Table of Contents

Preface vi

Introduction

About this Book 1
Are You Nervous About Learning Celestial Navigation?..2
How to do the Home Study Course....................2
Frequently Asked Questions 2
Tools of the Trade....................3
Celestial Terminology....................3
How this Book is Structured 3

Chapter 1. Background & Overview

1.1 Overview of Ocean Navigation....................5
1.2 Overview of Celestial Navigation....................7
1.3 Bird's Eye View of a Celestial Fix....................9
1.4 Latitude, Longitude, and Nautical Miles.................... 11
1.5 Arithmetic of Angles and Time....................13
1.6 Exercise on Adding and Subtracting Angles 17
1.7 Exercise on Adding and Subtracting Times 17
1.8 New Terminology....................18

Chapter 2. Sextants

2.1 About Sextants....................19
2.2 How to Take a Sight.................... 20
2.3 How to read a Sextant 24
2.4 Exercise on Sextant Reading....................27
2.5 New Terminology 28

Chapter 3. Noon Sights

3.1 Introduction to LAN 29
3.2 Step by Step LAN Procedure 31
3.4 Exercise on LAN Sights for Latitude....................39
3.5 Review: LAN Virtues and Drawbacks 42
3.6 New Terminology 44

Chapter 4. Piloting & Chart Work

4.1 Introduction....................45
4.2 Universal Plotting Sheets 45
4.3 Exercise on Universal Plotting Sheets 47
4.4 Plotting Lines of Position 47
4.5 Exercise on Plotting LOPs....................52
4.6 DR Plotting Exercise 54
4.7 More DR Plotting Practice....................55
4.8 New Terminology 56

Chapter 5. Sun Sights

5.1 Introduction 57
5.2 Sunrise, Sunset and, Twilight Times....................57
5.3 Sun Lines Using Starpath Work forms 59
5.4 Sun Sight Exercise, Sun #2 71
5.5 Sun Sight Exercise, Sun #3.................... 71
5.6 Sun Sight Fix Exercise, Sun #4 72
5.7 Sun Sight Fix Exercise, Sun #5....................72
5.8 Exercise—More Sun Sight Practice 73
5.9 Progress Report 74
5.10 New Terminology....................74

Chapter 6. Running Fixes

6.1 Introduction 75
6.2 Running Fixes in Coastal Nav 75
6.3 Running Fixes in Celestial Nav 77
6.4 Exercises on Running Fixes 78
6.5 Running Fix with Sun lines #6 and #7....................79
6.6 More Practice on Running Fixes.................... 80
6.7 New Terminology 82

Chapter 7. Star Sights

7.1 Introduction 83
7.2 Sight Reduction of Stars 84
7.3 Arcturus Sight Exercise, Star #2 85
7.4 Altair Sight Exercise, Star #3 86
7.5 Antares Sight Exercise, Star #4.................... 86
7.6 Arcturus Sight, Star #5....................87
7.7 Regulus Sight, Star #6 87
7.8 Latitude by Polaris.................... 88
7.9 Practice with Latitude by Polaris....................91
7.10 New Terminology....................91

Chapter 8. Planet Sights

8.1 Introduction....................93
8.2 Sight Reduction of Planets 94
8.3 Jupiter Sight Exercise, Planet #2....................97
8.4 Venus Sight Exercise, Planet #3 97
8.5 Jupiter-Hamal, Plot Exercise, Planet #2, Star #7 ... 98
8.6 Venus-Sirius, Plot Exercise, Planet #3, Star #8 98
8.7 New Terminology 98

Chapter 9. Moon Sights

9.1 Introduction 100
9.2 Sight Reduction of the Moon 100
9.3 Exercise on converting Moon's Hs to Ho 103
9.4 Moon Sight Reduction, Moon #1 103
9.5 Moon-Sun Running Fix Exercise, Moon #2 104
9.6 Moon-Sun Running Fix Exercise, Sun #8 104
9.7 Moon-Arcturus Fix Exercise, Moon #3 105
9.8 Moon-Arcturus Fix Exercise, Star #9 105
9.9 Moon Exercise, Moon #4 106
9.10 Use of the Moon and Planets 106
9.11 New Terminology 108

Chapter 10. Principles

10.1 A One-hour Course in Cel Nav 109
10.2 Distant Light Rays 114
10.3 Zenith Distance = Distance to the GP. 114
10.4 Why the Sun Rises and Sets 116
10.5 Lat and Lon Without Math 117
10.6 How Sight Reduction Works 118
10.7 New Terminology 121

Chapter 11. In Depth

New Terminology 123
11.1 Bowditch and other References 124
11.2 Taking Your Departure 125
11.3 Electronic Navigation 126
11.4 Mercator Charts 131
11.5 Time Keeping in Navigation 132
11.6 Dip Short 136
11.7 Solar Index Correction 138
11.8 Optimizing Plastic and Metal Sextant Sights 141
11.9 Longitude from LAN 144
11.10 Ocean Plotting Sheets 146
11.11 Ocean Dead Reckoning 147
11.12 Practice with Time Prediction 151
11.13 Practice Choosing the AP 151
11.14 Practice with Pub. 249 Vol. 2, 3 153
11.15 AM to PM Running Fixes 154
11.16 An Ocean-going Nav Station 155
11.17 Offshore Navigation Checklist 157
11.18 Checking a Sextant with the Stars 158
11.19 Artificial Horizons 161
11.20 Storm Warnings at Sea 164
11.21 Compass Checks at Sea 165
11.22 Great Circle Sailing 166
11.23 Rhumb-line Sailing 169
11.24 Optimizing Celestial Fixes 174
11.25 Star and Planet ID 178
11.26 Emergency Procedures 183
11.27 Pub. 249 Vol. 1, Selected Stars 184
11.28 Computed Solutions 189
11.29 NAO Sight Reduction Tables 191
11.30 N(x) Table 196
11.31 Nuts and Bolts of Ocean Navigation 199
11.32 Most Likely Position from Three LOPs 202

Appendix

Glossary 203
Answers 221
Examples with Full Work Form Solutions 221
Table Selections 243
Workforms 272
Index 285

Preface

Our goal is to teach readers how to do celestial navigation and do it well. This book evolved from interactions with many thousands of students over the past 20 years, both in the classroom and in online training. The structure of the book reflects what we have learned. One influence of that experience was to break up the early study between tables and number crunching with hands on plotting exercises. Another is to teach how to do it as quickly as possible up front, and only after that, or during that, do we fill in details of the practice and theory. The goal is to get readers carrying out the full process from beginning to end, so they can then be practicing the process and catching mistakes early, as we slowly add the background. In short, the background goes to the back.

Practical, self-reliant celestial navigation is easy to do. It is done today much as it was 100 years ago, and as it will likely be done 100 years from now. We risk losing sight of that if we choose to understand all the math and science background before getting started on the actual navigation, which itself requires no math beyond arithmetic. We have a proven compromise at hand. There are In-depth references to the back of the book at each stage of the learning for those who are more comfortable having the background at hand. Many readers, however, will follow the background more readily once they know how it works in practice.

We have also learned that a well-designed work form is key to versatile cel nav practice. Our unique forms guide you though the process, step by step. They make all sights essentially the same, and provide an easy reminder of the next step at each stage.

Preface to the Second Edition

We are pleased to say that after ten more years of using this text we do not find reason to change the basic approach and methods of the teaching. We still use most of the same examples, which are now quite old, but that is the beauty of celestial navigation. It has not changed, so we do not benefit in anyway from making all new examples, which would bring with them more chance of error in a book of many numbers.

