

Last painting by Gilbert Stuart (1828). Considered by the family of Bowditch to be the best of various paintings made, although it was unfinished when the artist died.

NATHANIEL BOWDITCH

(1773-1838)

Nathaniel Bowditch was born on March 26, 1773, in Salem, Mass., fourth of the seven children of shipmaster Habakkuk Bowditch and his wife, Mary.

Since the migration of William Bowditch from England to the Colonies in the 17th century, the family had resided at Salem. Most of its sons, like those of other families in this New England seaport, had gone to sea, and many of them became shipmasters. Nathaniel Bowditch himself sailed as master on his last voyage, and two of his brothers met untimely deaths while pursuing careers at sea.

It is reported that Nathaniel Bowditch's father lost two ships at sea, and by late Revolutionary days he returned to the trade of cooper, which he had learned in his youth. This provided insufficient income to properly supply the needs of his growing family, and hunger and cold were often experienced. For many years the nearly destitute family received an annual grant of 15 to 20 dollars from the Salem Marine Society. By the time Nathaniel had reached the age of 10, the family's poverty necessitated his leaving school and joining his father in the cooper's trade.

Nathaniel was unsuccessful as a cooper, and when he was about 12 years of age, he entered the first of two shipchandlery firms by which he was employed. It was during the nearly 10 years he was so employed that his great mind first attracted public attention. From the time he began school Bowditch had an all-consuming interest in learning, particularly mathematics. By his middle teens he was recognized in Salem as an authority on that subject. Salem being primarily a shipping town, most of the inhabitants sooner or later found their way to the ship chandler, and news of the brilliant young clerk spread until eventually it came to the attention of the learned men of his day. Impressed by his desire to educate himself, they supplied him with books that he might learn of the discoveries of other men. Since many of the best books were written by Europeans, Bowditch first taught himself their languages. French, Spanish, Latin, Greek, and German were among the two dozen or more languages and dialects he studied during his life. At the age of 16 he began the study of Newton's *Principia*, translating parts of it from the Latin. He even found an error in that classic, and though lacking the confidence to announce it at the time, he later published his findings and had them accepted.

During the Revolutionary War a privateer out of Beverly, a neighboring town to Salem, had taken as one of its prizes an English vessel which was carrying the philosophical library of a famed Irish scholar, Dr. Richard Kirwan. The books were brought to the Colonies and there bought by a group of educated Salem men who used them to found the Philosophical Library Company, reputed to have been the best library north

of Philadelphia at the time. In 1791, when Bowditch was 18, two Harvard-educated ministers, Rev. John Prince and Rev. William Bentley, persuaded the Company to allow Bowditch the use of its library. Encouraged by these two men and a third—Nathan Read, an apothecary and also a Harvard man—Bowditch studied the works of the great men who had preceded him, especially the mathematicians and the astronomers. By the time he became of age, this knowledge, acquired before and after his long working hours and in his spare time, had made young Bowditch the outstanding mathematician in the Commonwealth, and perhaps in the country.

In the seafaring town of Salem, Bowditch was drawn to navigation early, learning the subject at the age of 13 from an old British sailor. A year later he began studying surveying, and in 1794 he assisted in a survey of the town. At 15 he devised an almanac reputed to have been of great accuracy. His other youthful accomplishments included the construction of a crude barometer and a sundial.

When Bowditch went to sea at the age of 21, it was as captain's writer and nominal second mate, the officer's berth being offered him because of his reputation as a scholar. Under Captain Henry Prince, the ship *Henry* sailed from Salem in the winter of 1795 on what was to be a year-long voyage to the Ile de Bourbon (now called Reunion) in the Indian Ocean.

Bowditch began his seagoing career when accurate time was not available to the average naval or merchant ship. A reliable marine chronometer had been invented some 60 years before, but the prohibitive cost, plus the long voyages without opportunity to check the error of the timepiece, made the large investment an impractical one. A system of determining longitude by "lunar distance," a method which did not require an accurate timepiece, was known, but this product of the minds of mathematicians and astronomers was so involved as to be beyond the capabilities of the uneducated seamen of that day. Consequently, ships navigated by a combination of dead reckoning and parallel sailing (a system of sailing north or south to the latitude of the destination and then east or west to the destination). The navigational routine of the time was "lead, log, and lookout."

To Bowditch, the mathematical genius, computation of lunar distances was no mystery, of course, but he recognized the need for an easier method of working them in order to navigate ships more safely and efficiently. Through analysis and observation, he derived a new and simplified formula during his first trip.

John Hamilton Moore's *The Practical Navigator* was the leading navigational text when Bowditch first went to sea, and had been for many years. Early in his first voyage, however, the captain's writer-second mate began turning up

errors in Moore's book, and before long he found it necessary to recompute some of the tables he most often used in working his sights. Bowditch recorded the errors he found, and by the end of his second voyage, made in the higher capacity of supercargo, the news of his findings in *The New Practical Navigator* had reached Edmund Blunt, a printer at Newburyport, Mass. At Blunt's request, Bowditch agreed to participate with other learned men in the preparation of an American edition of the thirteenth (1798) edition of Moore's work. The first American edition was published at Newburyport by Blunt in 1799. This edition corrected many of the errors that Moore had failed to correct. Although most of the errors were of little significance to practical navigation as they were errors in the fifth and sixth places of logarithm tables, some errors were significant.

The most significant error was listing the year 1800 as a leap year in the table of the sun's declination. The consequence was that Moore gave the declination for MARCH 1, 1800, as $7^{\circ} 11'$. Since the actual value was $7^{\circ} 33'$, the calculation of a meridian altitude would be in error by 22 minutes of latitude.

Bowditch's principal contribution to the first American edition was his chapter "The Method of finding the Longitude at Sea," which was his new method for computing the lunar distance. Following publication of the first American edition, Blunt obtained Bowditch's services in checking the American and English editions for further errors. Blunt then published a second American edition of Moore's thirteenth edition in 1800. When preparing a third American edition for the press, Blunt decided that Bowditch had revised Moore's work to such an extent that Bowditch should be named as author. The title was changed to *The New American Practical Navigator* and the book was published in 1802 as a first edition. Bowditch vowed while writing this edition to "put down in the book nothing I can't teach the crew," and it is said that every member of his crew including the cook could take a lunar observation and plot the ship's position.

Bowditch made a total of five trips to sea, over a period of about nine years, his last as master and part owner of the three-masted *Putnam*. Homeward bound from a 13-month voyage to Sumatra and the Ile de France (now called Mauritius) the *Putnam* approached Salem harbor on December 25, 1803, during a thick fog without having had a celestial observation since noon on the 24th. Relying upon his dead reckoning, Bowditch conned his wooden-hulled ship to the entrance of the rocky harbor, where he had the good fortune to get a momentary glimpse of Eastern Point, Cape Ann, enough to confirm his position. The *Putnam* proceeded in, past such hazards as "Bowditch's Ledge" (named after a great-grandfather who had wrecked his ship on the rock more than a century before) and anchored safely at 1900 that evening. Word of the daring feat, performed when other masters were hove-to outside the harbor, spread along the coast and added greatly to Bowditch's reputation. He was, indeed, the "practical navigator."

His standing as a mathematician and successful shipmaster earned him a lucrative (for those times) position ashore within a matter of weeks after his last voyage. He was installed as president of a Salem fire and marine insurance company at the age of 30, and during the 20 years he held that position the company prospered. In 1823 he left Salem to take a similar position with a Boston insurance firm, serving that company with equal success until his death.

From the time he finished the "*Navigator*" until 1814, Bowditch's mathematical and scientific pursuits consisted of studies and papers on the orbits of comets, applications of Napier's rules, magnetic variation, eclipses, calculations on tides, and the charting of Salem harbor. In that year, however, he turned to what he considered the greatest work of his life, the translation into English of *Mecanique Celeste*, by Pierre Laplace. *Mecanique Celeste* was a summary of all the then known facts about the workings of the heavens. Bowditch translated four of the five volumes before his death, and published them at his own expense. He gave many formula derivations which Laplace had not shown, and also included further discoveries following the time of publication. His work made this information available to American astronomers and enabled them to pursue their studies on the basis of that which was already known. Continuing his style of writing for the learner, Bowditch presented his English version of *Mecanique Celeste* in such a manner that the student of mathematics could easily trace the steps involved in reaching the most complicated conclusions.

Shortly after the publication of *The New American Practical Navigator*, Harvard College honored its author with the presentation of the honorary degree of Master of Arts, and in 1816 the college made him an honorary Doctor of Laws. From the time the Harvard graduates of Salem first assisted him in his studies, Bowditch had a great interest in that college, and in 1810 he was elected one of its Overseers, a position he held until 1826, when he was elected to the Corporation. During 1826-27 he was the leader of a small group of men who saved the school from financial disaster by forcing necessary economies on the college's reluctant president. At one time Bowditch was offered a Professorship in Mathematics at Harvard but this, as well as similar offers from West Point and the University of Virginia, he declined. In all his life he was never known to have made a public speech or to have addressed any large group of people.

