differentiated shapes. This system also used buoys that are painted distinctive colors to indicate their purpose, which alerts the mariner as to the side on which a buoy should be passed. For further identification of individual aids, numbers and/or letters are used. In this system, the buoys that mark the sides of



THE LATERAL SYSTEM

channels, have numbers which increase when proceeding from seaward.

Shapes. The different shapes of buoys used as aids to navigation in the buoyage system on navigable waters are described later in this chapter.

Colors. Buoys are colored red, green (or black) or a combination of red and green (or black). Some buoys are red and white (or black and white), while some are yellow. After the conversion is completed in 1989, all references to black as a characteristic color may be deleted. Green (or black) buoys mark the port (left) side of the channel when "proceeding from seaward" or the location of wrecks or obstructions that must be passed by keeping the buoy on the port side of the vessel when proceeding from seaward.

Red buoys mark the starboard (right) side of the channels, or location of wrecks or obstructions that must be passed on the starboard side of the vessel when "proceeding from seaward." (RED, RIGHT, RETURNING.) Junction buoys are green (or black) with a wide red horizontal band, or red with a wide horizontal green (or black) band. The topmost color indicates the preferred channel.

Mid-channel or fairway buoys are red (or black) and white vertically striped. They are "safe water" aids to navigation, and can be passed close-by on either side.

Yellow is the color used on all special purpose buoys according to the International Association of Lighthouse Authorities (IALA) plan which is in use in this country. This is discussed in further detail in the section on special purpose buoys.

Numbers. Most buoys, daybeacons and minor lights used on navigable waters have numbers, letters or a combination of both numbers and letters placed conspicuously on the aids. These markings usually are of reflective material to facilitate the identification of the aid.

- Odd numbers are used only on solid green (or black)aids.

- Even numbers are used only on solid red aids.

- Letters may be required with a number so as not to disturb the sequence of the numbering, but to indicate some other significance such as a particular shoal. Letters customarily mark junction and mid-channel buoys as well as buoys that are not solid green (or black) or solid red.

- Daymarks sometimes used in place of buoys, are numbered and/or lettered in the same manner as buoys.

Lights; Colors and Characteristics. Lights used on aids to mark the sides of channels along navigable waters are green and red. White lights are to be discontinued on the starboard and port hand aids in waters used by international mariners.

- Only green lights on solid green (or black) buoys are used to mark the port side of the channel when "proceeding from seaward." Lights are Flashing, Quick Flashing, or Occulting. The Light List may be checked for details.

- Red lights are used on solid red buoys marking the starboard side of the channel when "proceeding from seaward." Lights are Flashing, Quick Flashing, or Occulting. The applicable Light List outlines characteristics.

- Preferred channel aids will carry the light corresponding with the topmost color. The light characteristic of these aids is Composite Group Flashing (2+1).

- White lights are used on mid-channel or fairway (safe water) buoys with the flashing characteristic of Morse Code "A" (MoA).

- Yellow lights are to be used on special purpose buoys..

Intracoastal Waterway (ICW).
The buoyage system used on the Intracoastal Waterway is the same as that for navigable waters with some variations. The ICW follows a comparatively shallow channel in more protected waters that lie parallel with and extend along the Atlantic and Gulf coasts from New Jersey to the Mexican border. This passage, sometimes referred to as the "inside route," is considered to be "proceeding from seaward" as it follows the Atlantic coast in a southerly direction to the tip of Florida, and in a northerly and westerly direction along the Gulf of Mexico. Numbers on the ICW buoys and daymarks follow the basic system, beginning with the number 1 as if approaching from seaward. The numbers increase along the "inside route" up to the number 200, then begin again with the number 1.