We have, however, notably improved and expanded the book. Each section has been updated and reformatted for a clearer presentation, often in response to student questions over the years. New graphics have been added and older ones all updated. There is new content in the text, especially in the In-Depth chapter including more detailed discussion of the sailings and more background on the principles. New sections on general ocean navigation tactics and new sections on optimizing the fixes. We have also updated the electronic navigation section, and we no longer explain systems we will never see again!

Starpath instructors remain at hand to answer questions about the subject and we maintain an online support page for this book at www.starpath.com/celnavbook.

Introduction

About this Book

These study materials (text, examples, and practice exercises, along with the table selections and work forms in the Appendix) are used for classroom, home study, and online courses throughout the US. With home study, readers do not have the benefit of classroom discussion, but they do have the benefit of using materials that more than 30,000 celestial navigation students have used before them. Hopefully most of the questions that might come up are already answered.

The materials you have in this book are the basis for all three learning formats. For those who might like a classroom course, the Calendar section of starpath.com lists courses around the country that use this textbook and related materials. Online courses are also available that provide direct contact with instructors and individually graded practice quizzes. Various levels of certification are also available.

Without either of those options, however, we feel confident you can learn practical and versatile celestial navigation from these materials alone, studying at home on your own. Thousands have done so, and gone on to cross oceans or circumnavigate the globe.

Hands on instruction with sextant sights might seem the main factor missed in home study learning, but here too our experience with so many past students helps again. We have a thorough section on sextant handing and how to read the dials, along with crucial steps to taking good sights. Follow these procedures and you will learn quickly how to use the sextant.

In fact, the challenge of using a sextant is not as high as one might guess from scuttlebutt on the topic. The ingenuity of sextant design is not its ability to measure accurate angles—this could be done on land two centuries before sextants were invented—but rather it was its unique double reflection design that lets you measure accurate angles when you are bouncing around in a seaway. Standing still on a beach or the edge of a lake, you will learn the process quickly, and the ingenuity of the instrument design will let you carry these new-found skills on to the rolling platform of a boat at sea.

Also you will learn shortly that a real beauty of celestial navigation is its transparency. If you make a mistake, it will be obvious, and if you keep careful records of all the data that went into the sight process and analysis, you will be able to find that mistake. If you have a friend or teacher who is familiar with celestial navigation, they can also look at the data and help you learn what went wrong. Part of the learning process is exactly that. Leaning the pitfalls of possible mistakes and how to avoid them. This course offers so many practice examples, that you will have this under control before you set off. It is obviously much better to make all the mistakes on land, and save your time at sea for other matters.

The various subjects covered in our materials and the relative emphasis given them in the course is based on the latest information on these subjects—some of which is changing, though most is not—and our actual experience at sea (mostly under sail) covering more than 70,000 miles, some 25% of which were navigated by celestial alone (See *Hawaii by Sextant*, Starpath Publications, 2014). We concentrate on practical matters, presented and explained in a manner that we have learned from classroom experience suits most students best.

The various procedures of celestial navigation are presented in a step-by-step manner, with numerous examples and many practice problems. This is a practical approach, but not a cookbook approach. We delegate the astronomical and mathematical backbones of celestial to the optional topics at the end of course as they can in fact distract from learning how to do it, but we can promise that at the end of the course, you will know how to do it, and do it well, and also know how it works.

You will notice that some of the practice examples and sample data pages date from the late 70's when we first started teaching celestial navigation. Don't be alarmed by these dates. The *Nautical Almanac* pages that we teach from that originated in 1978 are identical to those printed today, and likely will be the same 30 years from now. One might be tempted to change all the examples to the present date to make them look up to date, but in reality there is no difference in the learning whatsoever, and by not doing this we avoid the chance of introducing typographic errors. There are a lot of numbers in a course on cel nav, so this is an important step toward maintaining the integrity of the materials.

Are You Nervous About Learning Celestial Navigation?

You will soon see that celestial navigation is an impressive and very rewarding thing to learn about; it is also an unusual subject in that it is technical stuff that many non-technical people want to learn. For people who do not routinely deal with numbers, graphs, or other technical matters, the onset of this course might well be more of a challenge than it is for those who are already comfortable with numerical work. If you do not work with numbers on a daily basis, your worries might be reinforced after skimming through this book, filled with numbers, tables, forms, and strange looking plots. Please let me assure you, however, that the chart and paperwork of celestial navigation looks more complicated than it is.

There is sophisticated science and mathematics buried in the subject, but it is well buried. The actual practice has evolved into a systematic process requiring no math beyond arithmetic and no science beyond reading the dials of a sextant and watch. The key to success is an organized approach to the paperwork and prudent tips on sextant use. This course is designed with that in mind. The course approaches the subject step by step, with planned changes in subject matter that lets earlier parts settle in, followed by a review of the past before proceeding on to something new. By the end of the course, the parts of this book that might have looked overwhelming at first will then be familiar. Step by step, you will have learned it all. In the end, as you flip through the book again, you will rightfully be proud of the accomplishment.

Thousands of people have used these notes to learn celestial. People in their early teens to people in their early 80's. People from every profession and every walk of life. Sailors who have spent years on the water, as well as those who have never been on a boat. The vast majority are totally unfamiliar with celestial to begin with, but we are equally proud of our success with those who "have tried every course available" and did not succeed until now. Our reputation is based on our record. Anyone who wants to learn celestial can do it with this course. That is our job.

How to do the Home Study Course

We suggest that you divide your study into sections that follow the Table of Contents. This is very similar to the way we present the materials in a classroom or online course. It divides up the course into sections, with logical breakpoints in between. It structures the reading and practice exercises. Answers are provided along with solutions in most cases in the back of the book. If you cannot get the right answer on a practice exercise, rework one of the illustrative examples to double check your procedure. If you have trouble finding an error, it is often easier to start from scratch with a clean slate, rather than going back over the numbers of a completed solution.

As you work through the practice, keep a bound notebook of your work, with each problem labeled carefully—as opposed to just using loose sheets of paper that may get lost. If a question or concern arises, jot it down and date it so you don't forget it. This is especially valuable practice for general questions or curiosities that have not stopped your progress. Most of these questions will likely be answered as you progress through the book. They will also be useful if you choose to work with an instructor later on or post questions in an online forum.

Frequently Asked Questions

How Long Does the Course Take?

The Starpath classroom course was eight 3-hour classes, with the assumption that students spent at least an equivalent amount of time outside of the classroom. We have estimated that our online version of the course would take about 70 hr, but some students spend more time than that. The time spent depends on the number of practice exercises needed to master a topic as well as how much of the special In-Depth material from Chapter 11 you choose to cover. Most classroom courses include some, but not all of that material.

Do I Need a Sextant to do the Course?

The answer to that is No, but you will eventually need one to do real sights. You can actually work though the course without one and get the sextant later—in fact, it is even best to read through Chapter 2 on sextants before making your choice. But once that chapter is presented, the practice exercises simply start out saying "the sextant read such-and-such at time such-and such" and you can work out your position lines from that.

When you start doing sights, be sure to keep careful records of your work. Take a notebook and record *everything* about the sight session. Use a GPS to know your exact location, and use it as well to check your watch time. Note the times of all sights, the height of eye above water level, the height of the tide at the time, the index correction, plus how and how often you checked it. If more than one sextant, which sextant goes with which sight, etc. Do not throw out sights—make a note on it, but keep it. If you do all this, you will eventually be able to figure out what is wrong if you do not get a good fix or good LOPs. That is the beauty of celestial navigation.

What Sight Reduction Tables Are Used?

