



# GLOBAL NAVIGATION for Pilots

International Flight Techniques and Procedures

**THIRD EDITION**

Dale De Remer, Ph.D.  
Gary M. Ullrich



# GLOBAL NAVIGATION for Pilots

International Flight Techniques and Procedures



**THIRD EDITION**

Dale De Remer, Ph.D.  
Gary M. Ullrich



AVIATION SUPPLIES & ACADEMICS  
NEWCASTLE, WASHINGTON



*Global Navigation for Pilots: International Flight Techniques and Procedures*

Third Edition

by Dale De Remer, Ph.D. / Gary M. Ullrich

Aviation Supplies & Academics, Inc.  
7005 132nd Place SE  
Newcastle, Washington 98059-3153  
asa@asa2fly.com | www.asa2fly.com

© 2019 Aviation Supplies & Academics, Inc. (1993-2018 by Dale De Remer)

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopy, recording or otherwise, without the prior written permission of the copyright holder.

**ASA-GNP-3**

ISBN 978-1-61954-889-3

Additional formats available:

Kindle ISBN 978-1-61954-891-6  
eBook ePub ISBN 978-1-61954-890-9  
eBook PDF ISBN 978-1-61954-892-3  
eBundle ISBN 978-1-61954-893-0 (print + eBook PDF download code)

Printed in the United States of America

2024 2023 2022 2021 2020 9 8 7 6 5 4 3 2 1

Cover photo: ©iStock/Assanta

Photography and other illustration credits: xiii—W.D. Van Wormer; xv—D. De Remer, Tyler Ingham/University of North Dakota; p.4—U.S. Army and Navy, Air Navigation, 1972; p.67—D. De Remer; p.73—American Avionics; p.77—Steven Fine (Wikimedia CC); p.78—D. De Remer; p.101—ICAO Doc. 007; p.109—Brazil AIP (DECEA); pp.115, 116, 123–138—ICAO Doc. 4444; p.140—GoogleEarth; pp.144–145, 151–156—OpsGroup; pp.157–164—NAV Canada; pp.165–197—ICAO NAT Doc. 007; p.200—Iceland AIP; pp.223–227—OpsGroup; p.256—A. Bernabeo; pp.264–266—reprinted with permission from World Meteorological Organization; p.290—W.D. Van Wormer; p.293—GPS.com; p.309—European Satellite Service Provider (ESSP) & GNS Systems Agency (GSA), used with permission; pp. 314–315—PilotWeb (faa.gov); p.331—Brazil AIP (DECEA); pp.345–348—ICAO Doc. 9613 Pt.B; p.357, 399—D. De Remer; p.405—Eurocontrol website; pp.406, 408–411, 416–419—OpsGroup.

*Library of Congress Cataloging-in-Publication Data:*

Names: De Remer, Dale, author. | Ullrich, Gary M., author.

Title: Global navigation for pilots : international flight techniques and procedures / Dale De Remer, Ph.D., Gary Ullrich.

Description: Third edition. | Newcastle, Washington : Aviation Supplies & Academics, Inc., [2020] | Includes bibliographical references and index.

Identifiers: LCCN 2019044624 | ISBN 9781619548893 (trade paperback) | ISBN 9781619548923 (pdf)

Subjects: LCSH: Navigation (Aeronautics) | Global Positioning System.

Classification: LCC TL586 .D443 2020 | DDC 629.132/51—dc23

LC record available at <https://lccn.loc.gov/2019044624>

# Contents

Foreword .....	xiii
About the Authors .....	xv
<b>1 Introduction and International Regulations .....</b>	<b>1</b>
<b>The Arrangement and Use of This Book .....</b>	<b>1</b>
Notes on the Book's Contents .....	1
What's New in this Third Edition? .....	3
<b>Introduction to Global Navigation.....</b>	<b>3</b>
Earlier Days of Navigation.....	3
The Science and Art of Navigation .....	5
Sources of Navigational Information .....	5
<b>A Historical Background of International Air Law .....</b>	<b>6</b>
The Question of Sovereignty in Airspace .....	6
The Paris Convention 1919 .....	6
The Havana Convention 1928.....	7
<b>Worldwide International Law .....</b>	<b>7</b>
The Warsaw Convention 1929.....	7
The Chicago Conference 1944 .....	8
<b>The History of ICAO .....</b>	<b>9</b>
The Bermuda Agreement 1946 .....	9
<b>ICAO—The Organization Described .....</b>	<b>10</b>
The Assembly.....	10
The Council.....	10
The Secretariat.....	10
ICAO Rules.....	11
ICAO Signals.....	19
The Safe Transport of Dangerous Goods by Air .....	20
<b>ICAO Identifying Codes .....</b>	<b>20</b>
Aircraft Nationality and Registration Marks .....	20
International Airport Identifiers .....	20
<b>Questions for Class Groups or Individual Study.....</b>	<b>27</b>
<b>2 Earth Reference Systems .....</b>	<b>29</b>
<b>Location.....</b>	<b>29</b>
<b>LOP and Fix .....</b>	<b>29</b>
<b>FRD.....</b>	<b>30</b>
<b>Direction .....</b>	<b>30</b>
Terms of Direction.....	30
Great Circle and Rhumb Line Direction .....	31
<b>Distance .....</b>	<b>32</b>
<b>Latitude and Longitude .....</b>	<b>32</b>
Size and Shape of the Earth .....	32
Great and Small Circles.....	33

Latitude and Longitude as a Reference System .....	33
A Change in the Geodetic Referencing System.....	36
<b>Summary.....</b>	<b>37</b>
<b>Study Questions.....</b>	<b>38</b>

3

<b>Maps and Charts .....</b>	<b>41</b>
<b>Charts vs. Maps.....</b>	<b>41</b>
Charts and Projections.....	41
Choice of Projection.....	42
<b>Classification of Projections.....</b>	<b>43</b>
Azimuthal Projections.....	43
Cylindrical Projections.....	46
Conic Projections.....	50
<b>Aeronautical Charts .....</b>	<b>57</b>
Scale .....	57
Jeppesen Sanderson.....	60
Governments .....	61
What's New in Aeronautical Charts?.....	61
<b>Study Questions.....</b>	<b>61</b>

4

<b>Basic Navigation Instruments .....</b>	<b>63</b>
<b>Introduction .....</b>	<b>63</b>
<b>Direction .....</b>	<b>63</b>
Basic Instruments .....	63
Earth's Magnetic Field.....	64
<b>Compasses.....</b>	<b>65</b>
Magnetic Compass .....	65
Direct Indicating Magnetic Compass.....	65
Compass Compensation.....	68
Vertical Card Compasses.....	69
Magnetic Compass Errors.....	70
Remote Indicating Magnetic Compass .....	71
Gyroscopes as Directional Indicators .....	72
Gyrocompass Errors .....	74
Using the Gyrocompass in the North.....	77
<b>Track.....</b>	<b>79</b>
Driftmeter .....	79
<b>Study Questions and Exercises.....</b>	<b>80</b>

5

<b>Basic Navigation Techniques.....</b>	<b>83</b>
<b>Introduction .....</b>	<b>83</b>
<b>Dead Reckoning Navigation.....</b>	<b>83</b>
The Running Fix .....	86
The Single LOP Approach.....	87
Precision Dead Reckoning.....	88
Doppler .....	90
<b>Explanation of Terms .....</b>	<b>90</b>