The ICW uses the same coloring of buoys and daymarks as the lateral (modified system with one exception: All buoys and daymarks that identify the ICW route have an additional yellow symbol, usually a band or horizontal bar. Basically green (or black) buoys and daymarks identify the port side of the channel, and red buoys and daymarks mark the starboard side of the channel, when proceeding from New Jersey to Mexico.
When the ICW coincides with another waterway marked according to the lateral (modified) system of buoyage, special ICW markings are used. They consist of ayellow square or a yellow triangle paintedare on a conspicuous part of the dual-purpose aid to navigation. The shape of the yellow mark indicates the side of the channel for the ICW. A yellow triangle on an aid means that the aid must be kept on the starboard side; a yellow square indicates that the aid must be kept on the port side when proceeding from "seaward." When yellow squares or triangles are used on dual purpose aids, the yellow band or bar is omitted. (Don't be confused, if you see a yellow square on a nun (red) buoy, or a yellow triangle on a can (green) buoy.)

Lights on buoys and fixed structures along the ICW follow the basic system of green lights on green (or black) aids, red lights on red aids, and white lights on safe water or mid-channel buoys. The lights carry the same characteristics as lights in the lateral (modified) buoyage system.

Western Rivers.
The buoyage system on Western Rivers (the Mississippi and Ohio and their tributaries) also utilizes the lateral (modified) system with some variations. The buoys conform in shape, color, and placement, but are not numbered or lettered because of the difficulty in keeping floating aids on station.
For this reason the buoys are not shown on charts. Sometimes the orientation is stated in the Light List as "the left descending" or "the right descending" bank. The terms "left bank" and "right bank" are used when following the flow of the stream (descending)-not when proceeding from seaward.
With the absence of numbers on aids, the river-boater can establish an accurate location by referring to mile boards. These aids are white rectangles with numbers that indicate the miles upstream from a given reference point. They are usually mounted on piles or dolphins.
In addition to regular lateral (modified) daymarks, the Western River system uses special marks to indicate "crossings." Daymarks to indicate "crossings" diamond shaped. They direct deep draft traffic to cross the river and head toward the marker in order to stay in the deepest water.
The green diamond with green reflective corners is used along the "right bank" and the red diamond with red reflective corners is used on the "left

bank."

Lights on Western Rivers are placed along the banks with special emphasis at "crossings" to facilitate steering. A single flashing green (or white) marks the port side going upstream. As with all lights, some will have an intensified section to identify safe channels. White lights may still be used on "crossing" aids. Lights on buoys marking channel junctions or obstructions show interrupted quick flashing characteristics. Lights on buoys marking wrecks show a quick flashing characteristic of appropriate color.

Uniform State Waterway Marking System (USWMS).

The Uniform State Waterway Marking System has been devised for lakes, ponds, and rivers within state boundaries and not navigable to the sea. Although not "navigable water," they may be either federal or solely state waters, depending upon their location. Regardless of their labels, these waterways may each be marked with the USWMS system. Most states have adopted this system and adjusted it to the individual state's regulations. Some states have altered the system slightly to suit local conditions. Boaters should become familiar with particular variations in an area before boating in inland waters (local knowledge). The USWMS uses two kinds of waterway markers - regulatory markers and aids to navigation. Aids and markers may be identified by number, letters or words. Odd numbers are used on solid black buoys or black-topped buoys. Even numbers are used on solid red buoys and red-topped buoys. All numbers increase in an upstream direction, or toward the head of navigation.
Lights may be used on the USWMS on markers and aids:

Characteristics. Lights will be regular flashing, regular occulting, or equal interval. Quick flashing will be used to signal the need for immediate caution.

Color. Red lights are used on solid red buoys. Green lights are used on solid black buoys. White lights are used on all other buoys and regulatory markers.

Regulatory Markers. The regulatory markers in the USWMS consist of buoys and signs which indicate information pertaining to rules and regulations. All regulatory markers have white backgrounds and orange borders. They may be circular, square, or diamond shaped.
The basic shape on a regulatory marker is to convey the idea of danger or control. It can be seen at a distance to alert the boater to approach the area with caution. Specific information within the shape identifies the danger or control. The nature of the regulation or danger is indicated by black letters or figures within the shape. (Refer to Chart No. 1 for illustrations.)

1. Diamond Shape. DANGER - rocks, wrecks, reefs, or other hazards.
2. Diamond Shape with a cross. Excludes boats from area.
3. Square Shape. Information, distances, directions.
4. Circular Shape. A restricted area, such as no skiing, no wake, 5 mph.