This question may or may not make sense to you at this point, depending on where you are starting, but it is a question that comes up frequently. The answer is we teach them all in this book, and our work forms can be used with any of the tables. The Table Selections we provide are from Pub. 249 and our solutions use those tables, but any version could be used to work the problems. Toward the end of the course we encourage students to consider the NAO Tables included in each edition of the almanac. And we have examples from Pub. 229. Those preparing for a USCG exam will have to eventually use Pub. 229. (Again, if this question and answer does not make sense, do not worry about it. It will all be clear very shortly.)

More Support?

For extra help see www.starpath.com/celnavbook. There are multiple resources there related to this book and the general study of celestial navigation, including several organizations and discussion groups that specialize in cel nav. There are also links to schools around the country that use this text for their courses. Sextants and related tools and materials are also available.

Tools of the Trade

The following is a list of the equipment and materials needed to do celestial navigation at sea. This is not a list of what you need for the course. Everything needed for the course is provided in this book except for standard plotting tools. We include this list early in the notes, only because it is consistently an early question we get in class. And it is certainly reasonable to wonder "What am I going to need after I learn this stuff and what will it cost?"

Celestial Equipment Needed Underway

Approximate 2015 prices are shown; options and alternatives are discussed later.

Metal Sextant	$659
Plastic backup sextant	$49
Two Watches	$80
Nautical Almanac	$30
Universal Plotting Sheets	$8
Sight Reduction Tables	$30
2102-D Star Finder	$39
Plotting tools	$60
Notebook	$10
Large waterproof cases	$15

The total cost is about $300 plus a sextant, but a radio of some kind is required to confirm the watch times. Generally, the minimum radio equipment one should consider for an ocean crossing is a SW receiver capable of receiving the high seas weather. Dependable portable models cost about $200. These will provide very good time signal reception, but it is not clear that this should be counted in as a celestial expense. You can, in fact, get accurate time from your GPS while it is working, but the radio is still the safest source.

If you happen to have a SSB transceiver or satellite phone on board for high-seas communication, then it will provide excellent weather and time signal coverage as well. It is a toss up these days as to which is best, if only one is to be had. Satellite phones are more convenient, but cost more to operate.

Celestial Terminology

Learning celestial navigation can be thought of in terms of several goals:

• Learning how to use a sextant to take sights (usually mastered in a few hours with good instructions).

• Learning how to use a dozen or so new tables (similar to learning to use a phone book or tide table for the first time).

• Learning a book keeping procedure for what to do with the numbers we get from the tables (we use a work form to guide us through this step; the only math required is adding and subtracting).

• Learning a new plotting procedure for putting the numerical results onto a chart (takes only an hour or so to master using our instructions).

• Learning a couple dozen or so new terms, which is the subject of this section.

Many of the terms to be used are already familiar, but we need to add precision to the meanings. Some celestial terms have recognizable origins (i.e. *zenith* is indeed the point overhead, as *sextant angle* is indeed the angle we measure with a sextant), but many terms have obscure names (sextant angle is usually called sextant height or sextant altitude; zenith distance is actually an angle, not a distance; ZD stands for zone description, not zenith distance, and so on). There is a temptation to rename some terms to simplify the learning (which some books give in to), but in the long run this is a serious disservice. It is best to stick with traditional terminology so everyone can speak the same language and read the same books.

Keeping these terms straight does not come instantly, but slowly it falls into place. To help with this, there is a thorough glossary at the back of the book, and we list new terms at the end of each Chapter.

How this Book is Structured

The body of the text presents a sequence of topic discussions with a few worked out numerical examples showing how the tables and forms are used to complete the task at hand, followed by practice exercises for the reader. Answers and selected solutions are in the back of the book, which also includes blank work forms and plotting sheets that can be photocopied as needed. Hi-res pdfs of the forms and plotting sheets are available for free download at www.starpath.com/celnavbook. The philosophy of the presentation was outline in the Preface.

Glossary

At the end of each chapter we include a list of the new terms defined or introduced in that chapter. The defined terms might appear later in the text without further definition. Please double check these terms in the Glossary to complete that Chapter.

The Glossary is meant to be more than just a list of definitions. There are details there that do not appear elsewhere in the book. Also, frequent questions about more technical meanings of some terms are answered only in the Glossary to keep this information from distracting from the course. In this sense, the Glossary is a mini encyclopedia.

As the course progresses and more terms are introduced, refer to the Glossary frequently to remind yourself of the meanings and interrelationships of the various terms.

Abbreviations

Cel nav is filled with abbreviations. We stick with the standard abbreviations for standard terms regardless of our own interpretation of the logic. Then when referring to standard references you will be at home. This terminology is part of the learning process, ie ZD is zone description, not zenith distance, which is a lower case z. Likewise, Z is a relative bearing (azimuth angle) whereas Zn is a true bearing (azimuth), and so on.

To help with this we have a list of abbreviations at the end of the Glossary, which could be a useful resource. We have also added a few editorial ones that are not standard to simplify the presentation, such as NA for *Nautical Almanac*, and T-2 to refer to the second table in our Table Selections.

Tables Selections

This section provides all the table data needed to work the standard exercises in the book. These are historic values in some cases, but this does not affect the learning as the procedures and table layouts have not changed. For your own navigation at home or underway you will need access to full sets of the sight reduction tables and a current *Nautical Almanac*, both are available online as free downloads (www.starpath.com/celnavbook).

Links to In-depth Topics

Throughout the book you will periodically see at the bottom of the page a cross reference link to a section of Chapter 11 on In Depth topics. These are presented in the book whenever there is related extra material available. The in-depth or special topics are removed to that section so they do not distract from the main progress of the course.

Sometimes these include new material that might be of interest to you but is not crucial to the content of the course, and sometimes they are just extra practice on a detail now being covered. These extra topics are not all specifically celestial navigation, but they are all related to doing or learning ocean navigation. Two samples are shown below.

...In Depth

11.1 *Bowditch* and other Resources

Our text is self-contained, providing all the information required for safe efficient navigation, but the quest for more details may come up, so we list standard and unique resources in this section...

...In Depth

11.2 Taking Your Departure

There are navigation procedures from the early days of sailing ships that have wandered out of the textbooks, but some remain valuable in modern times. In this section we help one wander back in...

Chapter 1

Background & Overview

1.1 Overview of Ocean Navigation

Navigation means two things: knowing where you are and choosing a safe, efficient route to where you want to go. The first aspect of navigation, finding and keeping track of position (out if sight of land), is the goal of this course on ocean navigation. The second aspect, choosing a route, is covered in *Modern Marine Weather* (Starpath Publications, 2012), since route planning for ocean-going yachts is more a matter of wind and current than it is of pure geographical navigation. These are equally important aspects of ocean navigation, but they are different subjects.

On inland and coastal waters we usually navigate using charted landmarks. This type of navigation is called piloting. If I sail up the Sound or down the coast going from one headland to the next, I am piloting. If I find my way home by going to Sears and turning left, I am piloting. Piloting is the technical name for the usual way we get from place to place. On inland and coastal waters, piloting techniques include natural ranges, depth sounding, bearing fixes, and the various methods of finding distance off by angle measurements. These techniques and the philosophy of navigation near land are covered in our book *Inland and Coastal Navigation* (Starpath Publications, 2013).