Many other honors came to Bowditch in recognition of his astronomical, mathematical, and marine accomplishments. He became a member of the American Academy of Arts and Sciences, the East India Marine Society, the Royal Academy of Edinburgh, the Royal Society of London, the Royal Irish Academy, the American Philosophical Society, the Connecticut Academy of Arts and Sciences, the Boston Marine Society, the Royal Astronomical Society, the Palermo Academy of Science, and the Royal Academy of Berlin.

Nathaniel Bowditch outlived all of his brothers and sisters by nearly 30 years. Death came to him on March 16, 1838, in his sixty-fifth year. The following eulogy by the

Salem Marine Society indicates the regard in which this distinguished American was held by his contemporaries:

“In his death a public, a national, a human benefactor has departed. Not this community, nor our country only, but the whole world, has reason to do honor to his memory. When the voice of Eulogy shall be still, when the tear of Sorrow shall cease to flow, no monument will be needed to keep alive his memory among men; but as long as ships shall sail, the needle point to the north, and the stars go through their wonted courses in the heavens, the name of Dr. Bowditch will be revered as of one who helped his fellow-men in a time of need, who was and is a guide to them over the pathless ocean, and of one who forwarded the great interests of mankind.”

The New American Practical Navigator was revised by Nathaniel Bowditch several times after 1802 for subsequent

editions of the book. After his death, Jonathan Ingersoll Bowditch, a son who made several voyages, took up the work and his name appeared on the title page from the eleventh edition through the thirty-fifth, in 1867. In 1868 the newly organized U.S. Navy Hydrographic Office bought the copyright. Revisions have been made from time to time to keep the work in step with navigational improvements. The name has been altered to the *American Practical Navigator*, but the book is still commonly known as “Bowditch.” A total of more than 900,000 copies has been printed in about 75 editions during the nearly two centuries since the book was first published in 1802. It has lived because it has combined the best techniques of each generation of navigators, who have looked to it as their final authority.

THE NEW AMERICAN
PRACTICAL NAVIGATOR;
BEING AN
EPITOME OF NAVIGATION;
CONTAINING ALL THE TABLES NECESSARY TO BE USED WITH THE
NAUTICAL ALMANAC,
IN DETERMINING THE
L A T I T U D E;
AND THE
LONGITUDE BY LUNAR OBSERVATIONS;
AND
KEEPING A COMPLETE RECKONING AT SEA:
ILLUSTRATED BY
PROPER RULES AND EXAMPLES:
THE WHOLE ENCOMPASSED IN A
JOURNAL,

KEPT FROM
BOSTON TO MADEIRA,
IN WHICH ALL THE RULES OF NAVIGATION ARE INTRODUCED:
A L S O
The Description of the most useful Rules of Trigonometry: With many useful Problems in Mensuration, Surveying,
and Gauging; And a Dictionary of Sea-Terms; with the Manner of performing the most common Operations at Sea.
TO WHICH ARE ADDED,
Some General Instructions and Observations by Merchants, Masters of Vessels, and others concerned in Navigation,
relative to Maritime Laws and Maritime Customs.

FROM THE BEST AUTHORITIES.

ENRICHED WITH A NUMBER OF
NEW TABLES,
WITH ORIGINAL IMPROVEMENTS AND ADDITIONS, AND A LARGE
VARIETY OF NEW AND IMPORTANT MATTER:
A L S O,
MANY THOUSAND ERRORS ARE CORRECTED,
WHICH HAVE APPEARED IN THE BEST SYSTEMS OF NAVIGATION YET PUBLISHED.

BY NATHANIEL BOWDITCH,
FELLOW OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES.

ILLUSTRATED WITH COPPERPLATES.

First Edition.

PRINTED AT NEWBURYPORT, (Mass.) 1802,

BY
EDMUND M. BLUNT, (Proprietor)
FOR CUSHING & APPLETON, SALEM.

AND BY STEPHEN BROWNELL, BOSTON; AND MATHIAS BRADSHAW, NEW-YORK,
IN THE UNITED STATES AND WEST-INDIES.

PREFACE

The Naval Observatory library in Washington, D.C., is unnaturally quiet. It is a large circular room, filled with thousands of books. Its acoustics are perfect; a mere whisper from the room's open circular balcony can be easily heard by those standing on the ground floor. A fountain in the center of the ground floor softly breaks the room's silence as its water stream slowly splashes into a small pool. A library clerk will lead you into a small antechamber where there is a vault containing the Observatory's most rare books. In this vault, one can find an original 1802 first edition of the *New American Practical Navigator*.

One cannot hold this small, delicate, slipcovered book without being impressed by the nearly 200-year unbroken chain of publication that it has enjoyed. It sailed on U.S. merchantmen shortly after the quasi-war with France and during British impressment of merchant seamen that led to the War of 1812. It sailed on U.S. Naval vessels during operations against Mexico in the 1840's, on ships of both the Union and Confederate fleets during the Civil War, and with the U.S. Navy in Cuba in 1898. It went with the Great White Fleet around the world, across the North Atlantic to Europe during both World Wars, to Asia during the Korean and Vietnam Wars, and to the Middle East during Operation Desert Storm.

As navigational requirements and procedures have changed throughout the years, *Bowditch* has changed with them. Originally devoted almost exclusively to celestial navigation, it now also covers a host of modern topics. It is as practical today as it was when Nathaniel Bowditch, master of the *Putnam*, gathered the crew on deck and taught them the mathematics involved in calculating lunar distances. It is that practicality that has been the publication's greatest strength. It is that practicality that makes the publication as useful today as it was in the age of sail.

Seafarers have long memories. In no other profession is tradition more closely guarded. Even the oldest and most cynical acknowledge the special bond that connects those who have made their livelihood plying the sea. This bond is not comprised of a single strand; rather, it is a rich and varied tapestry that stretches from the present back to the birth of our nation and its seafaring culture. As this book is a part of that tapestry, it should not be lightly regarded; rather, it should be preserved, as much for its historical importance as for its practical utility.

Since antiquity, mariners have gathered available navigation information and put it into a text for others to follow. One of the first attempts at this involved volumes of Spanish and Portuguese navigational manuals translated into English between about 1550 to 1750. Writers and translators of the time "borrowed" freely in compiling nav-

igational texts, a practice which continues today with works such as *Sailing Directions* and *Pilots*.

Colonial and early American navigators depended exclusively on English navigation texts because there were no American editions. The first American navigational text, *Orthodoxal Navigation*, was completed by Benjamin Hubbard in 1656. The first American navigation text published in America was Captain Thomas Truxton's *Remarks, Instructions, and Examples Relating to the Latitude and Longitude; also the Variation of the Compass, Etc., Etc.*, published in 1794.

The most popular navigational text of the late 18th century was John Hamilton Moore's *The New Practical Navigator*. Edmund M. Blunt, a Newburyport publisher, decided to issue a revised copy of this work for American navigators. Blunt convinced Nathaniel Bowditch, a locally famous mariner and mathematician, to revise and update *The New Practical Navigator*. Several other men also assisted in the revision. Blunt's *The New Practical Navigator* was published in 1799. Blunt also published a second American edition of Hamilton's book in 1800.

By 1802, when Blunt was ready to publish a third edition, Nathaniel Bowditch and others had corrected so many errors in Hamilton's work that Blunt decided to issue the work as a first edition of the *New American Practical Navigator*. It is to that 1802 work that the current edition of the *American Practical Navigator* traces its pedigree.

The *New American Practical Navigator* stayed in the Bowditch and Blunt family until the government bought the copyright in 1867. Edmund M. Blunt published the book until 1833; upon his retirement, his sons, Edmund and George, took over publication. The elder Blunt died in 1862; his son Edmund followed in 1866. The next year, 1867, George Blunt sold the copyright to the government for \$25,000. The government has published *Bowditch* ever since. George Blunt died in 1878.

Nathaniel Bowditch continued to correct and revise the book until his death in 1838. Upon his death, the editorial responsibility for the *American Practical Navigator* passed to his son, J. Ingersoll Bowditch. Ingersoll Bowditch continued editing the *Navigator* until George Blunt sold the copyright to the government. He outlived all of the principals involved in publishing and editing the *Navigator*, dying in 1889.

The U.S. government has published some 52 editions since acquiring the copyright to the book that has come to be known simply by its original author's name, "*Bowditch*". Since the government began production, the book has been known by its year of publishing, instead of by the edition number. During a revision in 1880 by Commander Phillip H. Cooper, USN, the name was changed to *American Prac-*

tical Navigator. Bowditch's original method of taking "lunars" was finally dropped from the book in 1914. After several more minor revisions and printings, *Bowditch* was extensively revised between 1946 and 1958.

