An Introduction to NAVIGATION and NAUTICAL ASTRONOMY

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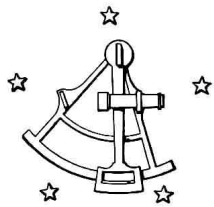

Illustrations by

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THE MACMILLAN COMPANY · *New York* · 1944

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THE MACMILLAN COMPANY
NEW YORK · BOSTON · CHICAGO · DALLAS
ATLANTA · SAN FRANCISCO

MACMILLAN AND CO., LIMITED
LONDON · BOMBAY · CALCUTTA · MADRAS
MELBOURNE

THE MACMILLAN COMPANY
OF CANADA, LIMITED
TORONTO

PREFACE

This book has been written to meet a national need. At the present time the United States Navy, Merchant Marine, Coast Guard, and Air Transport, together with the Air Branches of our armed forces, are, each in its own field, rapidly becoming the greatest in the world. As a result of this gigantic expansion, there has arisen a tremendous demand for a trained personnel capable of navigating our ever increasing fleets of surface, undersea, and air craft. The purpose of the authors is to provide a practical introductory text in navigation and nautical astronomy, primarily designed for those who have entered or are planning to enter one of the above-mentioned services.

This book is particularly suitable for students of cadet training schools of the different services, for college students, and for senior groups of preparatory and high schools. It is also recommended for those who are members of no formal class but who wish, by home study, to gain a knowledge of the science of present-day surface or air navigation.

This text is written in a language that a beginner in navigation can understand. Technical terms and phrases are not avoided but are carefully defined and explained. Before a new phase of the subject is introduced, preceding material is frequently summarized to show the correlation with what has gone before. Thus the student is constantly reviewing his previous work. Before the subject of celestial navigation is introduced, all necessary basic astronomy is carefully explained, with particular emphasis on its application from the navigator's point of view. In the Appendix, a refresher course in logarithms and plane trigonometry is included.

Illustrations and diagrams are profusely distributed throughout the book. The simplest sketch is carefully executed so that the exact idea of the authors is conveyed to the student. For each type of problem at least one illustrative example is given and each step of the solution is explained in detail.

This text is complete in itself. No supplementary books, charts, tables, almanacs, or work sheets are necessary. The H.O. 211 Table

is given in full in the Appendix, as well as complete tables of logarithms and trigonometric functions. Excerpts from *The American Nautical Almanac, The American Air Almanac,* and the H.O. 214 Tables are sufficient for the solution of all problems given. The student is shown how to work problems of position on ordinary graph paper, thus the difficulty and expense of obtaining special plotting sheets or charts is eliminated. Throughout the text, tables and diagrams from publications of the United States Coast and Geodetic Survey, the Hydrographic Office of the United States Navy, and the United States Coast Guard are reproduced and explained so that the student will become acquainted with these important aids to navigation. Two simplified charts are included to illustrate the more important legends, markings, and symbols used thereon. This book, therefore, furnishes a complete course to the beginner.

The descriptive explanations and methods of procedure conform as much as is possible in an introductory text to the standards demanded by the United States Navy and the United States Merchant Marine. The material is stated simply and in detail without loss of scholastic rigor. Abundant problems and exercises are included so that the student may apply the knowledge he has gained; for most of these problems answers have been given.

Without the generous assistance of the United States Navy this work would have been literally impossible. The department has given us permission to use excerpts and material from all Hydrographic Office publications, including Bowditch's *American Practical Navigator,* and from *The American Nautical Almanac* and *The American Air Almanac* issued by the Naval Observatory. They have given us access to the best and most accurate of all nautical information. We are particularly indebted to Rear Admiral Randall Jacobs, U.S.N., Chief of Navy Personnel, and Commander R. W. Berry, U.S.N., for this assistance.

Commander E. S. Hochuli, U.S.N., of the United States Merchant Marine Academy at King's Point, New York, has given us sound advice and direction. Lieutenant Mordett J. Engs, U.S.N., of the same school, has read the entire text carefully and made numerous emendations and suggestions for which we are exceedingly grateful. The authors, however, assume full responsibility for the material appearing in the text. Commander Harold O'D. Hunter, U.S.N., and Lt. Commander J. P. Knowles, U.S.N., of the Yale Naval

Unit, Lieutenants John Y. Millar, John J. Maher, William G. Maxson, Robert L. Davis, and Ensign C. Burgess Ayres, U.S.N.R., have made helpful recommendations and useful suggestions.