To keep track of our intermediate position as we sail from one landmark to the next we use dead reckoning—an unusual term used by mariners since the late 1500s. To navigate by dead reckoning, we deduce our new position, as we move away from a known position, using the shipboard instruments—primarily the compass, which tells us which way we went, and the ship's log (odometer), which tells us how far we went. We also need a logbook to record how far we went on each heading and when we made course changes. We can then plot our course on a chart or plotting sheet, 10 miles this way, then 5 miles that way, and so on, and this way keep track of our position. An accurate logbook and careful dead reckoning are always the keys to good navigation, regardless of what other navigation aids we may have on board.

But no vessel can travel far by dead reckoning alone. Small errors in the compass or log accumulate with time, and even with precise instruments we can't hold a precise course in all wind and sea conditions. Besides this, we have no way of knowing the effects of ocean currents while we navigate by dead reckoning alone. Dead reckoning tells us our track through the water, but it does not tell us anything about the motion of the water itself. It is like knowing exactly where you are in a large bathtub, but not knowing where the bathtub is. Typical ocean currents (averaged worldwide) might drift us off course by 10 to 20 miles a day; in extreme cases (such as the Gulf Stream) the current drift could be as large as 50 to 100 miles a day. Other sources of DR error are even more likely, such as changing course and forgetting to log it, or not really steering the average course we thought we were, because of brief but consistent course alterations at each wave in a seaway. These and other influences on DR accuracy are discussed later in this course.

To keep track of our position over a long voyage we must periodically check and correct our dead reckoning. In the ocean we do this with celestial navigation—the subject of this book. In sight of land we might do this by taking bearings to various landmarks. Two crossed bearing lines tell us where we are—gives us a position fix. We can then compare our true position, our fix, with where we thought we were on the basis of our dead reckoning. This usually tells us something about the accuracy of our dead reckoning—especially if we are right where we thought we were.

If we are not where we thought we were, we have more work to do to figure out why. In this case we must keep a record of our dead reckoning errors long enough to spot a trend, or a distinct lack of trend. And maybe then we can figure out if our errors are due to currents, instrument error, or helmsmanship. Oftentimes apparent errors in DR are just errors in the logbook entries—after neglecting to promptly record a course change, we error in reconstructing what we did do, or when we did it. The best way to keep track of DR errors in the ocean is to record how far off the fix was from the DR position and in what direction. Also record how many miles you have logged since the last fix and how long in time you have sailed since the last fix. For example, fix position 4.9 miles from DR in direction 225 T; error occurred during a 38-mile run that lasted 6 hours and 20 minutes. Although the magnitudes of the numbers will be different, the same information is crucial to good inland navigation as well. Later in the course we discuss how to analyze this type of important information.

In any event, once we have a true position fix from whatever means, we restart our DR from the new position and abandon our previous DR track on the chart. Any long voyage proceeds as a series of position fixes, with navigation by DR in between the fixes. And throughout this process the on-going goal of the navigator is to improve the accuracy of the dead reckoning. The reason for this is simple: we may

Chapter 2
Sextants

2.1 About Sextants

The raw data of celestial navigation is obtained from a hand-held instrument called a sextant. Technical aspects of sextants are described in detail in *Bowditch*. A metal sextant, as opposed to a plastic one, should be considered when relying on celestial as a primary means of navigation. New metal sextants vary in price (in 2014) from about $660 to $2,500, and maybe more if you shop around. Plastic sextants are discussed in Section 11.8, which also includes notes on optimizing sights with metal sextants.

The more expensive ones are indeed better instruments, but they won't necessarily do a better job at what we want. In the vast majority of cases, ultimate accuracy in a position fix at sea depends on what we do with the sextant, not the actual specifications of the instrument. The more expensive ones are inherently more accurate, but we can rarely benefit from this extra accuracy. If we choose to sell apples by the pound, for example, we could quite successfully use a scale accurate to an ounce; we do not need an expensive scale that is accurate to a thousandth of an ounce. Furthermore, an apple weight accurate to a thousandth of an ounce does not have much validity anyway. This weight will vary with the relative humidity of the room, etc. There are similar uncertainties in sextant sights at sea that ultimately limit the obtainable accuracy of any single sight. And all metal sextants on the market surpass this limit.

On the other hand, if a bargain sextant falls apart a thousand miles from land, it wasn't such a good deal after all. Fortunately, we can do celestial without any sextant at all, so we don't have to be anxious about this unlikely event coming about.

Used models of high quality instruments sell for $700 to $1000 or so. In most cases, if the instrument looks good and all parts move smoothly, chances are it is OK. If you do not have experience with sextants, however, it is probably best to buy used sextants from a reputable sextant dealer or have one check it out for you.

Brass versus Aluminum

Just about any metal sextant that is not damaged will do the job and provide essentially the same level of accuracy in the final fix at sea. Sextants, do however, vary in their ease of use. Key factors are the size of the mirrors, style of mirrors, kinds of telescopes, and weight. Weights vary from about 2+ lbs (for aluminium alloy models) to as much as 4+ lbs for brass models. Light weight is a big advantage, because when the arms tire, we are not as careful as we should be. Do not believe the nonsense published in some catalogs that claim professionals prefer a heavy instrument because it has inertia, which makes it more stable. The same companies offer an unadvertised expensive custom model made of aluminum alloy, which they claim is the very top of the line because it is so light! (Should we hang a piece of lead on these when doing sights?) The advantage of brass is the metal itself, not its weight. More accurate gears can be cut in brass alloys than in aluminum alloys. Brass alloys withstand the sea air environment better than aluminium ones, but very little of the metal itself is exposed. With reasonable cleaning, either will last a lifetime. More important is the quality of the paint and primer that is protecting the bulk of the instrument.

Sextant Use

Sextant usage can be learned from a manual or textbook, but it is quickest to have it demonstrated by an experienced navigator. These days there are many videos online that show the process, but like much info online we must carefully evaluate what we see. Look at several not just one, and keep in mind what we say here about the process. We have seen some that are well made and indeed start out nicely, but then toward the end they spin out, and expose a limited experience in actually taking sights underway. Also check www.starpath.com/videos.

Sextant use is readily learned; exceptional skills and extensive training are not required. Don't worry if you have learned on land with shorelines or artificial horizons and not yet practiced at sea. Sights are often easier at sea than they are on land, even with some motion of the boat to contend with. Sextants do what they are supposed to: allow you to measure vertical angles precisely from a moving platform.

To do sextant sights, you go on deck with a sextant and your watch, along with paper and pencil to record the sights. A small notebook dedicated to this use is convenient. The sights are generally taken standing some place with good visibility and some means of support. On a sailboat, this is often on the after deck or amidships next to the shrouds. In rougher seas, it is best to wrap an arm around shrouds or stays during the sights—or wrap the short tether of your safety harness around the shrouds and lean back. Some system is needed to free both hands to operate the sextant while still providing support against sudden boat motion. It is difficult to imagine any reason to go forward

Chapter 3

Noon Sights (LAN)

In this chapter Sec. 3.1 gives an overview of the full noon sight process, then we back up in Section 3.3 and go step-by step through the numerical procedures. Do not worry about learning the process in these introductions, just skim through them to get the overview and come back to them later if you like. In Section 3.3 we start all over, explaining each step and how to use the tables needed. When new terms appear, it might be useful to check the Glossary for more explanation. We explain the new terms in Sec 3.3.

This chapter introduces the use of several key tables and how to move around in the study materials from text, to tables, to answers, etc. At the end of this chapter you will have completed some 75% of the total learning process for celestial navigation.

3.1 Introduction to LAN

The first step in learning celestial navigation is the noon sight of the sun. It is a quick, easily-learned process for finding your latitude at midday. It requires a sextant, a *Nautical Almanac*, and a watch. You can learn the process in an evening, practice next day, and master it the next. The latitude you find this way will be as accurate as your sextant sight—about 0.5 mi at best, more like 1 or 2 miles on the average.