Aids to Navigation. Aids to navigation used in the USWMS are red and black buoys to mark channel limits. The red and black buoys usually are employed in pairs so that boats can pass between them. The red buoy will be on the left (descending side of the river or stream) and the black will be located on the right.

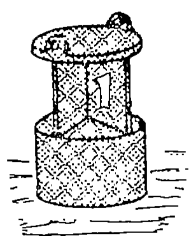
1. Solid red buoys and solid black buoys mark channels.
2. White buoys with red tops must be passed to the south or west.
3. White buoys with black tops must be

passed to the north or east.

4. Vertical red and white striped buoys indicate that vessels must not pass between the buoy and the nearest shore.
5. White buoys with horizontal blue bands midway between the top of the buoy and the waterline are identified as mooring buoys.

Aids to navigation are designed to assist mariners in following natural and improved channels and in establishing their positions. Those aids that keep the mariner aware of hidden dangers and in safe channels are symbolized on charts. Aids to navigation range from fixed and floating structures such as buoys and lighthouses to electronic aids, as radio beacons, RACON, and LORAN, for example. All aids serve the same general purpose.
Structural differences, as those between an unlighted buoy and lightship, or a lighthouse and a radiobeacon, are solely for the purpose of meeting the conditions and requirements of the particular location at which the aid is established.

Aids to navigation may be described in several different ways - fixed or floating, lighted or unlighted, electronic, sound signals, short-range or long-range. Categories include buoys, daybeacons, lights, ranges, and sound-producing aids. The term "aids to navigation" is reserved for objects and structures that have been established specifically to assist in navigation. In order for the United States to be in accord with buoyage systems around the world, and to be in agreement with IALA Plan B (International Association of Lighthouses Authorities), the United States maintained aids to navigation are being modified during the 6-year period that began in 1983. The major changes are to be green on buoys and daymarks instead of black, vertical red and white stripes on fairway and mid-channel buoys


A CAN BUOY

instead of black and white vertical stripes, and yellow used on all special-purpose buoys.

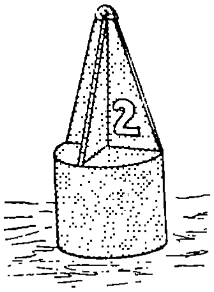
A conspicuous object on shore, such as a flagpole, stack or tower, which is shown on a chart, also may assist the navigator to direct the craft so as to stay in safe waters or to reach the destination. Such features, natural or man-made, are called landmarks.

Buoys.

Buoys are floating objects anchored to the bottom at specific locations so as to function as aids to navigation. They may be unlighted or lighted, with a visual signal of definite color and flashing pattern. There are also sound buoys with audible signals of various natures, and buoys which have both light and sound. Buoys are depicted on charts by various symbols and abbreviations that indicate the type, color, and numbering or lettering, and visual and/or sound signals, if any. The actual size of a buoy is not shown on a chart.

Shapes. In order to provide ready identification, certain unlighted buoys are differentiated by shape.
Can buoys are cylindrical. The upper part of the cylindrical shape may consist of two metal plates at right angles to each other; these serve as a radar reflector without changing the appearance of the buoy from a distance.

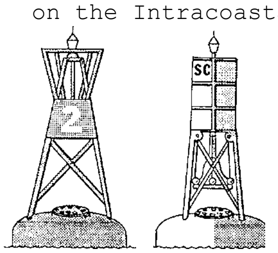
Nun buoys consist of shorter cylinders topped with blunted conical caps or metal plates that give the conical appearance at a distance.



A NUN BUOY

Safe-water buoys marking mid-channels and fairways are to be spherical, or have spherical topmarks by 1989. This shape will replace previously used non-differentiated shapes.

Other lighted and sound buoys may be pillar or spar shaped. Illustrations may be found in Chart No. 1, Nautical Chart Symbols and Abbreviations.
Colors. All buoys are painted with one or two of the basic colors - black or green, red, white and yellow. Can buoys are either black or green. Nun buoys are red. The distinctive color of a buoy is the primary feature that indicates its navigation significance. Some buoys may be green (or black) with a horizontal red band, or red with a horizontal green (or black) band. Buoys which are vertically striped will be red and white (or black and white). Yellow is used on buoys to identify all special aids in all systems except the Uniform State Waterway Marking System. It is also used as an identification on the Intracoastal Waterway aids.