The present volume, while retaining the basic format of the 1958 version, reorganizes the subjects, deletes obsolete text, and adds new material to keep pace with the extensive changes in navigation that have taken place in the electronic age.

This 1995 edition of the *American Practical Navigator* incorporates extensive changes in organization, format, and content. Recent advances in navigational electronics, communications, positioning, and other technologies have transformed the way navigation is practiced at sea, and it is clear that even more changes are forthcoming. The changes to this edition of BOWDITCH are intended to ensure that this publication remains the premier reference work for practical marine navigation. Concerted efforts were made to return to Nathaniel Bowditch's original intention "to put down in the book nothing I can't teach the crew." To this end, many complex formulas and equations have been eliminated, and emphasis placed on the capabilities and limitations of various navigation systems and how to use them, instead of explaining complex technical and theoretical details. This edition replaces but does not cancel former editions, which may be retained and consulted as to navigation methods not discussed herein.

The former Volume II has been incorporated into this volume to save space and production cost. A larger page size has also been chosen for similar reasons. These two changes allow us to present a single, comprehensive navigation science reference which explains modern navigational methods while respecting traditional ones. The goal of the changes is to put as much useful information before the navigator as possible in the most understandable and readable format.

TAB 1, FUNDAMENTALS, has been reorganized to include an overview of the types and phases of marine navigation and the organizations which support and regulate it. It includes chapters relating to the structure, use and limitations of nautical charts; chart datums and their importance; and other material of a basic nature. The former chapter on the history of navigation has been largely removed. Historical facts are included in the text where necessary to explain present practices or conventions.

TAB 2, PILOTING, now emphasizes the practical aspects of navigating a vessel in restricted waters.

TAB 3, ELECTRONIC NAVIGATION, returns to the position it held in the 1958 edition. Electronic systems are now the primary means of positioning of the modern navigator. Chapters deal with each of the several electronic methods of navigation, organized by type.

TAB 4, CELESTIAL NAVIGATION, has been streamlined and updated. The text in this section contains updated examples and problems and a completely re-edited sight reduction chapter. Extracts from necessary tables have been

added to the body of the text for easier reference.

TAB 5, NAVIGATIONAL MATHEMATICS, includes chapters relating to such topics as basic navigational mathematics and computer use in the solution of navigation problems.

TAB 6, NAVIGATIONAL SAFETY, discusses aspects of the new distress and safety communications systems now in place or being implemented in the next several years, as well as navigation regulations, emergency navigation procedures, and distress communications.

TAB 7, OCEANOGRAPHY, is updated and consolidated, but largely unchanged from the former edition.

TAB 8, MARINE METEOROLOGY, (formerly WEATHER) incorporates new weather routing and forecasting methods and material from former appendices. Included are new color plates of the Beaufort Sea States (Courtesy of Environment Canada).

The Glossary has been extensively edited and updated with modern navigational terms, including computer terminology.

This edition was produced largely electronically from start to finish, using the latest in publishing software and data transfer techniques to provide a very flexible production system. This ensures not only that this book is the most efficiently produced ever, but also that it can be easily updated and improved when it again becomes dated, as it surely will.

The masculine pronoun "he" used throughout is meant to refer to both genders.

This book may be kept corrected using the Notice to Mariners and Summary of Corrections. Suggestions and comments for changes and additions may be sent to:

NAVIGATION DIVISION
ST D 44
DMA HYDROGRAPHIC/TOPOGRAPHIC CENTER
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BETHESDA, MD 20816-5003

This book could not have been produced without the expertise of dedicated personnel from many organizations, among them: U.S. Coast Guard, U.S. Naval Academy, U.S. Naval Oceanographic Office, Fleet Training Center (Norfolk), Fleet Numerical Meteorology and Oceanography Center (Monterey), the U.S. Naval Observatory, U.S. Merchant Marine Academy, U.S. Coast and Geodetic Survey, the National Ocean Service, and the National Weather Service. In addition to official government expertise, we appreciate the contributions of private organizations, in particular the Institute of Navigation, and other organizations and individuals too numerous to mention by name. Mariners worldwide can be grateful for the experience, dedication, and professionalism of the people who generously gave their time in this effort.

THE EDITORS

CHAPTER 1

INTRODUCTION TO MARINE NAVIGATION

DEFINITIONS

100. The Art And Science Of Navigation

Marine navigation blends both science and art. A good navigator gathers information from every available source, evaluates this information, determines a fix, and compares that fix with his pre-determined “dead reckoning” position. A navigator constantly evaluates the ship’s position, anticipates dangerous situations well before they arise, and always keeps “ahead of the vessel.” The modern navigator must also understand the basic concepts of the many navigation systems used today, evaluate their output’s accuracy, and arrive at the best possible navigational decisions.

Navigation methods and techniques vary with the type of vessel, the conditions, and the navigator’s experience. Navigating a pleasure craft, for example, differs from navigating a container ship. Both differ from navigating a naval vessel. The navigator uses the methods and techniques best suited to the vessel and conditions at hand.

Some important elements of successful navigation cannot be acquired from any book or instructor. The *science* of navigation can be taught, but the *art* of navigation must be developed from experience.

101. Types Of Navigation

Methods of navigation have changed through history. Each new method has enhanced the mariner’s ability to complete his voyage safely and expeditiously. One of the most important judgments the navigator must make involves choosing the best method to use. Commonly recognized types of navigation are listed below.

- **Dead reckoning (DR)** determines position by advancing a known position for courses and distances. A position so determined is called a dead reckoning (DR) position. It is generally accepted that only course and speed determine the DR position. Correcting the DR position for leeway, current effects, and steering error result in an **estimated position (EP)**. An inertial navigator develops an extremely accurate EP.
- **Piloting** involves navigating in restricted waters with frequent determination of position relative to geographic and hydrographic features.

- **Celestial navigation** involves reducing celestial measurements to lines of position using tables, spherical trigonometry, and almanacs. It is used primarily as a backup to satellite and other electronic systems in the open ocean.
- **Radio navigation** uses radio waves to determine position by either radio direction finding systems or hyperbolic systems.
- **Radar navigation** uses radar to determine the distance from or bearing of objects whose position is known. This process is separate from radar’s use as a collision avoidance system.
- **Satellite navigation** uses artificial earth satellites for determination of position.

Electronic integrated bridge concepts are driving future navigation system planning. Integrated systems take inputs from various ship sensors, electronically display positioning information, and provide control signals required to maintain a vessel on a preset course. The navigator becomes a system manager, choosing system presets, interpreting system output, and monitoring vessel response.

In practice, a navigator synthesizes different methodologies into a single integrated system. He should never feel comfortable utilizing only one method when others are available for backup. Each method has advantages and disadvantages. The navigator must choose methods appropriate to each particular situation.

With the advent of automated position fixing and electronic charts, modern navigation is almost completely an electronic process. The mariner is constantly tempted to rely solely on electronic systems. This would be a mistake. Electronic navigation systems are always subject to failure, and the professional mariner must never forget that the safety of his ship and crew may depend on skills that differ little from those practiced generations ago. Proficiency in conventional piloting and celestial navigation remains essential.

102. Phases Of Navigation

Four distinct phases define the navigation process. The

mariner should choose the system mix that meets the accuracy requirements of each phase.

- **Inland Waterway Phase:** Piloting in narrow canals, channels, rivers, and estuaries.
- **Harbor/Harbor Approach Phase:** Navigating to a harbor entrance and piloting in harbor approach channels.

- **Coastal Phase:** Navigating within 50 miles of the coast or inshore of the 200 meter depth contour.
- **Ocean Phase:** Navigating outside the coastal area in the open sea.

The navigator's position accuracy requirements, his fix interval, and his systems requirements differ in each phase. The following table can be used as a general guide for selecting the proper system(s).

	<i>Inland Waterway</i>	<i>Harbor/Harbor Approach</i>	<i>Coastal</i>	<i>Ocean</i>
DR	X	X	X	X
Piloting	X	X	X	
Celestial			X	X
Radio		X	X	X
Radar	X	X	X	
Satellite	X*	X	X	X

Table 102. The relationship of the types and phases of navigation.

* Differential GPS may be used if available.

NAVIGATIONAL TERMS AND CONVENTIONS

103. Important Conventions And Concepts

Throughout the history of navigation, numerous terms and conventions have been established which enjoy worldwide recognition. The professional navigator, to gain a full understanding of his field, should understand the origin of certain terms, techniques, and conventions. The following section discusses some of the important ones.

Defining a **prime meridian** is a comparatively recent development. Until the beginning of the 19th century, there was little uniformity among cartographers as to the meridian from which to measure longitude. This did not lead to any problem because there was no widespread method for determining longitude accurately.