The process is called a noon sight or LAN sight for latitude. LAN stands for local apparent noon; it is the time of day when the sun crosses your meridian, meaning it bears either due south or due north. North of the tropics you always see the noon sun to the south, and south of the tropics the noon sun always bears north. Within the tropics it can bear either direction depending on your latitude and the time of year. Hence another name for this process: Latitude by meridian passage of the sun.

When the sun crosses your meridian at LAN it has reached its maximum height in the sky for that day. To find latitude at LAN we need to catch the sun in the sextant at this moment. We need to know the precise maximum height of the sun. But this is not as hard to come by as you might guess, because the arc of the sun's path is fairly flat at the top. In other words, the sextant height (Hs) of the sun does not change much during the few minutes just before and after its maximum height. To insure that we do indeed get the maximum value, however, the standard procedure is to start a series of sun sights just before LAN, continue them until the height starts to drop, and then take the maximum value of Hs from the list of heights recorded.

Once the maximum height (Hs-max) is in hand, you make 3 numerical corrections to it, and subtract the result from 90°. What is left is called the *zenith distance* (z) of the sun. Then use the *Nautical Almanac* to look up the declination of the sun. Your latitude is then the sum of the zenith distance you measured and the declination you looked up—or it could be the difference between these two numbers, but there is rarely any confusion between whether to add or subtract.

And that's all there is to it. With little practice and good procedure, the entire process takes about 30 minutes: a few minutes to predict the proper time to start taking the sights, 15 minutes or so for the sextant sights themselves, followed by another few minutes of arithmetic as outlined above and explained in detail below.

We now take a brief look at the principles behind this process with a numerical example, and then move in to the specifics of each step.

The point on earth directly underneath the sun at any moment is called the *Geographical Position* (GP) of the sun. If you were standing at the GP of the sun, the sun would be precisely overhead, at your zenith. The declination of the sun is defined as the latitude of the sun's GP. It varies slowly throughout the year from the Tropic of Cancer (overhead at 23° 26' N) on the Summer Solstice (June 21st) to the Tropic of Capricorn (overhead at 23° 26' S) on the Winter Solstice (Dec. 21st), as shown in Figure 3.1-1. The declination of the sun is 0° 0' (overhead at the equator) on the two equinoxes (Mar. 21st and Sept. 23rd).

As the earth turns beneath the sun daily, the GP of the sun circles the earth at a constant latitude equal to its declination. If the sun passed directly over head at noon, you would find your latitude by simply looking up the declination of the sun on that date and time in the *Nautical Almanac*. If the sun passed exactly overhead you must, by definition, be at the latitude of the sun. Hence the main job of the *Nautical Almanac*: to tell us the precise latitudes (and longitudes) of the GPs of all celestial bodies (sun, moon, stars, and planets) at all times.

If we were not at the sun's latitude, the sun would not pass overhead. If you were 1° "north of the sun"—meaning your latitude was 1° north of the sun's declination—the sun would pass 1° south of overhead. This is the key to understanding the LAN latitude sight; it is true in every case: 30° north of the sun, the sun passes 30° south of overhead, and so forth.

Chapter 4

Plotting & Chart Work

4.1 Introduction

At this point, after finishing LAN work, with all its numbers and table look ups, we take a break from that type of study and just use our hands for some plotting practice. We will be doing what is actually the last step of a cel nav fix—plotting the lines of position (LOPs). At this stage you will not know where the data came from (we learn that in the next chapter); this is being treated as a pure plotting exercise, done in this order specifically to take a break from the number crunching.

We will cover basic plotting tools and procedures as well as the special types of plotting sheets used in open ocean navigation. We also introduce DR plotting from typical logbook entries.

After this plotting practice, we move on to sun lines (more table work) in Chapter 5, and after that take another break with more plotting in Chapter 6. At that point, we are essentially done, meaning the density of new information is much reduced and we start applying what we have learned so far, with simple extensions to the other bodies.

4.2 Universal Plotting Sheets

A universal plotting sheet is a way to make a small nautical chart for any region on earth. The chart covers a rectangular area of some 120 nautical miles around the mid-latitude and mid-longitude that you choose for the sheet. The first universal plotting sheets were invented by Capt. Fritz Uttmark, a navigation instructor in New York City, in 1918 (US Patent No. 1337168, 4/13/20). The design has changed somewhat over the years but the basic idea is the same. The Uttmark charts were a boon to navigation at the time.

To Set Up the Plotting Sheet:

(1) Choose and label the mid-latitude on the center horizontal line, as shown in Figure 4.2-1, on the following page. The horizontal lines are latitude lines; the vertical lines are longitude lines. Then label the latitudes above and below your mid-latitude. In northern latitudes, latitude increases to the north, that is, to the top of the page. South of the equator, the latitude lines increase to the south.

(2) Next draw a horizontal line on the longitude diagram in the bottom right-hand corner at the position of your mid-latitude. This line is then the longitude scale you will use for reading and plotting the longitudes of points on the chart.

(3) Label the central vertical line with your mid-longitude. And now we draw in the other longitude lines, which is the main job in setting up these sheets.

(4) On the *outside scale* on the central compass rose, to the right of the mid-longitude line, go up from the mid-latitude line (0 on the curved scale) to your mid-latitude along the curved scale. If your mid-latitude is 42° N, go up 42°. Mark a point at this spot. Then go down from the center latitude line and mark another point in the same way. Draw a line between the two points to get the longitude line. You can do the same thing to the left of the center line to get another longitude line, but in this case the outer scale is not labeled, so you must just count off the degrees.

(5) Label the new longitude lines, remembering that west of Greenwich longitude increases to the west, or left. The chart is now set up and ready to go.

Using the Plotting Sheet:

(1) The latitude of any point is read from the vertical center line. Each tick mark is equal to 1' of latitude. Each latitude line is separated by 60 marks, since 60' = 1°.

(2) The longitude of any point is read from the diagram in the bottom right hand corner. For example, to set your dividers on 34' of longitude, set one side of them on the 30' mark and the other side on the second mark to the right of 0'. Each division on the right side of the diagram is equal to 2' of longitude. This special diagram is taking into account how the longitude scale changes with latitude. The changes that apply for different latitudes on the same plotting sheet are so small that you can use the same mid-latitude line for reading any longitude on the page.

(3) In measuring distances between points always use the central, vertical latitude scale. Each 1' of latitude equals 1 nautical mile. Recall that 1° of latitude always equals 60 nautical miles, but the number of miles per 1° of longitude changes with your latitude. At the equator 1° of longitude is 60 miles, but as you go north, it gets smaller. Check the example page to see that at latitude 40°N the distance between each longitude line is 46 nautical miles. This takes into account the convergence of the longitude lines at the north pole.

Since the earth is symmetric about the equator, everything is the same for southern latitudes. The only thing that changes is the labels. In the south, latitude increases toward the bottom of the page.

Chapter 5
Sun Sights

5.1 Introduction

We start with a discussion of sunrise and twilight, then move on to the main task of doing the full sight reduction of the sun for sun sights taken any time during the day—not just at noon as we did in Chapter 3. In the classroom course we say "roll up your sleeves and get an extra handful of M&Ms," after tonight's class it is all downhill. That is, once we learn the full process for sun sights at any time of day, the other bodies can all be added with just a note or two on the distinctions. You will also see that much of what we do with these we have learned in the LAN procedure.

We use the Starpath work forms, which will guide you through the process in a step-by-step manner. The forms themselves will then serve as instructions reminding you of the next step in the process.