Plotting.....	91
Plotting Procedure, Mercator Chart .....	91
Plotting Procedures, Lambert Conformal and Gnomonic Charts .....	92
<b>Study Questions and Class Discussion.....</b>	<b>98</b>
<b>6 International Trip Planning and Preparation .....</b>	<b>99</b>
<b>The Checklist .....</b>	<b>99</b>
Checklists for Pilots Flying Private or Commercial Aircraft .....	99
<b>Planning .....</b>	<b>100</b>
Planning Resources.....	100
Obtaining the Proper Aeronautical Charts for your International Flight.....	104
Other Vendors for Worldwide Aeronautical Charts .....	107
Planning Services.....	110
Preliminary Planning.....	111
<b>International Flight Planning—the Concept .....</b>	<b>112</b>
Prepare for What to Expect Upon Arrival.....	112
<b>The International Flight Plan Form.....</b>	<b>113</b>
Form Completion Instructions .....	113
Completing the Flight Planning Process .....	114
International Flight Planning Services (IFPS).....	114
<b>Study Questions.....</b>	<b>122</b>
<b>Appendix: Excerpt from ICAO Document 4444.....</b>	<b>123</b>
<b>7 Trans-Oceanic and Trans-Wilderness Planning .....</b>	<b>139</b>
<b>Flight Planning for Remote, Wilderness and Sparsely Settled Areas.....</b>	<b>139</b>
Canada and Areas of Featureless Terrain .....	140
<b>Flight Planning for the North Atlantic.....</b>	<b>141</b>
Key Sources for Compliance .....	142
NAT Doc 007: Ops Approval and System Requirements for Flight in the NAT HLA .....	142
Understanding the Organized Track System (OTS) .....	143
Flight Operations Below the NAT HLA .....	143
NAT Doc 007: Checklists for Pilots and Dispatchers.....	143
<b>Classic Concepts You Should be Aware of.....</b>	<b>146</b>
ETOPS.....	146
Mach Number Technique.....	146
Reduced Vertical Separation Minimum (RVSM) Airspace.....	147
<b>Finishing the Planning Job .....</b>	<b>147</b>
ETP and the Wet Footprint.....	147
<b>More Pilot Aids for Trans-Wilderness Flight.....</b>	<b>150</b>
<b>Appendix: Canadian AIP (Excerpt–Part 1 General) .....</b>	<b>157</b>
<b>Appendix: ICAO North Atlantic Operations Manual (NAT Document 007) Excerpts.....</b>	<b>165</b>
<b>8 International Flight Operations .....</b>	<b>199</b>
<b>Operational Considerations for International Flight .....</b>	<b>199</b>
Cabotage .....	199
Other Entry Requirements.....	199
The Nine “F’s” of International Flight .....	199

<b>North Atlantic (NAT) Operational Considerations</b> .....	<b>202</b>
Oceanic Airspace .....	202
<b>Preflight Procedures</b> .....	<b>203</b>
Clearances.....	203
Obtaining a Clearance.....	203
Oceanic Clearances .....	203
ATC System Loop Errors.....	206
International Air Traffic Control Phraseology .....	206
ATC Flight Plans .....	207
<b>In-Flight Procedures</b> .....	<b>208</b>
In-Flight Contingencies.....	208
<b>Procedures for Conducting the Flight in the NAT</b> .....	<b>209</b>
North Atlantic Operations Bulletin 2017-005, Oceanic Checklist .....	209
Leaving the Ramp.....	209
While on Airways .....	211
ATC Oceanic Clearance .....	211
Approaching the Ocean .....	211
Oceanic Boundary Position Report.....	212
Position Reporting Procedures.....	212
Routine Monitoring .....	213
Approaching Landfall.....	214
Monitoring During Distractions from Routine .....	214
Avoiding Confusion Between Magnetic and True .....	214
Navigation in the Area of Compass Unreliability .....	214
<b>North Atlantic Procedures—An Example Flight</b> .....	<b>215</b>
Route Planning.....	215
Track Planning.....	218
PRMS—Preferred Route Message.....	218
Preflight .....	218
ETOPS Planning .....	218
Takeoff and Enroute Alternates.....	219
Loading the Nav Systems.....	219
From Launch to Coast-Out Point.....	220
In NAT Airspace .....	220
In-Flight Emergencies .....	221
Nearing the Coast-In Point.....	221
Arrival.....	221
NAT Airspace—Changing Rules .....	222
<b>The Pacific Organized Track System (PACOTS)</b> .....	<b>228</b>
Introduction.....	228
General Information and Requirements .....	228
Aircraft System/Equipment Requirements .....	230
<b>WATRS/Caribbean Operations</b> .....	<b>232</b>
Caribbean, Central America, and South America .....	232
“WATRS Plus” Control Areas .....	232
South America and the Caribbean .....	237

	South America Weather Information.....	244
	Gulf of Mexico .....	245
	<b>Appendix: Gulf of Mexico Operations – ICAO Documents 7030, 9613, 4444, Annexes 2, 6.....</b>	<b>246</b>
	<b>Appendix: FAA ADS-B Gulf of Mexico Expansion .....</b>	<b>247</b>
<b>9</b>	<b>Flying in Europe .....</b>	<b>251</b>
	<b>European Air Traffic Flow Management .....</b>	<b>251</b>
	Organization and Procedures.....	251
	Flight Plan Filing Requirements.....	252
	The Slot Allocation Process.....	253
	The Flexible Use of Airspace Concept Within Europe—Conditional Routes.....	253
	<b>A Few Words About Joint Aviation Authorities (JAA) .....</b>	<b>254</b>
	JAR, JAR-Ops, EU-Ops and EASA.....	254
	<b>Hints for Flying in Europe .....</b>	<b>254</b>
	<b>Flying Within the European Control System: An Example Flight.....</b>	<b>255</b>
	Example Flight .....	255
<b>10</b>	<b>International Weather .....</b>	<b>259</b>
	<b>Aviation Weather Information.....</b>	<b>259</b>
	Meteorological Code .....	259
	<b>International Surface Reports (METAR) .....</b>	<b>260</b>
	General.....	260
	Reporting Type, Time and Reporting Station.....	260
	Wind .....	260
	Visibility .....	260
	Runway Visual Range.....	261
	Present Weather.....	261
	Clouds.....	261
	Temperature and Dew Point.....	262
	Altimeter Setting .....	262
	Trend Forecast ( <i>Not used in U.S.</i> ) .....	262
	Remarks.....	262
	Airborne Reports .....	263
	<b>Forecasts (TAFs).....</b>	<b>267</b>
	Terminal Forecasts.....	267
	<b>VOLMETs .....</b>	<b>268</b>
	<b>ICAO Annex 3—Meteorological Services for International Air Navigation.....</b>	<b>268</b>
	Definitions.....	268
	World Area Forecast System and Meteorological Offices.....	268
	<b>New Stuff?.....</b>	<b>269</b>
	<b>Study Questions.....</b>	<b>269</b>
<b>11</b>	<b>Inertial Navigation.....</b>	<b>271</b>
	<b>Introduction .....</b>	<b>271</b>
	<b>Inertial Navigation System Basics.....</b>	<b>272</b>
	<b>Principles of Strapdown Inertial Navigation .....</b>	<b>278</b>
	Introduction.....	278
	Modes of Operation.....	281