LIGHT AND SOUND BUOYS
Numbers. Buoys are usually numbered in sequence as "proceeding from seaward." Odd numbers (1, 3, 5, etc.) are placed on green buoys. Even numbers (2, 4, 6, etc.) are placed on red buoys. Numbers are customarily used on buoys that mark the sides of channels. Letters are used in some instances to designate additional channels or junctions. Numbers and letters are of a contrasting color to the buoy, usually white, and are of a reflective material to be easily identified at night.

Reflectors. Most buoys, lighted or unlighted, have patches of optical reflective material that greatly facilitates their location at night. These reflectors show up brightly in the rays of a searchlight, hand-held electric lantern, or a strong flashlight.
Reflective material may be white, green, red or yellow and has the same significance as lights of the same color. The numbers and letters on a buoy also are of reflective material, usually white, for easy identification at night.

Many modern buoys, and especially larger ones in high fog areas, have radar corner-reflectors built into their superstructure to enhance detection by vessels equipped with radar.

Lighted buoys. Some or all of the buoys

may be equipped with lights in an area where there is significant night-time traffic on the water. Lighted buoys are painted either green (black) or red when replacing an unlighted can or nun buoy. In these cases, no lateral significance can be placed on the shape of the lighted buoy, since the appearance of all lighted buoys are essentially pillar shaped. Neither can-shaped nor nun-shaped buoys display lights.

Green lights are used only on green (or black) buoys, and on green (or black) and red horizontally banded buoys with the topmost band green (or black).
Red lights are used only on red buoys and on red and green (or black) horizontally banded buoys with the topmost band red.
At present, white lights may be used on any color buoy where the greater range of visibility of a white light is required, or where needed to distinguish one buoy from others showing red and green lights. However, when the modifications are complete, white lights will only be used on safe-water (mid-channel and fairway) aids.
Light characteristics of each lighted buoy can be found in the applicable Light List. Lights on red and green buoys will always be flashing, occulting, or quick flashing.

Flashing. The light flashes at the rate of 50 or fewer flashes per minute. The normal rate is once every 2 1/2, 4, or 6 seconds. In a flashing light, the light is off longer than it is on. Thus, the periods of darkness are interrupted by short flashes of light.

Occulting. The light is on longer than it is off. This light is steady with interrupted short eclipses of darkness, thus - "on" more than "off."

Quick flashing. When it is desired that a flashing light have a distinct cautionary significance, such as sharp turns or sudden constrictions in the channel, or to mark wrecks or hazardous obstructions which can be passed safely on one side only, the frequency of flashes will be at a rate of 50-8- or more per minute.
Lights on green and red horizontally-banded buoys will always show a Composite Group Flashing (CGpFl) (2+1).
This is a sequence of 2 flashes followed by a single flash. Such buoys are placed to indicate preferred channels.
Lights on red and white vertically-striped buoys consist of a short flash followed by a long flash, the letter "A" of the Morse Code. This series of a short, then a long flash recurs at a rate of about 8 times per minute. These buoys are placed at mid-channels, fairways and in entrances to harbors.
Almost every lighted buoy is equipped with a special device which automatically causes the light to operate during the hours of darkness and to be extinguished during the daylight hours. These devices are not of equal sensitivity, and therefore, all lights do not come on or go off at the same time.

Sound. Some buoys are equipped with sound signals to increase their effectiveness during periods of restricted visibility. One should be cautioned that buoys with bells and gongs sounded by the motion of the sea, do not emit regular signal characteristics. They cannot be depended upon when the sea is calm. There may be no signal at all.
Bell buoys have 4 clappers hung loosely about a bell so that even a slight rolling of the buoy causes the bell to ring.
Gong buoys have multiple gongs, usually 4, of different tones, each with a separate clapper. The gongs are rung in random order by the motion of the buoy in the sea.
Whistle buoys use air, captured and compressed by the rising and falling of the buoy in the sea. Such buoys are used in open and exposed areas where

sufficient ground-swell exists to operate the mechanism.
Horns may be used on some buoys. The signal is produced at regular intervals by electrical means.