Again, this is the main content of the course. After the sun lines are mastered, we can explain all the other bodies in a half a page or so each. For the most part, the other bodies use the identical procedure, we just select the needed data from different columns in the tables.

5.2 Sunrise, Sunset and, Twilight Times

For both inland and ocean navigation we often like to know the time of sunset or sunrise—or, more generally, when it's going to get dark or light. On coastwise on inland routes, navigation at night is different than during the day—it's not necessarily harder, in some circumstances it's even easier, but it is different, and generally we like to know where we will be when it gets dark. In the ocean, on the other hand, we need these times accurately each day to prepare for celestial sights, because we can only take star sights during twilight, when we can see both stars and horizon.

Several factors enter into these time predictions. Rarely can we get, even on inland or coastal waters, what we want by simply looking these times up in the current issue of a newspaper the day before a sail. Obviously in the ocean we can't do that, nor can we get them from a radio broadcast. We may get the time of sunrise or sunset that way, but we would still have to make some guess at the length of twilight. If we are a long way from the city that prepared the newspaper or broadcast, even the times of sunrise and sunset could be way off. Likewise, sunrise and sunset times on calendars and commercial tide tables are only applicable to their city of origin.

The times of sunset and twilight (and the length of twilight) depend on the date, our latitude, and our longitude. The seasonal changes are well known: in the summer the sun rises early, sets late, and the days are long; in the winter the sun rises late, sets early, and the days are short. In the Northern Hemisphere summer, if you head south you are headed toward the Southern winter, so you are headed toward shorter days, earlier sunsets, and so on. With this reasoning you can always figure what will happen to these times if you head north or south, in the summer or winter, in either hemisphere.

Accurate sunrise and set times change with longitude even within the same time zone, because everyone in a particular time zone keeps the same time on their watch, even though one may be as much as 900 miles to the east of the other. Since the sun (GP of the sun) comes from the east as it circles the earth, an observer to the east sees it first. If you live in Seattle and are on the phone to a friend in Spokane (some 5° of longitude to the east), and your friend tells you the sunrise is beautiful, you will have to take their word for it. You won't see the sunrise in Seattle for another 20 minutes or so. Sunset is officially defined as the moment the top edge (upper limb) of the sun drops below the visible horizon. The assumption here is that we are at sea or some such place where we can indeed see the true horizon. Nevertheless, the times we figure always apply to that definition, even if we can't see the horizon. If there are mountains between us and the true horizon, the sun will set over the mountain horizon earlier than the sunset time we figured.

This might make us realize that the time of sunrise also depends on the height of eye (HE). At higher heights you see a horizon that is farther off, and thus see the sunrise earlier than someone viewing from a lower perspective. But for practical work on using this data for navigation from the deck of a vessel this correction is rarely used.

...In Depth

11.12 Practice with Time Prediction

The procedure for predicting sunrise, sunset, and twilight times is the same as given in Sec 3.2 for LAN. We include a few practice exercises here...

Chapter 6

Running Fixes

6.1 Introduction

We often say in class that the transition from prudent skipper to navigator takes place with the mastering of the running fix. Most basic navigation prior to that involves finding a fix from two separate objects, whereas the running fix lets you find a fix from a single object. We can also do the same by finding distance off and a bearing, but those piloting methods are not as universally applicable as is the running fix.

The technique is not so often learned because it is not so often needed on inland waters, but when it is needed, you need a navigator. Now in the age of GPS, it is even less needed, and such skills are almost doomed in the eyes of many skippers. On the other hand, when it is needed now, the need for a navigator is even more pronounced.

One of the benefits of learning celestial navigation is the necessity of learning the running fix. Whereas it is rare to need a running fix in sight of land, it is a crucial daily chore of routine celestial navigation.

In this chapter, we discuss the process and then offer practice problems, starting with the simplest and leading up to a specially constructed set of exercises that can be used to master sun line navigation in all hemispheres.

For anyone behind in the sun line sight reduction processes from Chapter 5, however, we recommend that you complete some of the sun line sight reduction exercises before starting these plotting exercises.

6.2 Running Fixes in Coastal Nav

One of the important challenges a navigator faces is finding position from a single landmark or celestial body. On inshore waters, the problem occurs in the fog whenever a single light is the only reference; it also occurs on clear days whenever only one coastal feature (peak, tower, islet) can be identified. When relying on celestial navigation offshore, the problem arises daily when navigating by the sun alone—the moon is well positioned for simultaneous fixes with the sun for only about a week or so each month. Depending on the circumstances, there are several ways to find position from a single reference (both inshore and offshore), but a running fix is the most reliable and versatile method. It is a plotting technique that combines piloting and dead reckoning.

When done with compass bearings, the procedure boils down to taking one bearing, moving far enough that this bearing changes by 30° or more, and then figuring out where you must be in order to see what you saw after doing what you did. With the two lines of position (LOPs) plotted on the chart, the chart work is equivalent to finding the one place along the first LOP that you could leave from, sail the distance you did in the direction you did, and end up on the second LOP (see Figure 6.2-1).

Running-fix Procedure

(1) Take a magnetic bearing to the light and plot the LOP on the chart labeled with the log reading and watch time of the sight.

(2) Hold a steady course and speed until the magnetic bearing to the light has changed by at least 30°, preferably more. Smaller bearing changes give weaker fixes, but there is little to be gained by waiting beyond a bearing change of 60°. With a log available to count miles run, it is not necessary to keep a constant boat speed.

(3) Take a second magnetic bearing to the light and plot this LOP, labeled with the second watch time and second log reading. Subtract the two log readings to find the distance run between sights; without a log, figure distance run from average speed and time between sights.

(4) Starting from any point A on the first LOP, draw a line in the direction sailed between sights and mark off the distance run between sights along that line. Then use parallel rules to *advance* the first LOP to the point B, which marks the distance run between sights. Label the advanced LOP with both log readings (or times) joined by an arrow. Your position at the time of the second LOP is the place where the advanced LOP crosses the second LOP.

Advancing an LOP means moving it without rotating it. this can be achieved with parallel rules or a roller plotter.

A running fix is as accurate as a conventional bearing fix from near-simultaneous bearings to two separated objects provided the dead reckoning (DR) between the two sights of the running fix is accurate. This requires a calibrated log or knotmeter, a corrected compass, and careful records between sights. It also requires that you know the currents present—so far we have assumed they do not exist. Leeway should also be included when sailing to windward in very strong or very light air–also not added yet.

On coastal waters, the object of the sights must be close enough that its bearing changes significantly in a reasonable time. If the object is too far away, or too near the bow

Chapter 7
Star Sights

7.1 Introduction

The true power of celestial navigation for position fixing comes with the use of the stars. Sun sights are often considered easier, in the sense that they can be taken anytime of day, and the sun is usually perceived as easier to find in the sky than is some specific star in its background of myriads—but these are, for the most part, uninformed biases.

The disadvantage of the sun is that it gives only one LOP, and after completing the running fix some time later, the accuracy of the final fix is limited by the accuracy of the DR between the two sights. In actual practice, the total time devoted to getting a fix from star sights will be shorter than from sun sights, and the star results will be more accurate.

Also, as we shall see, when done right, it is actually easier and usually faster to set up the sextant for a particular star sight and have it ready to be measured than it is to get the sun set up in the sextant with the proper shades in place. The special preparation needed for the star sights takes just minutes. The process is called precomputing star sights. We postpone this process till Chapter 10 on Star Identification purely so we can complete the learning of sight reductions for all bodies first—while we are warmed up and in the process of mastering these procedures.