<b>Theory of Operation.....</b>	<b>286</b>
Accelerometer Principle of Operation .....	286
Triple-Axis Navigation Computation .....	286
Laser Principle of Operation.....	287
The Pilot’s Perspective About INS Errors.....	290
Procedures and Regulations .....	291
RNP .....	291
<b>Study Questions.....</b>	<b>291</b>
<b>12 Global Positioning System.....</b>	<b>293</b>
<b>Where to Find Current System News and Updates.....</b>	<b>293</b>
<b>GPS System Overview .....</b>	<b>293</b>
General System Description .....	293
System Technical Description.....	295
System Performance.....	297
Navigation Using GPS .....	298
<b>GPS Specification and Design Issues.....</b>	<b>299</b>
System Availability .....	299
Geometric Dilution of Precision.....	300
User Range Accuracy .....	300
Satellite Elevation Angle (Masking Angle) .....	300
External Aids.....	300
Figure of Merit.....	301
<b>Aiding Capabilities for a GPS Receiver .....</b>	<b>301</b>
Types of Aiding .....	301
Aiding During Acquisition of Initial Track .....	302
Aiding to Replace a Satellite Measurement .....	303
Aiding to Maintain Satellite Track .....	303
<b>GPS System Tools for Pilots .....</b>	<b>304</b>
ADS-B SAPT .....	304
Receiver Autonomous Integrity Monitoring (RAIM).....	304
<b>Differential GPS.....</b>	<b>304</b>
Introduction.....	304
Differential GPS Concept.....	305
DGPS Implementation Types .....	305
<b>WAAS and LAAS .....</b>	<b>306</b>
LPV Approaches Around the World .....	308
<b>GPS Error Sources .....</b>	<b>310</b>
Selective Availability (SA) Errors .....	310
Ionospheric Delays .....	310
Tropospheric Delay Error .....	310
Ephemeris Errors.....	310
Satellite Clock Errors.....	310
Positioning Errors and DGPS.....	310
Additional GPS System Errors.....	311
Pilot Error.....	313

	GPS Use in North and South Polar Regions .....	316
	GPS Peripheral Systems .....	316
	ADS-B In and Out .....	316
	GPS, in a Nutshell.....	316
	Study Questions.....	317
<b>13</b>	<b>New Systems and the Changes They Bring</b>	
	<b>ADS-C, RNAV, CPDLS, and RNP.....</b>	<b>319</b>
	<b>Upcoming Changes to Approaches .....</b>	<b>319</b>
	RNAV versus RNP .....	319
	Enroute Flight: RNP and RNP Levels.....	319
	Localizer Performance with Vertical Guidance.....	320
	Localizer Navigation Without Vertical Guidance.....	321
	RNAV and RNP Leg Types.....	321
	RNP Instrument Approach Procedures with Authorization Required (AR) .....	322
	<b>Automatic Dependent Surveillance – Broadcast (ADS-B) .....</b>	<b>326</b>
	ADS-B Out .....	327
	ADS-B In.....	327
	Automatic Dependent Surveillance – Contract (ADS-C) .....	327
	Traffic Information Services – Broadcast (TIS-B).....	327
	Automatic Dependent Surveillance – Rebroadcast (ADS-R).....	329
	Flight Information Services – Broadcast (FIS-B) .....	329
	<b>Controller to Pilot Datalink Communication (CPDLC).....</b>	<b>329</b>
	CPDLC – A Basic Description .....	329
	CPDLC Information Published in the Applicable State AIP.....	330
	<b>Important Terms and Concepts .....</b>	<b>332</b>
	<b>Study Questions.....</b>	<b>333</b>
	<b>Appendix: Key Terms Glossary.....</b>	<b>334</b>
<b>14</b>	<b>Flight Management Systems.....</b>	<b>339</b>
	<b>FMS Navigation .....</b>	<b>339</b>
	<b>System Description.....</b>	<b>339</b>
	Introduction.....	339
	Navigation Management Functions .....	340
	Navigation Modes.....	341
	Database .....	342
	Navigation Database Currency .....	343
	Guidance.....	344
	Map Displays .....	344
	ICAO Document 9613: FMS Functions and Display Requirements.....	344
	<b>Controls.....</b>	<b>349</b>
	Control Display Unit.....	349
	<b>Navigation.....</b>	<b>354</b>
	<b>Study Questions.....</b>	<b>356</b>

<b>15</b>	<b>Time</b> .....	<b>357</b>
	<b>A Concept of Vital Importance to Pilots</b> .....	<b>357</b>
	<b>The Evolution of the Calendar</b> .....	<b>358</b>
	The Calendar of Romulus.....	358
	The Numa Calendar .....	358
	The Julian Calendar.....	358
	The Gregorian Calendar.....	360
	The First Almanacs.....	360
	The Greek Olympiads.....	360
	The Hebrew Calendar .....	361
	The French Revolutionary Decimal Calendar.....	361
	The Soviet Russia Experiments in Calendar Changing .....	361
	The Julian Day of the Astronomers.....	362
	Calendar Improvement .....	362
	<b>Kinds of Time</b> .....	<b>363</b>
	Universal Time.....	363
	Stellar or Sidereal Time .....	363
	The Earth’s Rotation and Universal Time.....	363
	Ephemeris Time.....	364
	Length of the Year .....	365
	<b>The Timekeepers</b> .....	<b>365</b>
	NBS and USNO .....	365
	The Bureau International de l’Heure .....	366
	History of Time Broadcasts.....	366
	<b>Standard Time Zones and Daylight-Saving Time</b> .....	<b>367</b>
	<b>How Pilots Know What Time It Is</b> .....	<b>369</b>
	<b>Time From the Sky</b> .....	<b>369</b>
	Measuring Time .....	369
	Apparent Solar Time.....	370
	Mean Solar Time.....	370
	Greenwich Mean Time (GMT) and Universal Coordinated Time (UTC) .....	371
	Local Mean Time (LMT).....	371
	Relationship of Time and Longitude .....	372
	Relationship of Time and Latitude .....	372
	<b>Study Questions</b> .....	<b>374</b>
<b>16</b>	<b>Navigation System Errors and Limitations</b> .....	<b>375</b>
	<b>Risk Management</b> .....	<b>375</b>
	<b>Navigation System Limitations</b> .....	<b>375</b>
	<b>The Mandatory Accuracy Check</b> .....	<b>377</b>
	<b>The Gross Error Check</b> .....	<b>377</b>
	<b>Procedures Used to Minimize Errors</b> .....	<b>377</b>
	The Use of a Master Document .....	379
	FAA Sample Checklists .....	380
	Clearances.....	380
	From ICAO NAT Doc. 007 .....	381