Special Purpose Buoys. Special aids are used to mark areas that have no lateral significance. These special buoys will be all yellow, and if lighted, will show a yellow light. Among them are:

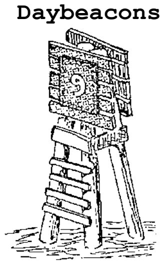
1. Ocean Data Acquisition Systems (ODAS).
2. Traffic separation schemes, where channel marking could be confusing.
3. Dredging buoys, where conventional channel marking would be confusing.
4. Fish net areas.
5. Spoil grounds.
6. Military exercise zones.
7. Anchorage areas. (White buoy and light)

Note: The use of yellow for special purpose buoys does not apply to the Uniform State Waterway Marking System (USWMS).

Station Buoys. Sometimes it is necessary to place a buoy in close proximity to a floating aid to mark the station in case the regular aid is accidentally shifted or otherwise incapacitated. Station buoys are colored and numbered or lettered the same as the regular aid to navigation. If the buoy that is being temporarily replaced has a sound signal, the station buoy should carry the same sound signal.
Large Navigation Buoys (LNB) are discussed under Major Lights and shown in

Figure 12-9.

Daybeacons.



A DAYBEACON AND DAYMARK

Daybeacons are unlighted fixed structures in shallow waters (sometimes as much as 20 feet), or onshore. The daybeacon consists of a simple structure of a single pile of wood, concrete, or metal, or a group of piles tied together at the top, called a dolphin. On the structure are one or more signboards called daymarks, to convey navigational information.
Daymarks are signboards that can be identified by shape and color, and have navigational significance. They are covered with reflective material, and also have retro-reflective borders so as to be more easily located at night with the aid of a searchlight.

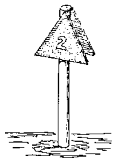
Shape and Purpose.

1. Square daymarks are used the same as can buoys to mark the port (left) side of channels when proceeding from seaward. The color is green the same as can buoys.

2. Triangular daymarks are used the same as nun buoys - to mark the starboard (right) side of channels when proceeding from seaward, and carry the same color (red) as nun buoys.

3. Preferred channel daymarks can be square or triangular to mark junctions in channels, wrecks, or obstructions.

The shape of the daymark and the color of the top half indicate the preferred channel.



A Daybeacon and Daymark

4. Octagonal-shaped daymarks are used to mark the fairway or middle of the channel. These daymakrs will be vertically divided, half red or black and half white.

5. For daymarks on Western Rivers, refer to the Western Rivers Buoyage System, discussed later in this chapter.

Numbers and Letters. Daymarks are numbered and/or lettered much the same as buoys. The numbers are white and reflective to be more easily identied with the aid of a searchlight at night. They are used to mark the sides of channels, and are given numbers and letters in accordance with the lateral (modified) system of buoyage.

Ranges.
Two fixed aids to navigation can be established to form a range which may be lighted or unlighted. These aids are arranged so that one mark is behind and higher than the other. When the mariner has the vessel in a position that both markers of the range are in line, that vessel is certain to be at some point on a known line of position. These ranges may be located on structures built specifically for that use, or they may be located on permanent structures such as buildings, piers, etc. Entrance channels to harbors or piers may be marked by ranges, as may successive straight reaches. Ranges should be used only after a careful examination of the applicable chart. It is particularly important to determine the distance over which the range can be safely followed. This information is not obtainable from visual inspection of the daymarks and/or lights. There are specific distances both toward and away from the range front marker that a range can be followed safely.

Ranges are colored or lighted to stand out from their background. The appropriate Light List should be consulted for the exact light characteristics and color combinations of the daymarks. The variour designs for range markers are being replaced with standardized rectangular daymarks that are mounted with the greater length vertically. They are painted in vertical stripes of contrasting colors. (See the color plate of buoyage systems found in Chart No. 1.)