Ptolemy, in the 2nd century AD, measured longitude eastward from a reference meridian 2 degrees west of the Canary Islands. In 1493, Pope Alexander VI established a line in the Atlantic west of the Azores to divide the territories of Spain and Portugal. For many years, cartographers of these two countries used this dividing line as the prime meridian. In 1570 the Dutch cartographer Ortelius used the easternmost of the Cape Verde Islands. John Davis, in his 1594 *The Seaman's Secrets*, used the Isle of Fez in the Canaries because there the variation was zero. Mariners paid little attention to these conventions and often reckoned their longitude from several different capes and ports during a

voyage.

The meridian of London was used as early as 1676, and over the years its popularity grew as England's maritime interests increased. The system of measuring longitude both east and west through 180° may have first appeared in the middle of the 18th century. Toward the end of that century, as the Greenwich Observatory increased in prominence, English cartographers began using the meridian of that observatory as a reference. The publication by the Observatory of the first British Nautical Almanac in 1767 further entrenched Greenwich as the prime meridian. An unsuccessful attempt was made in 1810 to establish Washington, D.C. as the prime meridian for American navigators and cartographers. In 1884, the meridian of Greenwich was officially established as the prime meridian. Today, all maritime nations have designated the Greenwich meridian the prime meridian, except in a few cases where local references are used for certain harbor charts.

Charts are graphic representations of areas of the earth for use in marine or air navigation. Nautical charts depict features of particular interest to the marine navigator. Charts have probably existed since at least 600 BC. Stereographic and orthographic projections date from the 2nd century BC. In 1569 Gerardus Mercator published a chart using the mathematical principle which now bears his name. Some 30 years later, Edward Wright published cor-

rected mathematical tables for this projection, enabling cartographers to produce charts on the Mercator projection. This projection is still widely in use.

Sailing directions or **pilots** have existed since at least the 6th century BC. Continuous accumulation of navigational data, along with increased exploration and trade, led to increased production of volumes through the Middle Ages. “Routiers” were produced in France about 1500; the English referred to them as “rutters.” In 1584 Lucas Waghenauer published the *Spiegel der Zeevaerdt* (*The Mariner’s Mirror*), which became the model for such publications for several generations of navigators. They were known as “Waggoners” by most sailors. Modern pilots and sailing directions are based on extensive data collection and compilation efforts begun by Matthew Fontaine Maury beginning in 1842.

The **compass** was developed about 1000 years ago. The origin of the magnetic compass is uncertain, but Norsemen used it in the 11th century. It was not until the 1870s that Lord Kelvin developed a reliable dry card marine compass. The fluid-filled compass became standard in 1906.

Variation was not understood until the 18th century, when Edmond Halley led an expedition to map lines of variation in the South Atlantic. **Deviation** was understood at least as early as the early 1600s, but correction of compass error was not possible until Matthew Flinders discovered that a vertical iron bar could reduce errors. After 1840, British Astronomer Royal Sir George Airy and later Lord Kelvin developed combinations of iron masses and small magnets to eliminate most magnetic compass error.

The **gyrocompass** was made necessary by iron and steel ships. Leon Foucault developed the basic gyroscope in 1852. An American (Elmer Sperry) and a German (Anshutz Kampfe) both developed electrical gyrocompasses in the early years of the 20th century.

The **log** is the mariner’s speedometer. Mariners originally measured speed by observing a chip of wood passing down the side of the vessel. Later developments included a wooden board attached to a reel of line. Mariners measured speed by noting how many knots in the line unreel as the ship moved a measured amount of time; hence the term **knot**. Mechanical logs using either a small paddle wheel or a rotating spinner arrived about the middle of the 17th century. The taffrail log still in limited use today was developed in 1878. Modern logs use electronic sensors or spinning devices that induce small electric fields proportional to a vessel’s speed. An engine revolution counter or shaft log often measures speed onboard large ships. Doppler speed logs are used on some vessels for very accurate speed readings. Inertial and satellite systems also provide highly accurate speed readings.

The Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 established the **metric system** of weights and measures in the United States. As a result, the government is converting charts to

the metric format. Considerations of expense, safety of navigation, and logical sequencing will require a conversion effort spanning many years. Notwithstanding the conversion to the metric system, the common measure of distance at sea is the **nautical mile**.

The current policy of the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) and the National Ocean Service (NOS) is to convert new compilations of nautical, special purpose charts, and publications to the metric system. This conversion began on January 2, 1970. Most modern maritime nations have also adopted the meter as the standard measure of depths and heights. However, older charts still on issue and the charts of some foreign countries may not conform to this standard.

The **fathom** as a unit of length or depth is of obscure origin. Posidonius reported a sounding of more than 1,000 fathoms in the 2nd century BC. How old the unit was then is unknown. Many modern charts are still based on the fathom, as conversion to the metric system continues.

The sailings refer to various methods of mathematically determining course, distance, and position. They have a history almost as old as mathematics itself. Thales, Hipparchus, Napier, Wright, and others contributed the formulas that permit computation of course and distance by plane, traverse, parallel, middle latitude, Mercator, and great circle sailings.

104. The Earth

The earth is an oblate spheroid (a sphere flattened at the poles). Measurements of its dimensions and the amount of its flattening are subjects of geodesy. However, for most navigational purposes, assuming a spherical earth introduces insignificant error. The earth’s axis of rotation is the line connecting the North Pole and the South Pole.

A **great circle** is the line of intersection of a sphere and a plane through its center. This is the largest circle that can be drawn on a sphere. The shortest line on the surface of a sphere between two points on the surface is part of a great circle. On the spheroidal earth the shortest line is called a **geodesic**. A great circle is a near enough approximation to a geodesic for most problems of navigation. A **small circle** is the line of intersection of a sphere and a plane which does not pass through the center. See Figure 104a.

The term **meridian** is usually applied to the **upper branch** of the half-circle from pole to pole which passes through a given point. The opposite half is called the **lower branch**.

A **parallel** or parallel of latitude is a circle on the surface of the earth parallel to the plane of the equator. It connects all points of equal latitude. The equator is a great circle at latitude 0°. See Figure 104b. The poles are single points at latitude 90°. All other parallels are small circles.



Figure 104a. The planes of the meridians meet at the polar axis.



Figure 104b. The equator is a great circle midway between the poles.

105. Coordinates

Coordinates, termed **latitude** and **longitude**, can define any position on earth. **Latitude (L, lat.)** is the angular distance from the equator, measured northward or southward along a meridian from 0° at the equator to 90° at the poles. It is designated north (N) or south (S) to indicate the direction of measurement.

The **difference of latitude (l, DLat.)** between two places is the angular length of arc of any meridian between their parallels. It is the numerical difference of the latitudes if the places are on the same side of the equator; it is the sum of the latitudes if the places are on opposite sides of the equator. It may be designated north (N) or south (S) when appropriate. The middle or **mid-latitude (Lm)** between two places on the same side of the equator is half the sum of their latitudes. Mid-latitude is labeled N or S to indicate whether it is north or south of the equator.

The expression may refer to the mid-latitude of two places on opposite sides of the equator. In this case, it is equal to half the difference between the two latitudes and takes the name of the place farthest from the equator. However, this usage is misleading because it lacks the significance usually associated with the expression. When the places are on opposite sides of the equator, two mid-latitudes are generally used. Calculate these two mid-latitudes by averaging each latitude and 0° .

Longitude (l, long.) is the angular distance between

the prime meridian and the meridian of a point on the earth, measured eastward or westward from the prime meridian through 180° . It is designated east (E) or west (W) to indicate the direction of measurement.

The **difference of longitude (DLo)** between two places is the shorter arc of the parallel or the smaller angle at the pole between the meridians of the two places. If both places are on the same side (east or west) of Greenwich, DLo is the numerical difference of the longitudes of the two places; if on opposite sides, DLo is the numerical sum unless this exceeds 180° , when it is 360° minus the sum. The distance between two meridians at any parallel of latitude, expressed in distance units, usually nautical miles, is called **departure (p, Dep.)**. It represents distance made good east or west as a craft proceeds from one point to another. Its numerical value between any two meridians decreases with increased latitude, while DLo is numerically the same at any latitude. Either DLo or p may be designated east (E) or west (W) when appropriate.