	<b>Guarding Against Complacency—A Caution .....</b>	<b>383</b>
	Rare Causes of Errors .....	383
	More Common Causes of Errors .....	383
	Hints to Help Avoid Complacency .....	384
	<b>Study Questions.....</b>	<b>385</b>
<b>17</b>	<b>Celestial Concepts .....</b>	<b>387</b>
	<b>Celestial Navigation .....</b>	<b>387</b>
	<b>Celestial Concepts.....</b>	<b>388</b>
	<b>Motions of Celestial Bodies .....</b>	<b>390</b>
	Apparent Motion.....	390
	<b>Seasons.....</b>	<b>391</b>
	<b>Celestial Coordinates.....</b>	<b>391</b>
	<b>The Celestial LOP .....</b>	<b>394</b>
	Observed Altitude .....	395
	True Azimuth .....	396
	<b>The Celestial Fix.....</b>	<b>396</b>
	<b>Duration of Daylight.....</b>	<b>397</b>
	Altitude Effect .....	398
	<b>Study Questions.....</b>	<b>400</b>
<b>18</b>	<b>The Future of International Operations.....</b>	<b>401</b>
	<b>Future Directions .....</b>	<b>401</b>
	NextGen New Technology Programs .....	401
	FAA Resource Guides and Online Documents .....	403
	ICAO Documents and Websites .....	403
	<b>Online Options—International Flying Information .....</b>	<b>407</b>
	The Bottom Line .....	407
	<b>The Last Word.....</b>	<b>410</b>
	<b>Appendix: Fact Sheet – FAA Caribbean Initiative.....</b>	<b>412</b>
	<b>Appendix: Ops Group Blog – New NAT Contingency Procedures for 2019.....</b>	<b>416</b>
	<b>Appendix .....</b>	<b>421</b>
	<b>Readings in International Etiquette and Customs.....</b>	<b>423</b>
	<b>Acronyms/Abbreviations Glossary.....</b>	<b>425</b>
	<b>Index.....</b>	<b>441</b>



Some pages are omitted  
from this preview



# Earth Reference Systems

## LOCATION

“We are not lost...we’re here...it’s where we’re going that’s lost!”

Most pilots have experienced the undesirable feeling of not knowing exactly where they are and also the good feeling of re-establishing their position. Knowing and expressing where the aircraft is at any given time is done in reference to a point on the earth’s surface. This point may be either real (an airport, a town, a navaid) or imaginary (intersection of a line of latitude and longitude, or VOR radial and DME distance). For most of us, our first reference point was the airport from which we departed, and for most of us, we concentrated so heavily on the mechanics of flying the airplane that we lost track of where the airport was. We had to rely on our instructor to help us find the airport. Remember?

In order to locate ourselves and to describe the location, reference systems are used to respond to the question: where are you? “I’m in room 206.” “I’m at the corner of 5th and Main streets.” “I’m in the garage.” These are all examples of reference systems that are used daily. There are many reference systems that can be used by navigators, but only two are in general use by modern air navigators. These two systems are called FRD and latitude/longitude. In addition, there is a *concept* that is used by all navigators. First, let’s take a look at that concept, which involves the LOP and the fix.

## LOP AND FIX

A **line of position (LOP)** is a line containing all possible geographic positions of the observer at a given instant of time. If I told you that I was on Main street, you would know that I was somewhere on a line as defined by Main street. Other examples of lines of position: the aircraft’s position is on the 335° radial of the VOR, or on the 335° bearing from the NDB, or on the center line of the LOC.

Additionally, the line of position doesn’t have to be a straight line. It can be a curved line such as on the 7-mile DME arc (actually, DME provides a hemispherical LOP), or an irregular line such as over the west coastline. One LOP only partially defines a position. Two intersecting LOPs are required to define a position or establish a **fix**. Examples of a fix defined by two intersecting LOPs are: 5th and Main streets; the 335° radial of the VOR at 7 DME (remember, a **radial** is an imaginary line drawn from the VOR); over the coastline (an irregular LOP) 10 miles south of the Golden Gate Bridge (an arc LOP).

The term “fix” describes a geographic position which can be defined by intersecting LOPs, latitude/longitude (actually two LOPs), the location of a navaid, a well-known geographical feature, etc.

## FRD

**FRD** is an acronym for Fix/Radial/Distance. It defines two LOPs, and thus a geographical position (fix). A distance and direction from a known geographical position defines the location of the aircraft. Examples are:

TVF / 094 / 14 ..... VOR / radial / distance

CKN / 176 / 24 ..... NDB or airport (co-located in this case) / radial (see *Note*, below) / distance

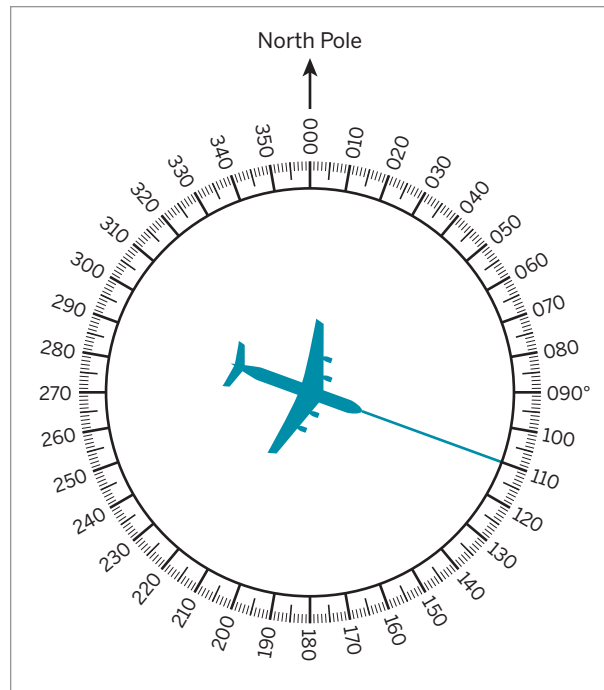
The above examples of FRDs would be acceptable as departure points, destinations, or enroute fixes when filing flight plans, provided the fix used in the FRD is defined in the NAS (National Airspace System computer).

*Note:* When studying VOR and NDB navigation, we learned that the term *radial* applied to VOR navigation and NDBs (ADF navigation stations) always used the term *bearing*, never radial. In the case of the FRD, however, *radial* refers to a magnetic direction from any fix. Perhaps it is time to pause and review the direction terms a pilot-navigator uses.

## DIRECTION

### Terms of Direction

Direction is the position of one point in space relative to another without reference to the distance between them. The time-honored nautical point system (22.5°/point) for specifying a direction (north, north-north-west, northwest, west-northwest, west, etc. or, in saltier terms: “steer two points west o’ north”) is not sufficiently accurate for modern navigation, but it provided the beginning of the compass rose direction system based on dividing the horizon into 360°. One of the two points in space, the reference point, is the direction to the true North Pole (000°) and the true South Pole (180°), giving a compass rose aligned to provide true direction (see Figure 2-1). If the compass rose is aligned with the magnetic north and south poles, magnetic direction values are provided. It is necessary for the navigator to always specify which system is in use.

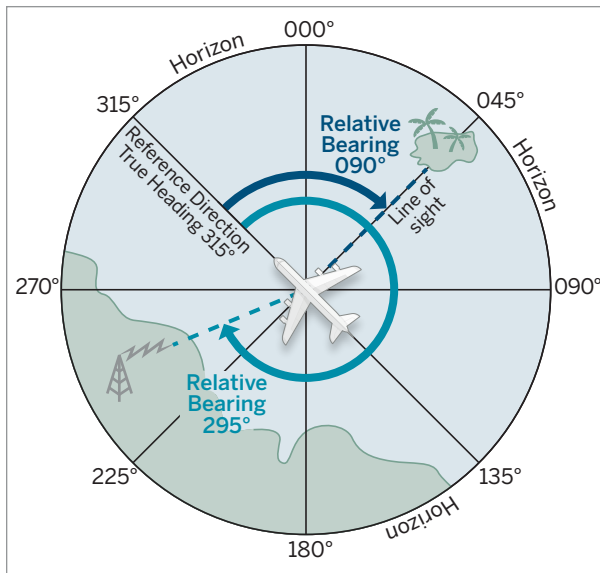


**Figure 2-1.** Compass rose, aligned to give true direction

Since determination of direction is one of the most important aspects of the navigator’s work, the various terms of direction should be clearly understood.