The main goal of this Chapter is just to learn and practice the sight reduction of stars, but before leaving the Chapter, please review Sections 1.2 and 1.3 on the overall picture of taking a star sight, along with Section 5.2 on twilight times—we usually take star sights between nautical and civil twilight.

The most basic star sight, in a sense, is a sight of Polaris, the North Star. A sight of this special star, which is essentially on our meridian at all times, is analogous to the LAN sight of the sun on our meridian. The full sight reduction collapses to the adding and subtracting of a few numbers. Latitude by Polaris alone is covered at end of this chapter, as it is a special case.

The Star Finder Book includes much information on star motions, colors, terminology, names, etc. along with notes on preparing the sights. If questions arise about terminology or star motions, please refer to Section 3.1 of that book along with the Glossary of this one.

New terms used for specifying star locations are Aries (♈), which is the "Greenwich meridian" of a star globe, and sidereal hour angle (SHA), which is the longitude of a star on the star globe relative to Aries, as shown in Figure 7.7-1.

The process of preparing for star sights and the general subject of star and planet identification is presented in Chapter 10, along with the option to use Pub. 249 Vol. 1 for selected stars. Here we are sticking with Vol 2 and 3, which covers stars with declinations less than 29º. Other options will be clear shortly.

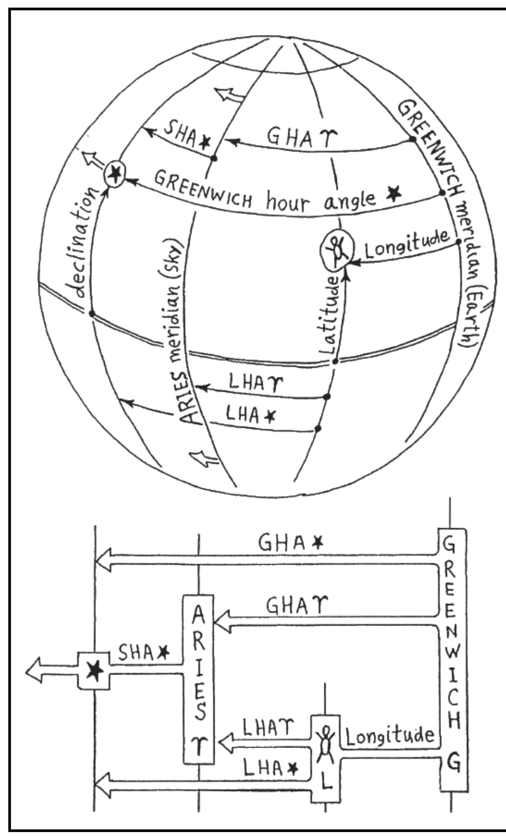


Figure 7.1-1 *Star coordinates. Aries is a specific line through the stars that serves as the Greenwich meridian of the sky. The almanac tells where it is relative to Greenwich at all times. The Sidereal Hour Angle (SHA) is the longitude of the star relative to Aries. It is a permanent property of the star, just as its declination is. GHA of Aries is how far Aries is west of Greenwich; The SHA of a star is how far it is west of Aries. Thus the GHA of star, which is how far it is west of Greenwich, is just the GHA of Aries plus the SHA of the star. Coordinates relative to us are called Local. The Local Hour Angle (LHA) of Aries is how far Aries is west of us. The LHA of the star is how far the star is west of us.*

Chapter 8
Planet Sights

8.1 Introduction

There are five planets visible to the naked eye that might be used for navigation: Mercury, Mars, Venus, Jupiter, and Saturn. Of these, only Mercury is not cataloged in the *Nautical Almanac* for use in celestial navigation. This is because it is so close to the sun that it can only be seen rarely and then just before sunrise or after sunset and its altitude will always be very low. As a rule, one tries to avoid sights below some 10°, because refraction uncertainties are largest at low angles. The appearances of Mercury throughout the year are discussed in the *Almanac* so we do not confuse it with Venus or a bright star.

Of the four other planets, only Venus and Jupiter are special, because of their exceptional brightness. If either of these is in the sky, it will be brighter than any of the stars. Mars does periodically go through periods of being very bright, but as a rule, Mars and Saturn are just there to confuse us as bright or medium bright stars sitting at places where no star should be. If well positioned and adequately bright, they can be combined with stars for routine sights, but they have no special significance other than that. The Planet Diagram (Figure 8.1-1) is a quick way to estimate what planets are in view.