106. Distance On The Earth

Distance, as used by the navigator, is the length of the **rhumb line** connecting two places. This is a line making the same angle with all meridians. Meridians and parallels which also maintain constant true directions may be considered special cases of the rhumb line. Any other rhumb line spirals toward the pole, forming a **loxodromic curve** or

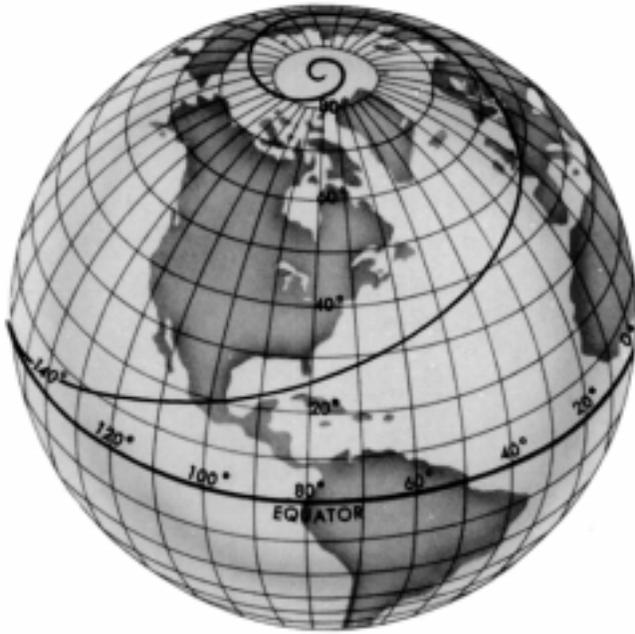


Figure 106. A loxodrome

loxodrome. See Figure 106. Distance along the great circle connecting two points is customarily designated **great-circle distance**. For most purposes, considering the nautical mile the length of one minute of latitude introduces no significant error.

Speed (S) is rate of motion, or distance per unit of time. A **knot (kn.)**, the unit of speed commonly used in navigation, is a rate of 1 nautical mile per hour. The expression **speed of advance (SOA)** is used to indicate the speed to be made along the intended track. **Speed over the ground (SOG)** is the actual speed of the vessel over the surface of the earth at any given time. To calculate **speed made good (SMG)** between two positions, divide the distance between the two positions by the time elapsed between the two positions.

107. Direction On The Earth

Direction is the position of one point relative to another. Navigators express direction as the angular difference in degrees from a reference direction, usually north or the ship's head. **Course (C, Cn)** is the horizontal direction in which a vessel is steered or intended to be steered, expressed as angular distance from north clockwise through 360°. Strictly used, the term applies to direction through the water, not the direction intended to be made good over the ground.

The course is often designated as true, magnetic, compass, or grid according to the reference direction. **Track made good (TMG)** is the single resultant direction from the point of departure to point of arrival at any given time. **Course of advance (COA)** is the direction intended to be made good over the ground, and **course over ground (COG)** is the direction between a vessel's last fix and an EP. A course line is a line drawn on a chart extending in the direction of a course. It is sometimes convenient to express a course as an angle from either north or south, through 90° or 180°. In this case it is designated course angle (C) and should be properly labeled to indicate the origin (prefix) and direction of measurement (suffix). Thus, C N35°E = Cn 035° (000° + 35°), C N155°W = Cn 205° (360° - 155°), C S47°E = Cn 133° (180° - 47°). But Cn 260° may be either C N100°W or C S80°W, depending upon the conditions of the problem.

Track (TR) is the intended horizontal direction of travel with respect to the earth. The terms intended track and trackline are used to indicate the path of intended travel. See Figure 107a. The track consists of one or a series of course lines, from the point of departure to the destination, along which it is intended to proceed. A great circle which a vessel intends to follow is called a **great-circle track**, though it consists of a series of straight lines approximating a great circle.

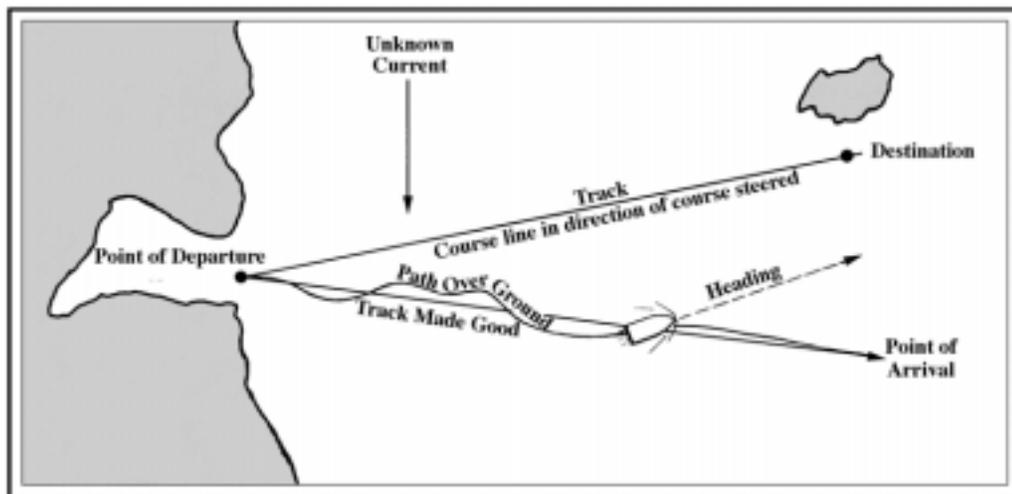


Figure 107a. Course line, track, track made good, and heading.

Heading (Hdg., SH) is the direction in which a vessel is pointed, expressed as angular distance from 000° clockwise through 360°. Do not confuse heading and course. Heading constantly changes as a vessel yaws back and forth across the course due to sea, wind, and steering error.

Bearing (B, Brg.) is the direction of one terrestrial point from another, expressed as angular distance from 000° (North) clockwise through 360°. When measured through 90° or 180° from either north or south, it is called bearing angle (B). Bearing and azimuth are sometimes used interchangeably, but the latter more accurately refers to the horizontal direction of a point on the celestial sphere from

a point on the earth. A relative bearing is measured relative to the ship's heading from 000° (dead ahead) clockwise through 360°. However, it is sometimes conveniently measured right or left from 0° at the ship's head through 180°. This is particularly true when using the table for Distance of an Object by Two Bearings.

To convert a relative bearing to a true bearing, add the true heading:

$$\begin{aligned} \text{True Bearing} &= \text{Relative Bearing} + \text{True Heading.} \\ \text{Relative Bearing} &= \text{True Bearing} - \text{True Heading.} \end{aligned}$$

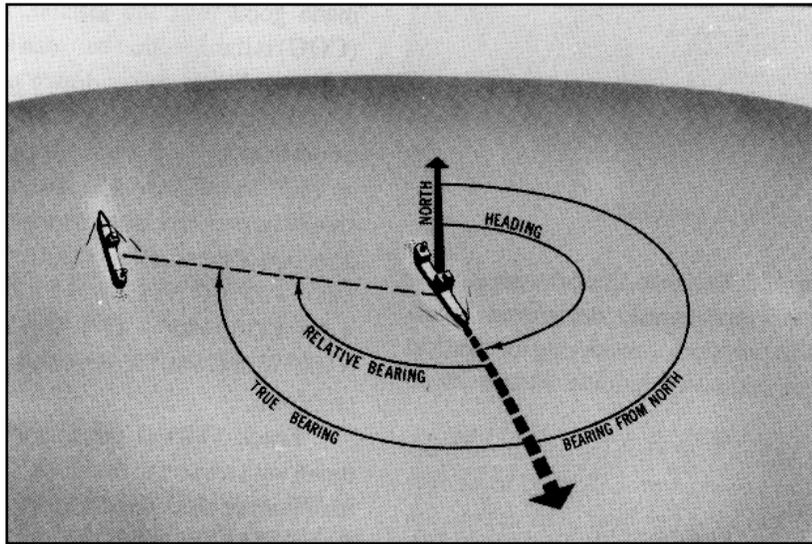


Figure 107b. Relative Bearing.

DEVELOPMENT OF NAVIGATION

108. Latitude And Longitude Determination

Navigators have made latitude observations for thousands of years. Accurate sun declination tables have been published for centuries, enabling experienced seamen to compute latitude to within 1 or 2 degrees. Mariners still use meridian observations of the sun and highly refined ex-meridian techniques. Those who today determine their latitude by measuring the altitude of Polaris are using a method well known to 15th century navigators.

A method of finding longitude eluded mariners for centuries. Several solutions independent of time proved too cumbersome. The lunar distance method, which determines GMT by observing the moon's position among the stars, became popular in the 1800s. However, the mathematics required by most of these processes were far above the

abilities of the average seaman. It was apparent that the solution lay in keeping accurate time at sea.

In 1714, the British Board of Longitude was formed, offering a small fortune in reward to anyone who could provide a solution to the problem.

An Englishman, John Harrison, responded to the challenge, developing four chronometers between 1735 and 1760. The most accurate of these timepieces lost only 15 seconds on a 156 day round trip between London and Barbados. The Board, however, paid him only half the promised reward. The King finally intervened on Harrison's behalf, and Harrison received his full reward of £20,000 at the advanced age of 80.

Rapid chronometer development led to the problem of determining **chronometer error** aboard ship. **Time balls**, large black spheres mounted in port in prominent locations,

were dropped at the stroke of noon, enabling any ship in harbor which could see the ball to determine chronometer error. By the end of the U.S. Civil War, telegraph signals were being used to key time balls. Use of radio signals to send time ticks to ships well offshore began in 1904, and soon worldwide signals were available.