**Azimuth** is the true direction to a point in space. Usually, the point in space is a celestial body (star, sun, moon or planet).

**Bearing** is the horizontal direction of one terrestrial point from another. As illustrated in Figure 2-2, the direction of the island from the aircraft is marked by the line of sight (a **visual bearing**). Bearings are usually expressed in terms of (1) true north (**true bearing**), (2) magnetic north (**magnetic bearing**), or (3) the direction clockwise from the nose of the aircraft (**relative bearing**). In Figure 2-2, the island is located on a visual relative bearing from the aircraft of 090° or a true bearing of  $315^\circ + 090^\circ = 405^\circ - 360^\circ = 045^\circ$ . (Remember from your study of ADF navigation that  $MH + RB = MB$ ). Likewise, in the diagram, the radio station bears 295° relative from the aircraft. What is the radio station’s true bearing from the aircraft?



**Figure 2-2.** Relative bearings

**Course** is the intended horizontal direction of travel. Remember to specify true or magnetic.

**Heading** is the horizontal direction in which an aircraft is pointed—the orientation of the longitudinal axis of the aircraft, with respect to true or magnetic north.

**Radial** is the bearing from a VOR station to the aircraft. Expressed as magnetic direction except for a few VOR stations that are located at very high latitudes. A notable variation is the use of the term when defining an FRD.

**Track** is the actual horizontal direction of travel made by the aircraft.

## Great Circle and Rhumb Line Direction

The *direction* of the **great circle route** (Figure 2-3) makes an angle of about  $50^\circ$  with the meridian of New York, about  $90^\circ$  with the meridian of Iceland, and a still greater angle with the meridian of London. In other words, the direction of the great circle with respect to true north is constantly changing as progress is made along the route, and is different at every point along the great circle. Flying such a route requires constant change of direction and therefore would be more difficult to fly than a rhumb line



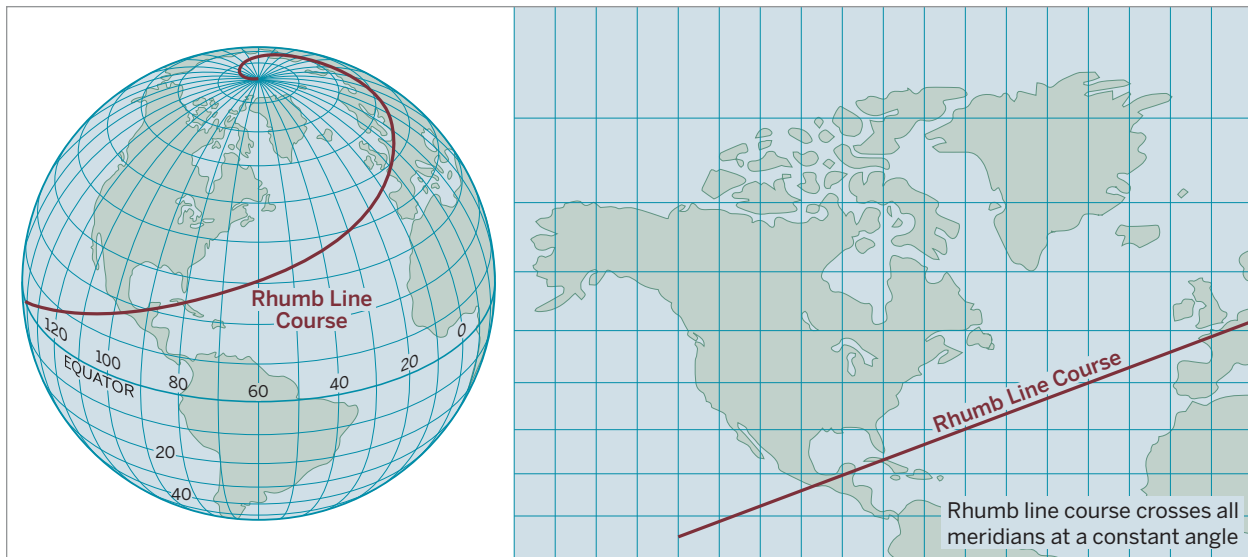
**Figure 2-3.** The great circle route crosses meridians at different angles.

course defined below. The great circle route is more desirable because it is the shortest route between two points on a spheroid such as the earth.

The exception to the above would be a flight tracking true north or south, since meridians (lines of constant longitude) are great circles, and no change of true course is necessary to fly along a meridian. Obviously, the more east-west a great circle route lies, the more true heading change is necessary to maintain the great circle route.

A line that makes the same angle with each meridian (except a true north or true south line) is called a **rhumb line**. An aircraft holding a constant true heading (that has an easterly or westerly component) is flying a rhumb line. The rhumb line path results in a greater distance traveled. If continued, a rhumb line spirals toward one of the poles in a constant true direction, but theoretically never reaches the pole. The spiral formed is called a **loxodrome** or loxodromic curve, as shown in Figure 2-4.





**Figure 2-4.** The rhumb line (or loxodrome) crosses all meridians at the same angle.

## DISTANCE

**Distance** is the spatial separation between two points. It is measured by the length of a line joining the two points, expressed in units of length such as kilometers, statute miles, nautical miles, etc. Distance measured between two points on a plane surface is a relatively simple matter. However, distance between two points on a sphere such as the earth involves the length of arcs and the use of spherical trigonometry. In order to simplify calculations, air navigation sometimes utilizes the assumption that the earth is a plane surface. To do so requires that the navigator accept the error associated with this assumption. When navigating long distances, this error becomes too large to be acceptable. The fact that the earth is nearly a sphere must be acknowledged in order to achieve accuracy.

In air navigation, the most common unit of measuring distances is the **nautical mile**. For most practical navigational purposes, all of the following units are used interchangeably as being equivalent to one nautical mile:

- 6,076.1 feet (nautical mile)
- 6,087.08 feet—one minute of arc on the earth's equator (geographic mile)
- One minute of arc of a great circle on a sphere having the same area as that of the earth

- One minute of arc of latitude—that is, one minute of arc along a **meridian** (a line of longitude)

Conversion of statute miles to nautical miles can be accomplished by using the ratio of 76 statute miles to 66 nautical miles, or roughly 7 to 6, or 1.15:1.

Closely related to the concept of distance is **speed**, the rate of change of position, or distance/time. It is customary to use the terms **knots** for “nautical miles per hour,” and MPH for statute miles per hour. For example, 150 nautical miles/hour is 150 knots, or 172.7 MPH. It is incorrect to use the term “150 knots/hour” unless referring to acceleration.

## LATITUDE AND LONGITUDE

Since **latitude** and **longitude** and **great** and **small circles** are terms specific to spheres like the earth, a little background knowledge about the earth's size and shape is important.

### Size and Shape of the Earth

For many navigational purposes, the earth is assumed to be a perfect sphere, although in reality it is not quite perfect. Inspection of the earth's crust reveals that there is a height variation of approximately 12 miles from the top of the tallest mountain to the bottom of the deepest point in the ocean.

Smaller variations in the surface (valleys, mountains, oceans, etc.) cause an irregular appearance.