The publications of the United States Coast Guard have been indispensable for the sections on lights, buoys, and radio. To the Coast and Geodetic Survey of the Department of Commerce we owe our thanks for the use of excerpts from their publications and charts. The publications of the Bureau of Marine Inspection of the same department also have been most valuable.

We are very grateful to the United States Naval Institute for permission to make use of Commander Benjamin Dutton's standard work, *Navigation and Nautical Astronomy*, and our special thanks is given to Rear Admiral A. T. Church of the Naval Institute for this courtesy.

Mr. George W. Mixter has graciously allowed us to make use of his ingenious idea of subscripts in the H.O. 211 work form. We are indebted to Mr. William E. Palmer and to Mr. John C. Manthorp of *Life* magazine, who kindly consented to the reproduction of photographs, including the frontispiece, which have contributed so much to the text. We are grateful also to Kelvin and Wilfrid O. White Company for a similar courtesy.

Our gratitude goes to Dr. George C. St. John and to our colleagues for their sound advice and practical help. To Tamzin K. Shute we are especially indebted for her assistance in putting in final form, through its several revisions, the manuscript of this text. Last of all, we realize the debt we owe to the students in our classes who have cooperated with us in our testing program and in our classroom procedure, thereby helping us to make the book teachable and clear. Many of them today are already using their skill at sea and in the air in the service of our country.

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MATHEMATICAL SYMBOLS

+	Plus (addition)	#	Answer
−	Minus (subtraction)	△	Triangle
×	Times (multiplication)	∠	Angle
÷	Divided by (division)	⌒	Arc
~	Algebraic difference	°	Degrees
±	Plus or minus	′	Minutes
=	Equals	″	Seconds

ABBREVIATIONS

The precise meaning and the practical use of the terms whose abbreviations are listed below are explained in the text. Consultation of the index will locate the references.

a	Altitude intercept
A.E., ≏	Autumnal equinox
Alt.	Alternating (lights)
A.M.	Forenoon (ante meridian)
A.P.	Assumed position
Az	Azimuth
B.M.I.	Bureau of Marine Inspection (Dept. of Commerce)
C	Chronometer
C	Course or course angle
C.	Can (buoy)
C. & G. S.	Coast and Geodetic Survey
C.C.	Chronometer correction
C.C.	Compass course
C.E.	Chronometer error
C.E.	Compass error
C.G.	Coast Guard
C_n	Course measured from true north
Co-L	Co-latitude
colog	Cologarithm
corr.	Correction
cos	Cosine

cot	Cotangent
covers	Coversed sine
csc	Cosecant
C – W	Chronometer minus watch
d	Distance
d, dec., decl.	Declination
^{d}	Day
Δd	Correction for declination (H.O. 214)
ΔL	Correction for latitude (H.O. 214)
Δt	Correction for hour angle (H.O. 214)
D.	Deviation
D.L.	Difference of latitude
D. Lo.	Difference of longitude
D.R.	Dead reckoned position (or dead reckoning)
E.	East, easterly
E.P.	Estimated position
Eq. T.	Equation of time
F.	Fixed (light)
Fl.	Flashing (light)
g	Lower branch of Greenwich meridian
G	Greenwich or Greenwich meridian
G.	Green
G.A.T.	Greenwich apparent time
G.C.T.	Greenwich civil time
G.H.A.	Greenwich hour angle
G.P.	Geographical position
Gp.	Group (light)
G.S.T.	Greenwich sidereal time
^{h}	Hour
H	Altitude
H.A.	Hour angle
hav	Haversine
H_c	Computed altitude
H.D.	Hourly difference
H_o	True altitude
H.O.	Hydrographic Office
H.P.	Horizontal parallax
H_s	Sextant altitude
Ht. Eye	Height of eye

I.C.	Index correction
I.E.	Index error
I. Qk. Fl.	Interrupted quick flashing (light)
K	Constant in H.O. 211
kc	Kilocycles
K ~ L	Algebraic difference of K and L
kt	Knot
l	Difference of latitude
L. or Lat.	Latitude
L.A.N.	Local apparent noon
L.A.T.	Local apparent time
L.C.T.	Local civil time
L.H.A.	Local hour angle
L_m	Middle latitude
Lo., Long., λ	Longitude
log, l	Logarithm
L.S.T.	Local sidereal time
m	Difference of meridional parts
m	Lower branch of ship's meridian
^{m}	Minute (of time)
M	Meridian of ship
M	Meridional parts
M.S.T.	Mean solar time
N.	North, northerly
N.	Nun (buoy)
N.A.	Nautical Almanac
Occ.	Occulting (light)
p	Departure
P.M.	Afternoon (post meridian)
P_n	North pole
P_s	South pole
p.s.c.	Per standard compass
p. stg. c.	Per steering compass
Qk. Fl.	Quick flashing (light)
R.	Red
R.A.	Right ascension
R.A.M.S.	Right ascension mean sun