The following guidelines help to determine when the mariner is in the middle of the channel:

1. If the upper (rear) mark is directly in line with the lower (front) mark, the vessel is in the center of the channel.

2. If the upper mark is seen to the left of the lower mark, the vessel is to the left of the center of the channel.

3. If the upper mark is seen to the right of the lower mark, the vessel is to the right of the center of channel.

Some ranges are in the form of a directional light which is a single light with a special lens that shows a white

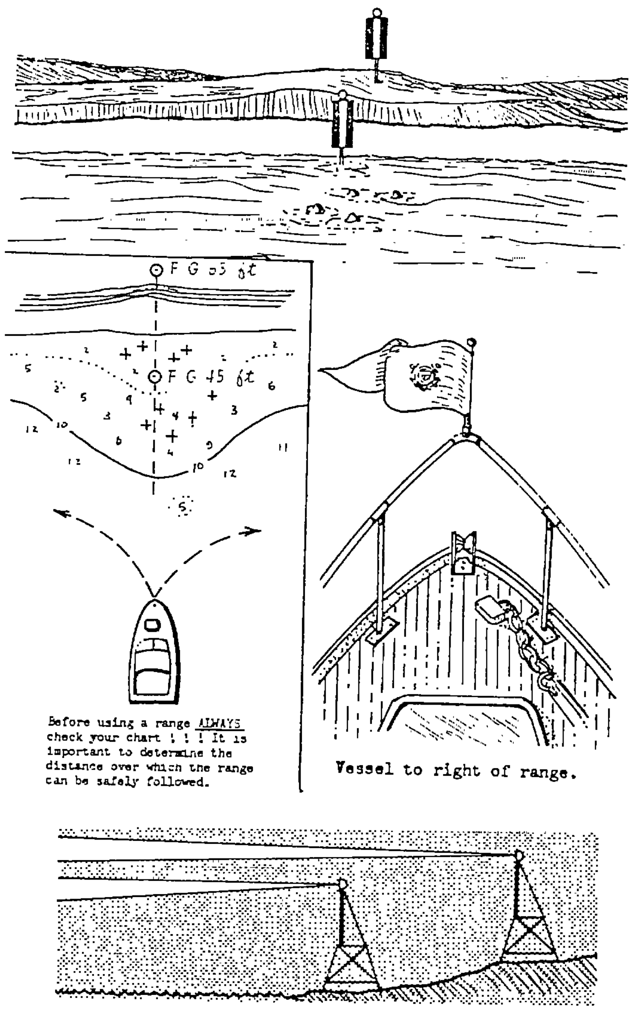
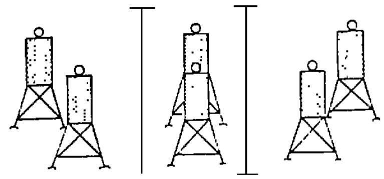


Fig. 12-7 Ranges

Ranges

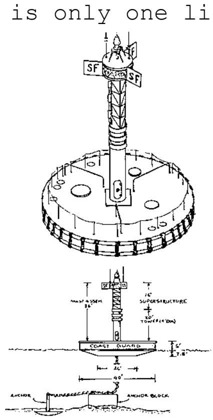


light in a specific direction. On either side of that narrow beam is a red or green light. The width of the sector varies with the particular location. The applicable Light List and chart should be checked for specific information.

Major Lights.
Besides the aids to navigation described earlier in this chapter that are used in various buoyage systems, there are major aids to navigation which also serve the mariner. These major aids include lights located along the seacoast to guide the mariner as the ship nears land, following a sea voyage. These powerful lights are in lighthouses, on lightships and on towers or large navigation buoys. Whether the "light" is classified as primary orsecondary depends upon the importance of its location, intensity and the prominence of its structure. Those of lesser importance are, of course, considered secondary. Refer to the Light List for the individual characteristics of each station.

Lighthouses have structure, of distinctive design and coloration to make identification easy. Until recent years all used to be manned, but they are gradually becoming automated. Besides the "light", many lighthouses are also equipped with fog signals and radiobeacons.