Measured at the equator, the earth is approximately 6,887.91 nautical miles in diameter, while the polar diameter is approximately 6,864.57 NM. This difference expresses the **ellipticity** of the earth. Sometimes, this is expressed as a ratio of the difference between polar and equatorial diameters to the equatorial diameter:

$$\text{Ellipticity} = (6,887.91 - 6,864.57)/6,887.91 = 1:295$$

Since the equatorial diameter exceeds the polar diameter by only 1 part in 295, the earth is very nearly spherical. A symmetrical body having the same dimensions as the earth, but with a smooth surface, is called an **oblate spheroid**.

In Figure 2-5, the points Pn, E, Ps, and W represent points on the surface of the earth. Points Pn and Ps represent the axis of rotation. As viewed from space at the perspective of this figure, points on the visible surface move from left to right or west to east. If the earth were to be viewed looking down on the north pole, the earth would appear to be rotating counterclockwise at the rate of 15.04° per hour or 360.96° per 24-hour day.

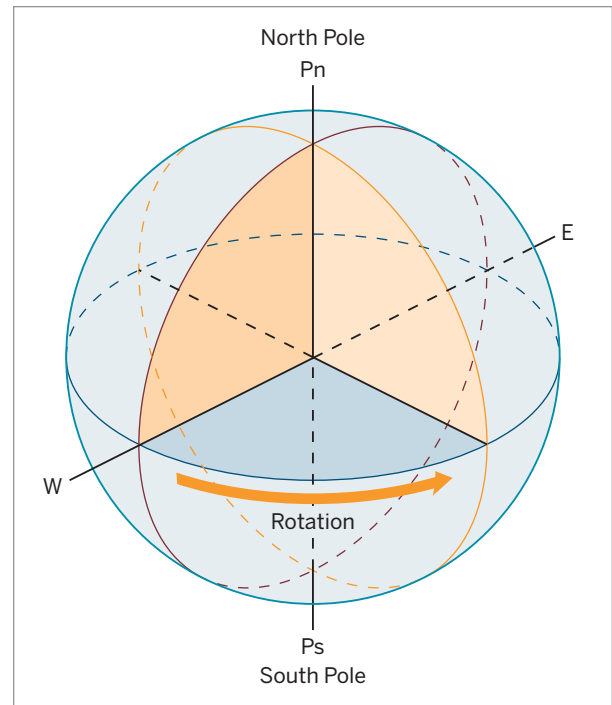
The **equator** (the circumference W-E) is defined as an *imaginary circle on the surface of the earth, equidistant from the north and south poles, whose plane passes through the center of the earth and is perpendicular to the axis of rotation.*

## Great and Small Circles

A **great circle** is a circle on the surface of a sphere whose center and radius are those of the sphere itself. It is the largest circle that can be drawn on the sphere. It is the intersection with the surface of the earth, of any plane which passes through the center of the earth.

Understanding the concept of the great circle is important to any navigator because the arc of a great circle is the shortest distance and most direct route between any two points on the surface of a sphere, just as a straight line is on a plane surface.

Circles on the surface of a sphere other than great circles are called **small circles**. Great and small circles are shown in Figure 2-6.



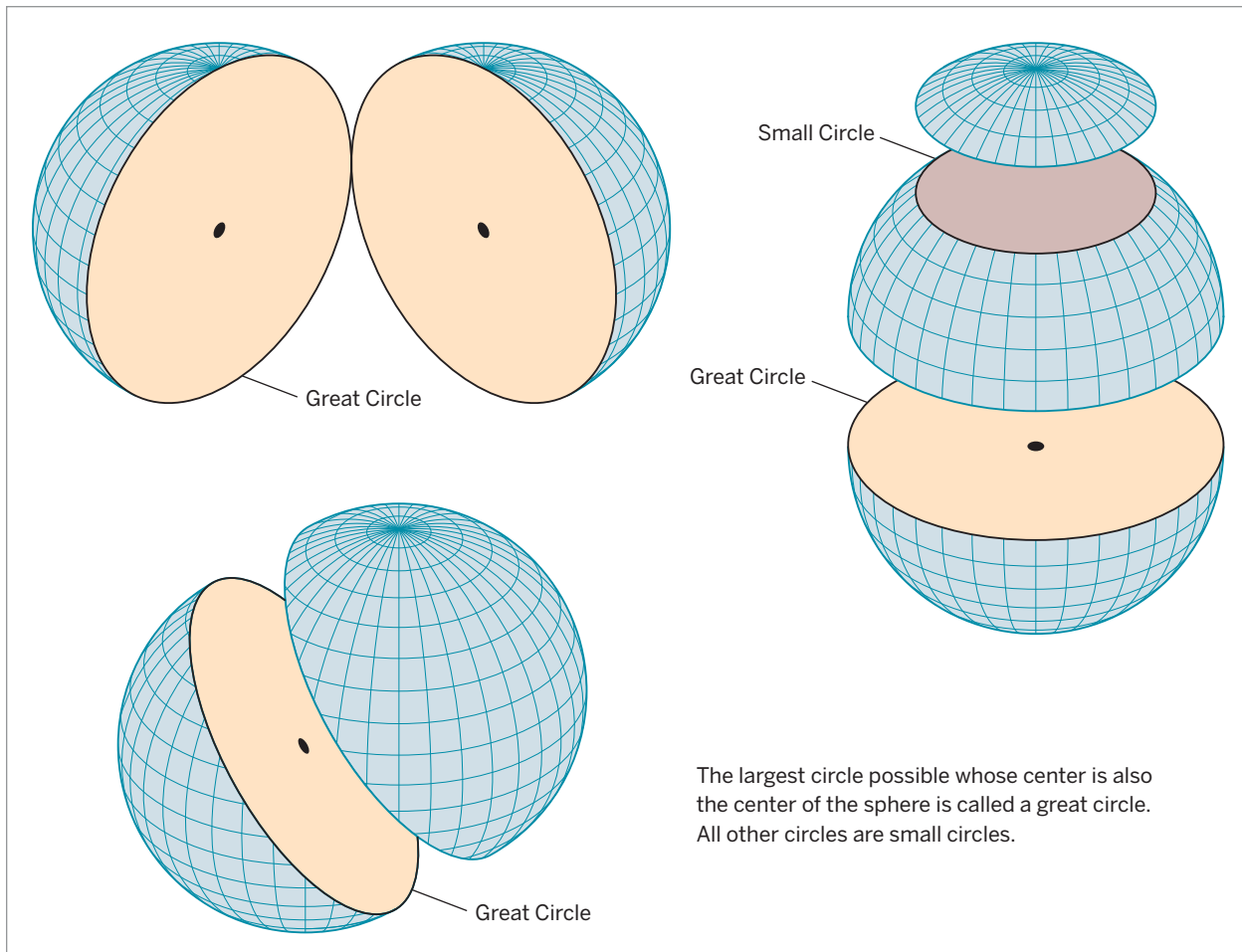
**Figure 2-5.** A representation of the earth showing rotation, spin axes, and equator.

## Latitude and Longitude as a Reference System

This is the geographical reference system most commonly used for spherical surfaces. Air and marine navigators, particularly those working with long distances, utilize this system to a great extent. All long distance navigation systems such as GPS and INS use the latitude/longitude system.

Once a day, the earth rotates on its north-south axis which is terminated by the north and south geographic poles. The imaginary line of the **equator** is constructed along the surface of our sphere, midway between the poles, creating a great circle. It is the only great circle on our planet that is oriented true east-west.