109. The Navigational Triangle

Modern celestial navigators reduce their celestial observations by solving a **navigational triangle** whose points are the elevated pole, the celestial body, and the zenith of the observer. The sides of this triangle are the polar distance of the body (**codeclination**), its zenith distance (**coalitude**), and the polar distance of the zenith (**colatitude** of the observer).

A spherical triangle was first used at sea in solving **lunar distance** problems. Simultaneous observations were made of the altitudes of the moon and the sun or a star near the ecliptic and the angular distance between the moon and the other body. The zenith of the observer and the two celestial bodies formed the vertices of a triangle whose sides were the two coalitudes and the angular distance between the bodies. Using a mathematical calculation the navigator "cleared" this distance of the effects of refraction and parallax applicable to each altitude. This corrected value was then used as an argument for entering the almanac. The almanac gave the true lunar distance from the sun and several stars at 3 hour intervals. Previously, the navigator had set his watch or checked its error and rate with the local mean time determined by celestial observations. The local mean time of the watch, properly corrected, applied to the Greenwich mean time obtained from the lunar distance observation, gave the longitude.

The calculations involved were tedious. Few mariners could solve the triangle until Nathaniel Bowditch published his simplified method in 1802 in *The New American Practical Navigator*.

Reliable chronometers were available in 1802, but their high cost precluded their general use aboard most ships. However, most navigators could determine their longitude using Bowditch's method. This eliminated the need for parallel sailing and the lost time associated with it. Tables for the lunar distance solution were carried in the American nautical almanac until the second decade of the 20th century.

110. The Time Sight

The theory of the **time sight** had been known to mathematicians since the development of spherical trigonometry, but not until the chronometer was developed could it be used by mariners.

The time sight used the modern navigational triangle. The codeclination, or polar distance, of the body could be determined from the almanac. The zenith distance (coalitude) was determined by observation. If the colatitude were known, three

sides of the triangle were available. From these the meridian angle was computed. The comparison of this with the Greenwich hour angle from the almanac yielded the longitude.

The time sight was mathematically sound, but the navigator was not always aware that the longitude determined was only as accurate as the latitude, and together they merely formed a point on what is known today as a **line of position**. If the observed body was on the prime vertical, the line of position ran north and south and a small error in latitude generally had little effect on the longitude. But when the body was close to the meridian, a small error in latitude produced a large error in longitude.

The line of position by celestial observation was unknown until discovered in 1837 by 30-year-old Captain Thomas H. Sumner, a Harvard graduate and son of a United States congressman from Massachusetts. The discovery of the "**Sumner line**," as it is sometimes called, was considered by Maury "the commencement of a new era in practical navigation." This was the turning point in the development of modern celestial navigation technique. In Sumner's own words, the discovery took place in this manner:

Having sailed from Charleston, S. C., 25th November, 1837, bound to Greenock, a series of heavy gales from the Westward promised a quick passage; after passing the Azores, the wind prevailed from the Southward, with thick weather; after passing Longitude 21° W, no observation was had until near the land; but soundings were had not far, as was supposed, from the edge of the Bank. The weather was now more boisterous, and very thick; and the wind still Southerly; arriving about midnight, 17th December, within 40 miles, by dead reckoning, of Tusker light; the wind hauled SE, true, making the Irish coast a lee shore; the ship was then kept close to the wind, and several tacks made to preserve her position as nearly as possible until daylight; when nothing being in sight, she was kept on ENE under short sail, with heavy gales; at about 10 AM an altitude of the sun was observed, and the Chronometer time noted; but, having run so far without any observation, it was plain the Latitude by dead reckoning was liable to error, and could not be entirely relied on. Using, however, this Latitude, in finding the Longitude by Chronometer, it was found to put the ship 15' of Longitude E from her position by dead reckoning; which in Latitude 52° N is 9 nautical miles; this seemed to agree tolerably well with the dead reckoning; but feeling doubtful of the Latitude, the observation was tried with a Latitude 10' further N, finding this placed the ship ENE 27 nautical miles, of the former position, it was tried again with a Latitude 20' N of the dead reckoning; this also placed the ship still further ENE, and still 27 nautical miles further; these three positions were then seen to lie in the direction of Small's light.

It then at once appeared that the observed altitude must have happened at all the three points, and at Small's light, and at the ship, at the same instant of time;

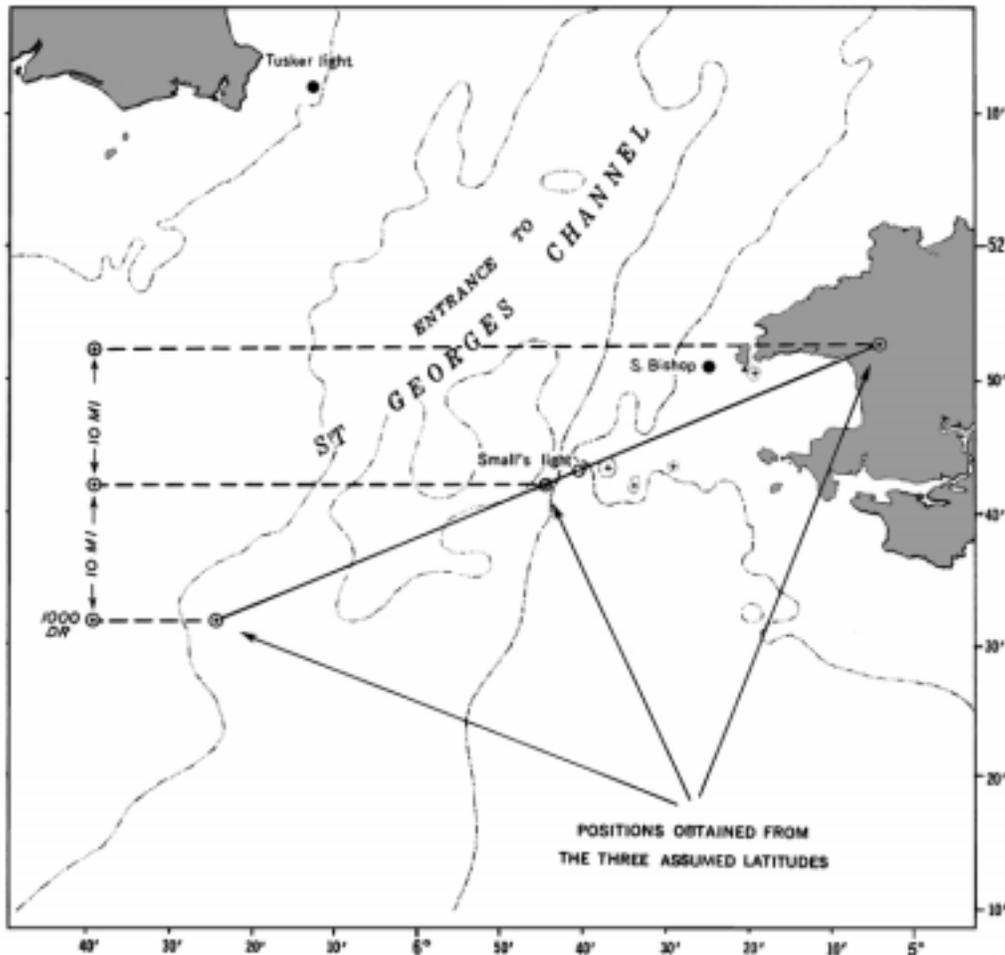


Figure 110. The first celestial line of position, obtained by Captain Thomas Sumner in 1837.

and it followed, that Small's light must bear ENE, if the Chronometer was right. Having been convinced of this truth, the ship was kept on her course, ENE, the wind being still SE., and in less than an hour, Small's light was made bearing ENE 1/2 E, and close aboard.

In 1843 Sumner published a book, *A New and Accurate Method of Finding a Ship's Position at Sea by Projection on Mercator's Chart*. He proposed solving a single time sight twice, using latitudes somewhat greater and somewhat less than that arrived at by dead reckoning, and joining the two positions obtained to form the line of position.

The Sumner method required the solution of two time sights to obtain each line of position. Many older navigators preferred not to draw the lines on their charts, but to fix their position mathematically by a method which Sumner had also devised and included in his book. This was a tedious but popular procedure.

111. Navigational Tables

Spherical trigonometry is the basis for solving every navigational triangle, and until about 80 years ago the nav-

igator had no choice but to solve each triangle by tedious, manual computations.

Lord Kelvin, generally considered the father of modern navigational methods, expressed interest in a book of tables with which a navigator could avoid tedious trigonometric solutions. However, solving the many thousands of triangles involved would have made the project too costly. Computers finally provided a practical means of preparing tables. In 1936 the first volume of Pub. No. 214 was made available; later, Pub. No. 249 was provided for air navigators. Pub. No. 229, *Sight Reduction Tables for Marine Navigation*, has replaced Pub. No. 214.