Lightships have distinctive shaped hulls, usually painted red with the name of the station in large white letters on each side. At present, there is only one lightship remaining on active service. It



is the NANTUCKET. Lightships are especially equipped to emit light, sound and radiobeacon signals. Lightships formerly were anchored at specific locations to serve as aids to navigation. Each required a crew of 15 to keep it in operation.

Light Towers have replaced many of the old lightships, and are located in deep water offshore to mark shoals and heavily traveled sea lanes. The foundation of each tower is firmly embedded in bedrock, and each tower is equipped with a light, a fog signal and radiobeacon. A tower is usually manned with a crew of 4 or 5.

Large Navigation Buoys (LNB) have also

been used to replace lightships and are the newest of the three offshore light stations. LNBs are 40 feet in diameter with 42-foot towers, and are fully automated. The light is visible for ten miles and the fog signal is audible to two and a half miles. The radiobeacon transmits a distance of about twenty-five miles.

Fog Signals.
Fog signals are established where fog or other forms of reduced visibility present a hazard to safe navigation. The function of the fog signal is to warn of danger and to indicate position. Fog signals, located at most lighthouse, Large Navigation Buoys and lightships, are operated by mechanical or electrical means, and also may be sounded on definite time schedules. The mariner must be able to identify the fog signal and know from what direction it originates. Different types of fog signals emit different tones produced by varied apparatus which facilitates recognition of the individual station. The type of fog signal for each station is stated in the Light List.

Fog signals are considered solely as warning devices, and cannot be relied upon in navigating a vessel. Every mariner should be aware of the various factors which may interfere with the reception of fog signals.

1. Sound signals in fog are not always dependable, as they may fade altogether from changes in the temperature of the air.

2. Some fog signals require a start-up interval, which means a time lapse between the onset of fog conditions and sounding the signal.

3. Some fog signals may be screened by land masses or other obstructions, or be placed on high cliffs, and the sound may skip.

4. A fog signal may not be heard if the engines of the vessel are operating.

5. If there is fog in some nearby areas, but not at the station, the signal may not be put in operation.

Various types of fog signals include diaphones, diaphragm horns, bells, sirens and whistles. Each type has a distinctive tone for easier recognition and identification.

1. Diaphones emit a blast that may consist of two tones of different pitch, with the first part of the blast high and the last part low. These alternate-pitch signals are called two-sound.

2. Diaphragm horns may produce a single blast, or a chime signal sounded by using more than one horn of differing pitch.

3. Bells are sounded by a hammer that can be manually or automatically actuated. They may be a lighthouses or other stations.

4. Sirens are also used as fog signals.

5. Whistles emit a piercing sound that is quite different from other fog signals, and are easily recognizable by the mariner.

Electronic Aids.
Electronic systems are additional aids to navigation, as they are useful in periods of limited visibility as well as when out of sight of land. The most commonly-used electronic aids include radiobeacons, RACON, and LORAN-C. Marine radiobeacons are electronic aids to navigation with an effective range of 10 to 175 miles. They are particularly helpful during periods of low visibility. On a nautical chart, their location is indicated by the letters "RBn" and a circle. Most radiobeacons transmit in the low frequency range, and are identified

by the distinctive Morse Code signature of their transmission. Radiobeacons transmit continuously or in a sequence. Some continuous radiobeacons, designated as marker beacons, are used as homing beacons to harbor areas.
RACON is an acronym for a radar beacon which transmits a reply when triggered by a ship's radar signal. This reply appears as "paint" on the radar's screen. The paint is in the shape of dashes and dots of a Morse Code letter, usually beginning with a dash. The paint originates at the RACON location and extends radially for 1-2 NM on the radar screen. Transmission characteristics of electronic aids may be found in the appropriate Light List.

LORAN-C is a pulsed hyperbolic, long-range navigation system that operates on a frequency of 100 kHz. A LORAN-C network consists of one "master" station and two or more secondary stations. The constant time differences (TD) obtained from the reading on one station pair provides a hyperbolic line of position. Special charts overprinted with LORAN-C hyperbolic curves are required to plot positions using LORAN-C. Conventional charts may be used when vessels are equipped with LORAN-C units which include microprocessor navigational computers. If so equipped, the unit will convert the TDs and display the actual latitude and longitude.