^{s}	Second (of time)
S	Speed
S.	South, southerly
S.	Spar (buoy)
S.D.	Semidiameter
sec	Secant
S.H.A.	Sidereal hour angle
sin	Sine
S–L Fl.	Short-long flashing (light)
t	Meridian angle
tan	Tangent
U.S.N.	United States Navy
V.	Variation
V.E., ♈	Vernal equinox
vers	Versed sine
V.P.D.	Variation per day
V.P.H.	Variation per hour
V.P.M.	Variation per minute
W	Watch time
W.	West, westerly
W.	White
W.E.	Watch error
z	Zenith distance
Z	Zenith
Z	Azimuth
Z.D.	Zone description
Z_n	Azimuth measured from true north
Z.T.	Zone time

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Part II. Celo-navigation

Appendix

PART I

GEO-NAVIGATION

CHAPTER I

The Terrestrial Sphere

101. Foreword. In beginning the study of navigation, we are embarking upon a great adventure. When we compare the crude instruments and imperfect methods used in the past with the accurate instruments and efficient methods used today we gain a profound respect for those early mariners who laid the foundations and devised the basic methods of our present-day science of navigation.

The early American who did most to change the practice of navigation from a hazardous venture to an almost exact science was the self-educated mathematician, Nathaniel Bowditch (1773–1838). He first published his writings and calculations as *American Practical Navigator* in 1802. The copyright of the text was purchased later by the United States Navy Department. Kept up to date by revisions, this volume is today an essential reference publication for American navigators. The *American Practical Navigator* consists of two parts: Part I is a concise summary of navigational principles and methods; Part II is composed of forty-one different tables, which the navigator uses in his computations as occasion demands. The *American Practical Navigator* is usually referred to simply as Bowditch.

Our purpose in this introductory text is to present the fundamental material by easy stages, with many practice problems, so that the student may gain a clear understanding of basic terms and methods. Within the covers of any book there can be no complete course in navigation. Only by observation and constant practice can the beginner attain the skill and proficiency of the expert navigators of the United States Navy, Coast Guard, or Merchant Marine. Yet from this book he will master the basic facts and principles of navigation, he will become acquainted with its useful tools, and he will learn how to solve its fundamental problems. With this foundation, the transition to the bridge of a ship from the classroom of college, academy, or school should not be too difficult.

102. Navigation: geo-navigation and celo-navigation. Navigation is the science which enables the navigator to conduct his ship from one position to another on the earth's surface, and to determine at any time with reasonable accuracy the position of the ship upon the surface of the earth.

There are two main branches of navigation. In the first, geo-navigation, the location of a ship is obtained by the use of aids on the earth's surface only. In the second, celo-navigation or nautical astronomy, position is determined by the observation of celestial bodies such as the sun, the moon, four of the planets, and a certain number of the stars.

103. Piloting and dead reckoning. The subject of geo-navigation can be divided into two main parts. Piloting, in the broader sense, is the science of determining position by means of visible objects such as lights and buoys, or by the use of radio signals, or by soundings for depths of water. Dead reckoning, a name which is probably a contraction of "deduced reckoning," is the science of deducing position by knowledge of direction and distance traveled by the ship from a previous known position. Positions determined by dead reckoning methods are used in celo-navigation as well.

104. The earth. "The earth is round and it moves!" The universal acceptance of the latter fact is more recent than the discovery of the western hemisphere, yet it is the basis of the science of navigation in modern times.

For almost all practical purposes of navigation it is sufficiently accurate to consider the earth as a sphere. Therefore, some important properties of a sphere should be thoroughly understood at the outset. By definition, a *sphere* is a closed surface all points of which are equidistant from a fixed point within, called the *center*. A straight line which passes through the center, and which intersects the surface at two points on opposite sides of the center, is a *diameter*. That diameter of a sphere upon which the sphere rotates is the *axis*. The extremities of the axis of a sphere are called the *poles*. A circle on the surface of a sphere whose plane passes through the center is called a *great circle* of a sphere. A circle on the surface of a sphere whose plane does not pass through the center is called a *small circle* of a sphere.

To those not versed in solid geometry these terms may seem vague and confusing. To make them more vivid, let us take an