Modern calculators are gradually replacing the tables. Scientific calculators with trigonometric functions can easily solve the navigational triangle. Navigational calculators readily solve celestial sights and perform a variety of voyage planning functions. Using a calculator generally gives more accurate lines of position because it eliminates the rounding errors inherent in tabular inspection and interpolation.

112. Electronics And Navigation

Perhaps the first application of electronics to navigation involved sending telegraphic time signals in 1865 to

check chronometer error. Transmitting radio time signals for at sea chronometer checks dates to 1904.

Radio broadcasts providing navigational warnings, begun in 1907 by the U.S. Navy Hydrographic Office, helped increase the safety of navigation at sea.

By the latter part of World War I the directional properties of a loop antenna were successfully used in the radio direction finder. The first radiobeacon was installed in 1921. Early 20th century experiments by Behm and Langevin led to the U.S. Navy's development of the first practical echo sounder in 1922.

Today, electronics touches almost every aspect of navigation. Hyperbolic systems, satellite systems, and electronic charts all require an increasingly sophisticated electronics suite. These systems' accuracy and ease of use make them invaluable assets to the navigator. Indeed, it is no exaggeration to state that, with the advent of the electronic chart and differential GPS, the mariner will soon be able to navigate from port to port using electronic navigation equipment alone.

113. Development Of Radar

As early as 1904, German engineers were experimenting with reflected radio waves. In 1922 two American scientists, Dr. A. Hoyt Taylor and Leo C. Young, testing a communication system at the Naval Aircraft Radio Laboratory, noted fluctuations in the signals when ships passed between stations on opposite sides of the Potomac River. In 1935 the British began work on radar. In 1937 the USS Leary tested the first sea-going radar. In 1940 United States and British scientists combined their efforts. When the British revealed the principle of the multicavity magnetron developed by J. T. Randall and H. A. H. Boot at the University of Birmingham in 1939, microwave radar became practical. In 1945, at the close of World War II, radar became available for commercial use.

114. Development Of Hyperbolic Radio Aids

Various hyperbolic systems were developed from World War II, including Loran A. This was replaced by the more accurate Loran C system in use today. Using very low frequencies, the Omega navigation system provides worldwide, though less accurate, coverage for a variety of applications including marine navigation. Various short range and regional hyperbolic systems have been developed by private industry for hydrographic surveying, offshore facilities positioning, and general navigation.

115. Other Electronic Systems

The **Navy Navigation Satellite System (NAVSAT)** fulfilled a requirement established by the Chief of Naval Operations for an accurate worldwide navigation system for all naval surface vessels, aircraft, and submarines. The system was conceived and developed by the Applied Physics Laboratory of The Johns Hopkins University. The underlying concept that led to development of satellite navigation dates to 1957 and the first launch of an artificial satellite into orbit. NAVSAT has been replaced by the far more accurate and widely available **Global Positioning System (GPS)**.

The first **inertial navigation system** was developed in 1942 for use in the V2 missile by the Peenemunde group under the leadership of Dr. Wernher von Braun. This system used two 2-degree-of-freedom gyroscopes and an integrating accelerometer to determine the missile velocity. By the end of World War II, the Peenemunde group had developed a stable platform with three single-degree-of-freedom gyroscopes and an integrating accelerometer. In 1958 an inertial navigation system was used to navigate the USS *Nautilus* under the ice to the North Pole.

NAVIGATION ORGANIZATIONS

116. Governmental Roles

Navigation only a generation ago was an independent process, carried out by the mariner without outside assistance. With compass and charts, sextant and chronometer, he could independently travel anywhere in the world. The increasing use of electronic navigation systems has made the navigator dependent on many factors outside his control. Government organizations fund, operate, and regulate satellites, Loran, and other electronic systems. Governments are increasingly involved in regulation of vessel movements through traffic control systems and regulated areas. Understanding the governmental role in supporting and regulating navigation is vitally important to the mariner. In the United States, there are a number of official organizations which support the interests of navigators. Some have a policy-making role; others build and operate

navigation systems. Many maritime nations have similar organizations performing similar functions. International organizations also play a significant role.

117. The Coast And Geodetic Survey

The **U.S. Coast and Geodetic Survey** was founded in 1807 when Congress passed a resolution authorizing a survey of the coast, harbors, outlying islands, and fishing banks of the United States. President Thomas Jefferson appointed Ferdinand Hassler, a Swiss immigrant and professor of mathematics at West Point, the first Director of the "Survey of the Coast." The survey became the "Coast Survey" in 1836.

The approaches to New York were the first sections of the coast charted, and from there the work spread northward and southward along the eastern seaboard. In 1844 the work

was expanded and arrangements made to chart simultaneously the gulf and east coasts. Investigation of tidal conditions began, and in 1855 the first tables of tide predictions were published. The California gold rush necessitated a survey of the west coast. This survey began in 1850, the year California became a state. Coast Pilots, or Sailing Directions, for the Atlantic coast of the United States were privately published in the first half of the 19th century. In 1850 the Survey began accumulating data that led to federally produced Coast Pilots. The 1889 Pacific Coast Pilot was an outstanding contribution to the safety of west coast shipping.

In 1878 the survey was renamed "Coast and Geodetic Survey." In 1970 the survey became the "National Ocean Survey," and in 1983 it became the "National Ocean Service." The Office of Charting and Geodetic Services accomplished all charting and geodetic functions. In 1991 the name was changed back to the original "Coast and Geodetic Survey," organized under the National Ocean Service along with several other environmental offices. Today it provides the mariner with the charts and coast pilots of all waters of the United States and its possessions, and tide and tidal current tables for much of the world. Its administrative order requires the Coast and Geodetic Survey to plan and direct programs to produce charts and related information for safe navigation of the Nation's waterways, territorial seas, and national airspace. This work includes all activities related to the National Geodetic Reference System; surveying, charting, and data collection; production and distribution of charts; and research and development of new technologies to enhance these missions.

118. The Defense Mapping Agency

In the first years of the newly formed United States of America, charts and instruments used by the Navy and merchant mariners were left over from colonial days or were obtained from European sources. In 1830 the U.S. Navy established a "Depot of Charts and Instruments" in Washington, D. C. It was a storehouse from which available charts, sailing directions, and navigational instruments were issued to Naval ships. Lieutenant L. M. Goldsborough and one assistant, Passed Midshipman R. B. Hitchcock, constituted the entire staff.

The first chart published by the Depot was produced from data obtained in a survey made by Lieutenant Charles Wilkes, who had succeeded Goldsborough in 1834. Wilkes later earned fame as the leader of a United States expedition to Antarctica. From 1842 until 1861 Lieutenant Matthew Fontaine Maury served as Officer in Charge. Under his command the Depot rose to international prominence. Maury decided upon an ambitious plan to increase the mariner's knowledge of existing winds, weather, and currents. He began by making a detailed record of pertinent matter included in old log books stored at the Depot. He then inaugurated a hydrographic reporting program among shipmasters, and the thousands of reports received, along

with the log book data, were compiled into the "*Wind and Current Chart of the North Atlantic*" in 1847. This is the ancestor of today's Pilot Chart. The United States instigated an international conference in 1853 to interest other nations in a system of exchanging nautical information. The plan, which was Maury's, was enthusiastically adopted by other maritime nations. In 1854 the Depot was redesignated the "U.S. Naval Observatory and Hydrographical Office." In 1861, Maury, a native of Virginia, resigned from the U.S. Navy and accepted a commission in the Confederate Navy at the beginning of the Civil War. This effectively ended his career as a navigator, author, and oceanographer. At war's end, he fled the country. Maury's reputation suffered from his embracing the Confederate cause. In 1867, while Maury was still absent from the country to avoid arrest for treason, George W. Blunt, an editor of hydrographic publications, wrote:

In mentioning what our government has done towards nautical knowledge, I do not allude to the works of Lieutenant Maury, because I deem them worthless. . . . They have been suppressed since the rebellion by order of the proper authorities, Maury's loyalty and hydrography being alike in quality.

After Maury's return to the United States in 1868, he served as an instructor at the Virginia Military Institute. He continued at this position until his death in 1873. Since his death, his reputation as one of America's greatest hydrographers has been restored.

In 1866 Congress separated the Observatory and the Hydrographic Office, broadly increasing the functions of the latter. The Hydrographic Office was authorized to carry out surveys, collect information, and print every kind of nautical chart and publication "for the benefit and use of navigators generally."

The Hydrographic Office purchased the copyright of *The New American Practical Navigator* in 1867. The first Notice to Mariners appeared in 1869. Daily broadcast of navigational warnings was inaugurated in 1907. In 1912, following the sinking of the *Titanic*, the International Ice Patrol was established.