Omega is another hyperbolic navigational system similar to LORAN but, unlike LORAN, any two stations from which signals can be received may be paired to produce a line of position.

A vessel equipped with a navigational satellite receiver (NAVSAT) is one which is able to take advantage of an accurate, all weather, world-wide navigation system. This system is designed primarily for use by large vessels engaged in long distance, open-water voyages. They depend upon the apparent change in radio wave frequency when the distance between transmitter and receiver changes to fix the position.

STUDENT COURSE CRITIQUE and QUESTIONNAIRE

We are asking you for your comments on improving this course. Please comment on the entire course as you desire. We would like definite answers on the following questions:

1. I found out about this course through: (Check those that apply.)

(a) Newspaper feature article ( )
(b) Newspaper classified as ( )
(c) Radio broadcast ( )
(d) TV program or spot ( )
(e) Word of mouth ( )
(f) Posters ( )
(g) Other (Please list below)

____

2. My impression of the course is that it has been:

(a) Very worthwhile ( )
(b) Good ( )
(c) Only fair ( )
(d) Poor ( )
(e) Too detailed ( )
(f) Too skimpy ( )
(g) Too long ( )
(h) Too short ( )
(i) Too costly ( )
(j) Other (Please indicate below)

____

3. I feel that more time should have been spent on ______________________________

____

4. I think that too much time was spent on ______________________________

____

5. I feel the course should be improved by ______________________________

____

6. What is your evaluation of the following training aids: ______________________________

(a) Slides ______________________________

(b) Films ______________________________

(c) Instructor's training aids ______________________________

(d) Student response ______________________________

7. Do you know of any group (Boating, industrial, church, scouts, fraternal, social etc.) who would be interested in one of the following: (Check ones that apply.)

(a) Three Lesson - Boating Course ( )
(b) Twelve Lesson - Boating Course ( )
(c) Twelve Lesson - Sail Course ( )
(d) A Speaker from the USCG Auxiliary ( )

8. If any of the above are checked, whom should we contact?

Name ______________________________

Address ______________________________

Phone Number ______________________________

9. Are you interested in joining the United States Coast Guard Auxiliary? If so please fill in the following:

Name ______________________________

Address ______________________________

Phone Number ______________________________

10. This course was sponsored by Flotilla __________. We meet at ______________________________

______________________________ on ______________________________

(Please make a note of the place and date. You will be most welcome to attend our next meeting and meet our other members.)

11. To make an appointment for a free COURTESY MARINE EXAMINATION of your boat please fill in the following:

Name ______________________________

Address ______________________________

Location of boat ______________________________

After you have completed this questionnaire, please tear it out and hand it to your Instructor or Course Supervisor. Thank you for you cooperation.

STUDENT COURSE CRITIQUE AND QUESTIONNAIRE

I WOULD LIKE MORE INFORMATION ON JOINING THE U.S. COAST GUARD AUXILIARY:

NAME: ______________________ PHONE #: __________

ADDRESS: ______________________

CITY: ______________ STATE ________ ZIP: ________

I own at least 25% interest in ☐ boat ☐ aircraft ☐ marine radio station

Make of boat: ____________ Length: ____________

Type of Aircraft: ______________________

My boat is kept at: ______________________

I would like a Courtesy Marine Examination: ☐ Date: ____________

I have the following special qualifications that would serve the Coast Guard Auxiliary's Safe Boating Program: ______________________

____

____

(Please turn this information sheet into the Auxiliary Instructor).

I WOULD LIKE MORE INFORMATION ON JOINING THE U.S. COAST GUARD AUXILIARY:

NAME: ______________________ PHONE #: __________

ADDRESS: ______________________

CITY: ______________ STATE: ________ ZIP: ________

I own at least 25% interest in ☐ boat ☐ aircraft ☐ marine radio station

Make of boat: ____________ Length: ____________

Type of Aircraft: ______________________

My boat is kept at: ______________________

I would like a Courtesy Marine Examination: ☐ Date: ____________

I have the following special qualifications that would serve the Coast Guard Auxiliary's Safe Boating Program: ______________________

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(Please turn this information sheet into the Auxiliary Instructor).