If one were able to journey to the exact center of the earth and there set up a surveyor's transit to measure the angle between a sight to the north or south pole and a sight to any point on the equator, the angle (Pn-C-Q or Ps-C-Q of Figure 2-7) would be found to be 90°. Arbitrarily, let us call the equator, which is the only possible great circle lying directly



**Figure 2-6.** Great and small circles

east-west, the reference for east-west lying lines of position, and assign it a value of zero degrees.

Now, after sighting from the center of the earth (C) to the equator (Q), imagine changing the angle of the sight  $30^\circ$  toward the north pole and having the surveyor's helper pound stakes wherever the line of the sight intersected the earth's surface. The stakes would mark the  $30^\circ$  north parallel (M-M'). It is labeled such because it is located in the northern hemisphere and is separated from the equator (the reference point) by  $30^\circ$  of arc (Q-M).

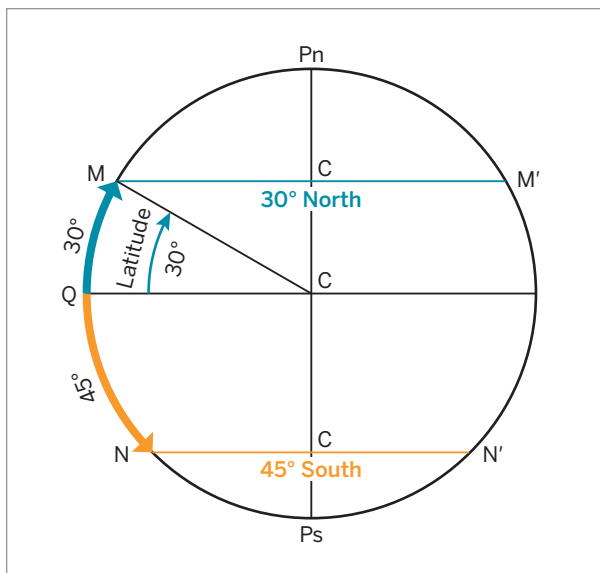
It is apparent from Figure 2-7 that the lines of **latitude** are labeled based on the degrees of angle or arc, north or south of the equator, and that these lines are circles (when viewed from a perspective above the north or south poles). Except for the equator, they are small circles because they do not fit the

definition of a great circle. They are all parallel to each other when viewed from the perspective of Figure 2-7, hence they are called **parallels**.

It should now be apparent that line N-N' (in Figure 2-7) describes the  $45^\circ$  south parallel. All points on this line are at latitude  $45^\circ$  south. The north pole is at latitude  $90^\circ$  north and the south pole is  $90^\circ$  south. Thus, any point on the surface of the earth may be assigned a value of latitude, which is a line of position (LOP) running E-W, parallel to the equator. The point requires another LOP (longitude) to properly define its location (fix) on the surface of the sphere.

Half of a great circle, which is a line drawn on the earth's surface from pole to pole, is called a **meridian**.

If a meridian is drawn from the north pole, through a point on the grounds of the royal observatory near



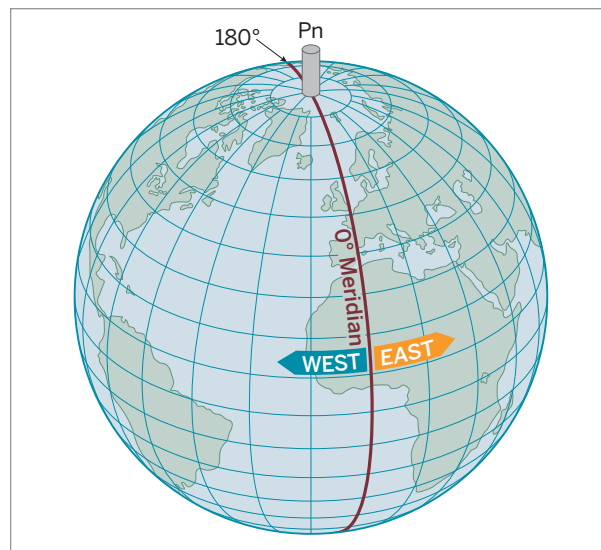
**Figure 2-7.** Latitude of M is angle QCM or arc QM.

Greenwich, England, to the south pole (remember, the plane within this semicircular line must pass through the center of the earth), the **Prime Meridian** is the result, which is given the value of 0° of longitude. The other half of this great circle, occurring halfway around a 360° circle, has a value of 180° of longitude and is the meridian called the **International Date Line**. (See Figures 2-8 and 2-9).

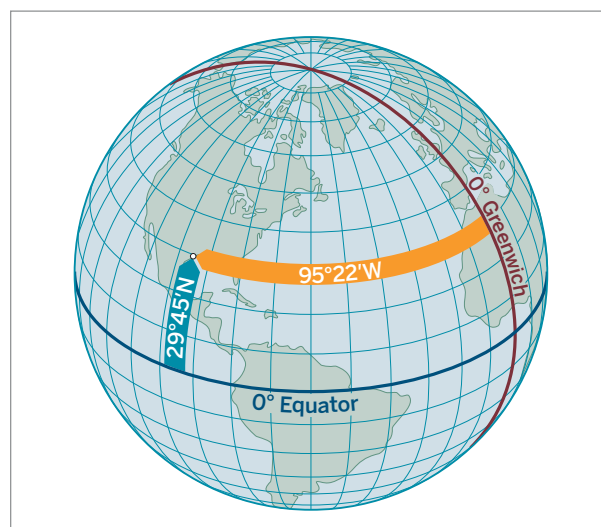
**Longitude** is the angular distance along the arc from the Prime Meridian or Greenwich Meridian to the location of the point. This defines a second LOP which runs N-S through the point. All lines of longitude (meridians) are great circles.

Values of latitude range from 0° to 90° north and 0° to 90° south. Values of longitude range from 0° to 180° east and west. When expressing latitude and longitude, latitude values are always given first. A degree may be broken down into its smaller parts: minutes and seconds. There are 60 seconds per minute and 60 minutes per degree. One minute of latitude (measured N-S along any meridian) is equal to one nautical mile. One minute of longitude (measured E-W along lines of latitude) is equal to one nautical mile *only at the equator*.

It is apparent that meridians get closer together as they approach the poles, so the distance between minutes of longitude decreases as latitude increases. Nautical miles per minute of longitude =  $1 \times \cos$  of



**Figure 2-8.** Longitude is measured east and west of the Greenwich Meridian.



**Figure 2-9.** Latitude is measured north and south from the equator. Longitude is measured east and west from the Prime Meridian.

the latitude. For example: at 50° north, one minute of longitude =  $1 \times \cos 50^\circ = .643$  NM.

### Formatting Lat/Lon Coordinates

Various formats for reporting lat./lon. are in use today, including degrees, minutes and seconds (ddd:mm:ss); degrees, minutes and decimal fractions of minutes (ddd:mm.m) or (ddd:mm.mm).



Converting from one to the other is not difficult, recalling that 60s = 1 NM, so 6s = .1 NM. For example, 35°12'18" converts to 35°12.3' and to 35.205'.

In addition, the computers in our navigation equipment today are not standardized with respect to lat./lon. input format. For example, the input format for the example in the paragraph above could be 3512.3, 35.12.3, 3512.30, 35.12.30, or 35123 or 351230, if the value was for latitude. Longitude values are slightly more complex as there is one more digit. Some computers require the input to be preceded by a zero if the value of longitude is less than 100°, and some computers do not require this. For example, the longitude 94°30 minutes west is input into the DUAT system as 9430 when filing a flight plan. It is input into the FAA (flight service station) computer as 09430. The values north and west (lat./lon.) are not required as they are assumed for U.S. flight plans because all areas within the U.S. are north latitudes and west longitudes.