In 1962 the U.S. Navy Hydrographic Office was redesignated the U.S. Naval Oceanographic Office. In 1972 certain hydrographic functions of the latter office were transferred to the **Defense Mapping Agency Hydrographic Center**. In 1978 the **Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC)** assumed hydrographic and topographic chart production functions. DMAHTC provides support to the U.S. Department of Defense and other federal agencies on matters concerning mapping, charting, and geodesy. It continues to fulfill the old Hydrographic Office's responsibilities to "navigators generally."

119. The United States Coast Guard

Alexander Hamilton established the **U.S. Coast Guard** as the Revenue Marine, later the Revenue Cutter Service, on August 4, 1790. It was charged with enforcing the customs laws of the new nation. A revenue cutter, the *Harriet Lane*, fired the first shot from a naval unit in the Civil War at Fort Sumter. The Revenue Cutter Service became the U.S. Coast Guard when combined with the Lifesaving Service in 1915. The Lighthouse Service was added in 1939, and the Bureau of Marine Inspection and Navigation was added in 1942. The Coast Guard was transferred from the Treasury Department to the Department of Transportation in 1967.

The primary functions of the Coast Guard include maritime search and rescue, law enforcement, and operation of the nation's aids to navigation system. In addition, the Coast Guard is responsible for port safety and security, merchant marine inspection, and marine pollution control. The Coast Guard operates a large and varied fleet of ships, boats, and aircraft in performing its widely ranging duties.

Navigation systems operated by the Coast Guard include the system of some 40,000 lighted and unlighted beacons, buoys, and ranges in U.S. waters; the U.S. stations of the Loran C system; the Omega navigation system; radiobeacons and racons; differential GPS (DGPS) services in the U.S.; and Vessel Traffic Services (VTS) in major ports and harbors of the U.S.

120. The United States Navy

The **U.S. Navy** was officially established in 1798. Its role in the development of navigational technology has been singular. From the founding of the Naval Observatory to the development of the most advanced electronics, the U.S. Navy has been a leader in developing devices and techniques designed to make the navigator's job safer and easier.

The development of almost every device known to navigation science has been deeply influenced by Naval policy. Some systems are direct outgrowths of specific Naval needs; some are the result of technological improvements shared with other services and with commercial maritime industry.

121. The United States Naval Observatory

One of the first observatories in the United States was built in 1831-1832 at Chapel Hill, N.C. The Depot of Charts and Instruments, established in 1830, was the agency from which the U.S. Navy Hydrographic Office and the **U.S. Naval Observatory** evolved 36 years later. Under Lieutenant Charles Wilkes, the second Officer in Charge, the Depot about 1835 installed a small transit instrument for rating chronometers.

The Mallory Act of 1842 provided for the establishment of a permanent observatory. The director was

authorized to purchase everything necessary to continue astronomical study. The observatory was completed in 1844 and the results of its first observations were published two years later. Congress established the Naval Observatory as a separate agency in 1866. In 1873 a refracting telescope with a 26 inch aperture, then the world's largest, was installed. The observatory, located in Washington, D.C., has occupied its present site since 1893.

122. The Royal Greenwich Observatory

England had no early privately supported observatories such as those on the continent. The need for navigational advancement was ignored by Henry VIII and Elizabeth I, but in 1675 Charles II, at the urging of John Flamsteed, Jonas Moore, Le Sieur de Saint Pierre, and Christopher Wren, established the **Greenwich Royal Observatory**. Charles limited construction costs to £500, and appointed Flamsteed the first Astronomer Royal, at an annual salary of £100. The equipment available in the early years of the observatory consisted of two clocks, a "sextant" of 7 foot radius, a quadrant of 3 foot radius, two telescopes, and the star catalog published almost a century before by Tycho Brahe. Thirteen years passed before Flamsteed had an instrument with which he could determine his latitude accurately.

In 1690 a transit instrument equipped with a telescope and vernier was invented by Romer; he later added a vertical circle to the device. This enabled the astronomer to determine declination and right ascension at the same time. One of these instruments was added to the equipment at Greenwich in 1721, replacing the huge quadrant previously used. The development and perfection of the chronometer in the next hundred years added to the accuracy of observations.

Other national observatories were constructed in the years that followed: at Berlin in 1705, St. Petersburg in 1725, Palermo in 1790, Cape of Good Hope in 1820, Parramatta in New South Wales in 1822, and Sydney in 1855.

123. The International Hydrographic Organization

The **International Hydrographic Organization (IHO)** was originally established in 1921 as the International Hydrographic Bureau (IHB). The present name was adopted in 1970 as a result of a revised international agreement among member nations. However, the former name, International Hydrographic Bureau, was retained for the IHO's administrative body of three Directors and a small staff at the organization's headquarters in Monaco.

The IHO sets forth hydrographic standards to be agreed upon by the member nations. All member states are urged and encouraged to follow these standards in their surveys, nautical charts, and publications. As these standards are uniformly adopted, the products of the world's hydrographic and oceanographic offices become more uniform. Much has been done in the field of standardization since the

Bureau was founded.

The principal work undertaken by the IHO is:

- To bring about a close and permanent association between national hydrographic offices.
- To study matters relating to hydrography and allied sciences and techniques.
- To further the exchange of nautical charts and documents between hydrographic offices of member governments.
- To circulate the appropriate documents.
- To tender guidance and advice upon request, in particular to countries engaged in setting up or expanding their hydrographic service.
- To encourage coordination of hydrographic surveys with relevant oceanographic activities.
- To extend and facilitate the application of oceanographic knowledge for the benefit of navigators.
- To cooperate with international organizations and scientific institutions which have related objectives.

During the 19th century, many maritime nations established hydrographic offices to provide means for improving the navigation of naval and merchant vessels by providing nautical publications, nautical charts, and other navigational services. There were substantial differences in hydrographic procedures, charts, and publications. In 1889, an International Marine Conference was held at Washington, D. C., and it was proposed to establish a "permanent international commission." Similar proposals were made at the sessions of the International Congress of Navigation held at St. Petersburg in 1908 and again in 1912.

In 1919 the hydrographers of Great Britain and France cooperated in taking the necessary steps to convene an international conference of hydrographers. London was selected as the most suitable place for this conference, and on July 24, 1919, the First International Conference opened, attended by the hydrographers of 24 nations. The object of the conference was "To consider the advisability of all maritime nations adopting similar methods in the preparation, construction, and production of their charts and all hydrographic publications; of rendering the results in the most convenient form to enable them to be readily used; of instituting a prompt system of mutual exchange of hydrographic information between all countries; and of providing an opportunity to consultations and discussions to be carried out on hydrographic subjects generally by the hydrographic experts of the world." This is still the major purpose of the International Hydrographic Organization.

As a result of the conference, a permanent organization was formed and statutes for its operations were prepared. The International Hydrographic Bureau, now the International Hydrographic Organization, began its activities in 1921 with 18 nations as members. The Principality of Monaco was selected because of its easy communication with the rest of the world and also because of the generous offer of Prince Albert I of

Monaco to provide suitable accommodations for the Bureau in the Principality. There are currently 59 member governments. Technical assistance with hydrographic matters is available through the IHO to member states requiring it.

Many IHO publications are available to the general public, such as the International Hydrographic Review, International Hydrographic Bulletin, Chart Specifications of the IHO, Hydrographic Dictionary, and others. Inquiries should be made to the International Hydrographic Bureau, 7 Avenue President J. F. Kennedy, B.P. 445, MC98011, Monaco, CEDEX.

124. The International Maritime Organization

The **International Maritime Organization (IMO)** was established by United Nations Convention in 1948. The Convention actually entered into force in 1959, although an international convention on marine pollution was adopted in 1954. (Until 1982 the official name of the organization was the Inter-Governmental Maritime Consultative Organization.) It is the only permanent body of the U. N. devoted to maritime matters, and the only special U. N. agency to have its headquarters in the UK.

The governing body of the IMO is the **Assembly** of 137 member states, which meets every two years. Between Assembly sessions a Council, consisting of 32 member governments elected by the Assembly, governs the organization. Its work is carried out by the following committees:

- Maritime Safety Committee, with subcommittees for:
 - Safety of Navigation
 - Radiocommunications
 - Life-saving
 - Search and Rescue
 - Training and Watchkeeping
 - Carriage of Dangerous Goods
 - Ship Design and Equipment
 - Fire Protection
 - Stability and Load Lines/Fishing Vessel Safety
 - Containers and Cargoes
 - Bulk Chemicals
 - Marine Environment Protection Committee
 - Legal Committee
 - Technical Cooperation Committee
 - Facilitation Committee

IMO is headed by the Secretary General, appointed by the council and approved by the Assembly. He is assisted by some 300 civil servants.

To achieve its objectives of coordinating international policy on marine matters, the IMO has adopted some 30 conventions and protocols, and adopted over 700 codes and recommendations. An issue to be adopted first is brought before a committee or subcommittee, which submits a draft to a conference. When the conference adopts the final text, it is submitted