I used to use a LORAN in which the same value was entered as 094.30.00 (west was assumed by the computer but could be changed during input). My more modern GPS allows the user to select the format from the three versions available. Be careful! You don't want to enter most countries if you are not expected.

The need for standardization is obvious, but it simply doesn't exist; therefore, there is a tremendous need to *exercise extreme caution when values are input into any navigation or flight planning system.*

Will standardization occur? A pessimist would say that we need only take a look at the CDI instruments manufactured by King and Narco to see standardization is not likely (flying an older airplane today with one of these radios in it?)—they were the “big two” general aviation avionics manufacturers during the past thirty years. One manufacturer's unit reads the value at the top and the reciprocal at the bottom, while the other's is reversed.

## A Change in the Geodetic Referencing System

On October 15, 1992, the horizontal geodetic referencing system used in all charts and chart products published by the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) changed from the North American Datum of 1927 (NAD 27) to the North American Datum of 1983 (NAD 83). Pilots should be familiar with this congressionally-mandated change because it affects the latitude and longitude coordinates of almost all points identified in the National Airspace System. The coordinates have changed by zero to 16 seconds (of latitude and longitude).

In the United States, latitude and longitude are based on a network of geodetic control points established and maintained by the National Geodetic Survey (Department of Commerce). Control point coordinates are determined mathematically based on a reference point. The NAD 27 used a reference point in Kansas for the lower 48 states (conterminous U.S.), Canada, and Alaska. Technological advances of Global Positioning Systems (GPS) and other systems now allow satellite systems to pinpoint much more accurately geographic locations by referencing the center of the earth. NAD 83 is based on the center of the earth and geodetically ties Puerto Rico and Hawaii to North America.

The greatest coordinate shifts are in Alaska and Hawaii where latitude has been moved by as much as 1,200 feet and longitude by up to 950 feet. In the conterminous U.S., the maximum changes were approximately 165 feet in latitude and 345 feet in longitude. Magnetic variation will be altered so minutely the aviation community need not be concerned.

Not so very long ago, my GPS mapping system showed our boat, chugging happily along, ashore on San Marcos Island in the Sea of Cortez when actually there was water all around us and visually, we were near the island. That changed to far better accuracy

when the mapping source was changed from NAD 27 to NAD 83. With some GPS units, the NAD in use is user-selectable.

The shift is not significant enough to change the latitude and longitude grid on Sectional Charts or WACs, but it could change the grid on the TACs, Helicopter Charts, and Sectional Insets, and most certainly will affect Airport Diagram Charts. All coordinates in the Digital Aeronautical Chart Supplement, Airport/ Facility Directory, Pacific and Alaska Chart Supplements, on enroute navigation charts and all digital products are carefully imprinted with a date, and some have the statement indicating they are based on the NAD 83 database. Also, check the user guide for the navigation systems you are using to be sure they are using the NAD 83 mapping database and which lat./lon. format is being used. Most are user changeable, as are the map systems available on the internet such as Google Earth.

pilot to gain the perspective needed to understand the navigational concepts and be able to predict what the surface that is about to be flown over should look like.

This brings us to the subject of maps and charts, which need to be understood in order to be able to fully utilize this major navigator's aid at a high level of sophistication. However, before going on to the study of maps and charts in Chapter 3, go through the study questions in order to fully understand the concepts presented in this chapter.

## SUMMARY

All of the information in this chapter is considered basic and necessary to the knowledge base of the pilot/navigator, so the reader should not consider this summary section as the “bottom line, all that's needed to know” part of the chapter. In fact, the reader should use the study questions at the end of this chapter in an effort to solidify the principles above into a position of familiarity.

If a globe has the circles of latitude and longitude drawn upon it according to the principles described, and the latitude and longitude of a certain point have been determined by observation, this point can be located on the globe in its proper position. In this way, a globe can be formed that resembles a small-scale copy of the spherical earth (see Figure 2-9). Thus, a small-scale reproduction of the surface above which the pilot navigates is produced, to allow the

## Study Questions

1. Find a globe of the earth. Note how the lines of latitude and longitude are placed. Find and list the latitude and longitude of ten major cities in the world, including one near the equator, one each nearest the south and north poles.
2. Set up a table with four columns labeled: city; lat./lon. from globe; airport lat./lon. from IFIM (International Flight Information Manual), ICAO airport identifier. From the globe, find the latitude and longitude of the following cities. Then, using the IFIM, list the airport lat./lon. and four-letter identifier for the city. Compare the two lat./lon. values. Are they close? Write a short conclusion about what you have learned from these efforts.
  - a. Lisbon
  - b. Tokyo
  - c. Yellowknife (Canada)
  - d. Moscow
  - e. Cairo
  - f. Georgetown (How many can you find?)
3. Show how you solved the following: how far is
  - a.  $46^{\circ}34'12''\text{N}/096^{\circ}12.0\text{W}$  from  $48^{\circ}10'00''\text{N}/096^{\circ}12.0\text{W}$ ?
  - b.  $12^{\circ}16'18''\text{N}/94^{\circ}30'\text{W}$  from  $10^{\circ}08'12''\text{S}/094^{\circ}30'\text{W}$ ?
  - c.  $00^{\circ}00'/80^{\circ}20'\text{W}$  from  $00^{\circ}00'/160^{\circ}20'\text{E}$ ? (Determine values for both short and long path.)
  - d.  $46^{\circ}30'\text{N}/93^{\circ}00'\text{W}$  from  $46^{\circ}30'\text{N}/94^{\circ}56'\text{E}$ ?

Now, error-proof your answer by using another method to solve the problem (it's okay to use a digital device here).

4. Define:
  - a. LOP
  - b. fix
  - c. radial
  - d. FRD
  - e. nautical compass point
  - f. bearing
  - g. azimuth
  - h. course
  - i. track
  - j. heading
  - k. knot
  - l. oblate spheroid

- m. equator
- n. great circle
- o. latitude
- p. longitude

5. This will require some outside-the-book research—include your sources: How many points do each of these compass roses have and how many degrees are between each point? Name the points.
    - a. Mariner's
    - b. Traditional
    - c. Meteorological
    - d. Primary points compass
  6. What is the difference between a bearing and a rhumb line? What is a rumbo in the Spanish language?
  7. If there is an error in your NAV system of each of the following values, what is the error expressed in nautical miles?
    - a. 1 degree (N-S)
    - b. 1 minute (N-S)
    - c. 1 second (N-S)
  8. The equator is the only east-west great circle. The rest of the east-west lines of equal latitude are called: \_\_\_\_\_ and/or \_\_\_\_\_.
  9. Convert these angles to both of the other formats:
    - a.  $123.2837^\circ$   
 \_\_\_\_\_ (DDD.MM.SS); \_\_\_\_\_ (DDD.mmm)
    - b.  $142^\circ 01' 14''$   
 \_\_\_\_\_ ( \_\_\_\_\_ ); \_\_\_\_\_ ( \_\_\_\_\_ )
    - c.  $003^\circ 12.13'$   
 \_\_\_\_\_ ( \_\_\_\_\_ ); \_\_\_\_\_ ( \_\_\_\_\_ )
  10. Are the numbers in Question 7 values of latitude or longitude? Why?
-