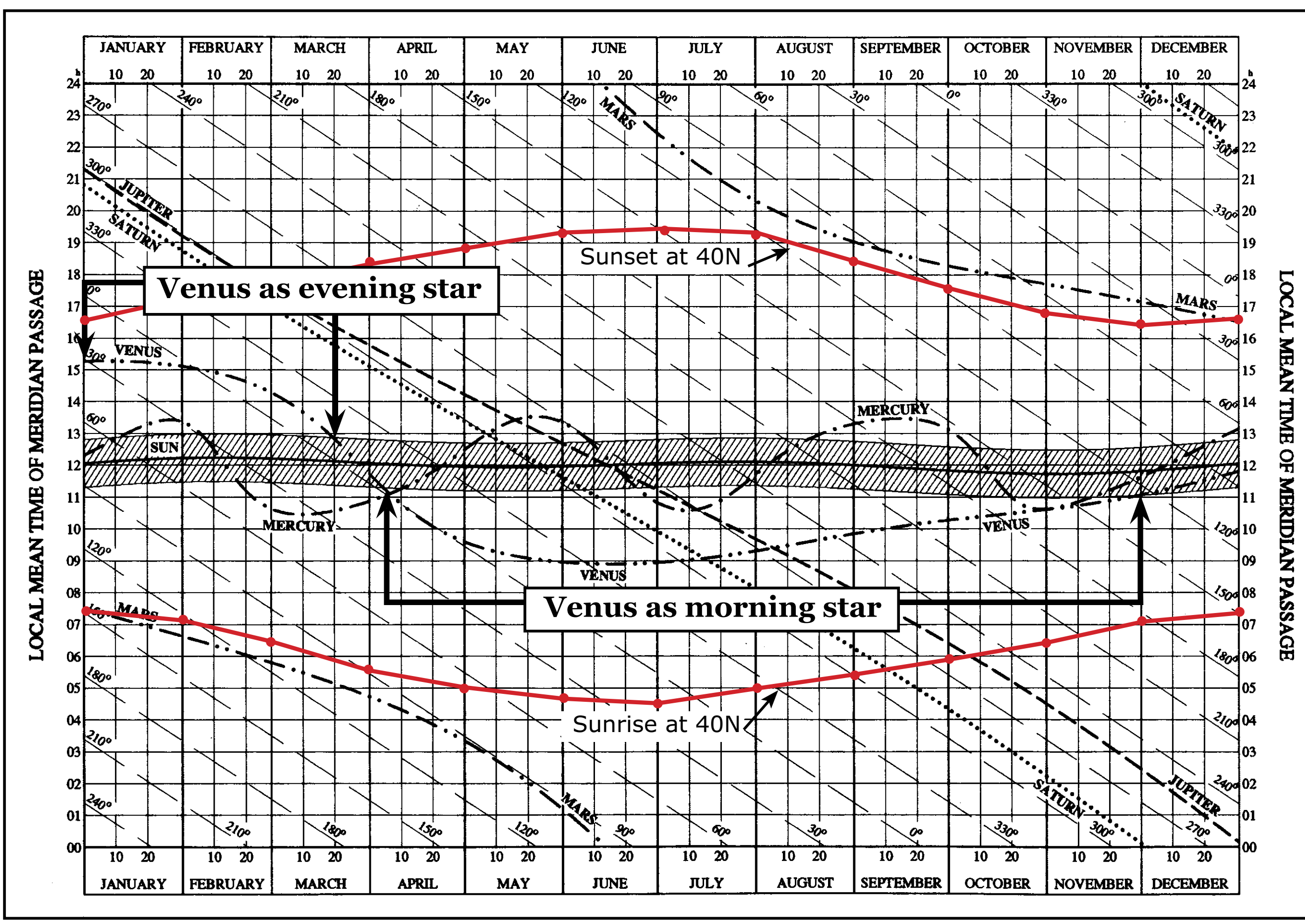


Figure 8.1-1 *A sample Planet Diagram from the* Nautical Almanac, *to which we have added sun rise and set times. Mer pass of stars can be estimated from the SHA lines shown. On Feb 1, Venus is 3h behind the sun, so it will be well to the east (left) of the sunset. At the end of mar it passes behind the sun and emerges as a morning star. At 40 N we see Mars is visible most of the night, throughout the year. More generally, any body crossing the meridian near midnight will be visible all night during that day. Shaded areas means bodies too close to the sun to see. We would see Mercury as an evening star in Sept. A study of this diagram with a 2102D Star Finder in hand is a good way to learn what all it tells us. The planet curves change each year. Always check the Planet Diagram notes in a new* Almanac.

Chapter 9

Moon Sights

9.1 Introduction

The moon is a mixed blessing in celestial navigation because when very prominent in the night sky its glare on the water can distort the horizon below it. Crescent moons, however, can be an asset in some circumstances.

The moon is most useful in routine navigation for daylight fixes with the sun, which can be done periodically throughout the month, as explained in Section 9.10. For now, the task is how to do the sight reductions, which is the same regardless of the phase of the moon. You will soon note that our work forms make doing moon sights as easy as any other sight, despite the fact that the moon has a few extra steps to its sight reduction.

In the *Emergency Navigation* book, we show the real power of the moon—its ability to tell us UTC if we happen to lose that crucial component of celestial navigation. The moon is the only body in the sky that moves relative to the stars fast enough to tell time from its position. The procedures for extracting that data from moon sights, however, is not at all routine and takes special instruction and resources.

We first get right to the sight reduction process, which is the last body to cover, and following that there is discussion of how to optimize the use of the moon in daily procedures.

9.2 Sight Reduction of the Moon

Moon sight reductions are similar to planets—meaning they are done the same as a sun line with the addition of a v-correction to the GHA and an additional altitude correction to Ha. The work forms are designed specifically to make moon sights easy.

The steps listed below are illustrated in Figure 9.2-1. In Step (2), to fill out Box 2 from the Daily Pages, you simply copy everything down on the work form exactly as it is listed in the Moon column of the Daily Pages of the *Nautical Almanac*. This will include the GHA, v-value, declination, d-value, and something new called HP, the horizontal parallax. These are listed in this order on the Daily Pages at the hour of the sight. This new parameter, HP, is a measure of the distance to the moon, which changes throughout the month. HP is used to find the additional altitude correction to Ha, which depends on the distance to the moon.

In Step (3), Box 3, find the v-correction to the GHA in the Increments and Corrections pages. The procedure is exactly the same as it is with planet sights.

The altitude corrections for the moon are listed in a special table on the back inside cover of the *Nautical Almanac*. There are two tables; one for Ha in the range of 0° to 35°, and one for 35° to 90°. These are Tables T-13 and 14 in the Tables Selections.

We find both the regular altitude correction and the additional altitude correction in this table. The altitude correction depends on Ha. Go across the top of the table to the correct range of Ha, and then down the column to the degrees part of Ha, and then farther on down till you are opposite the minutes part of Ha, which are listed at the sides of the table. The correction you find there is called the altitude correction; record it in the corresponding space on the work form.

Now to find the additional altitude correction: stay in the same column and continue on down to the bottom part of the table, and stop when you are opposite the value of HP recorded in Box 2. At that location in the table there are two corrections; one is for upper limb sights (U), the other is for lower limb sights (L). Choose the appropriate one and record it in the space marked "additional altitude correction." Both altitude corrections are always positive for the moon.

If the moon sight is of the upper limb, enter a -30' in the space marked "upper limb moon." For lower limb sights we just ignore this space on the work form. This step is simply a trick the almanac does that allows the other two corrections to always be positive. For upper limb sights you always subtract 30' regardless of the size of Ha.

To get Ho, add to Ha all corrections listed below it. For lower limb sights, these are the altitude correction and the additional altitude correction; and for upper limb, it is these two and an additional -30'.

The rest of the moon's sight reduction is the same as any other sight reduction. The d-value for the moon is listed every hour, but we use it the same way we do for sun and planet sights. Pick the sign of d (±) the same as with the sun or planets by noting if the declination is increasing (+) or decreasing (-) with time. *Don't make the mistake of using the d-value itself for this.* The d-value can go up with time when the declination is going down, and vice versa.

Form sections that are different for the moon are shown on the next page, ie only Box 2 and 3.

Chapter 10

PRINCIPLES OF CEL NAV

10.1 A One-hour Course in Cel Nav

If we understand just a few principles of celestial navigation, we can begin to use it immediately. To punctuate that thought, with just this Section 10.1 alone you should be able to find your way to any port in the world, from any place at sea, with nothing more than a *Nautical Almanac* and a watch. The rest of this chapter fills in other details we have relied upon in earlier parts of the book.

To begin with, the only reason we need a full book on celestial navigation—as opposed to knowing it intuitively since birth—is the fact that the earth turns on its axis, once every 24 hours. To prove this point, we look at the consequences of stopping this motion.

The visible stars around us are more or less evenly distributed across the hemisphere of the sky we see, regardless of whether we are in Seattle or in Auckland. In the real world, if we watch these stars throughout the night we see them rise from the eastern horizon, reach peak heights in the sky when bearing north or south, and then set somewhere on the western horizon. But if we stop the earth, all that motion stops. At the moment we stop the earth from rotating, every star we see in the sky freezes in position, right where it is, and it stays there, night after night, year after year. And that situation would have a dramatic influence on celestial navigation.

Imagine that each of these stars distributed across the stationary sky sent out a laser beam that went straight through the center of the earth (Figure 10.1-1). And as this beam burned through the surface of the earth it made a mark. That mark is called the *geographical position* of that star, usually abbreviated GP.

This is the concept underlying the construction of star globes seen in astronomy displays or book stores periodically. It is a static projection of the stars down onto the globe of the earth, although they don't usually show the map of the earth, but rather just a blue background. All the relative positions of the stars within the constellations are laid out on a sphere (Figure 10.1-2). Just imagine now that that sphere is a globe of the earth.

If you happened to be located at the GP of a star, you would observe that star precisely overhead—the laser beam going right through the top of your head. If you had a sextant, you would measure its height above the horizon as exactly 90°, ie overhead. If you were not at the GP of a star, that star would not appear overhead but rather off of the zenith, at a lower altitude in the sky. How much lower depends on how far you are from it.

There is a direct and simple correlation, which we will prove a bit later on. If you are 1° away from the GP, the star will have moved down 1° from the zenith—it would be 89° high in the sky. Move 10° away from the GP and the star would now be 80° high in the sky. We also clarify later that a distance of one degree on the surface of the earth is equal to 60 nautical miles, but do not be distracted by these details at this point. The summary is all that matters: If you are at the GP, the star is overhead, if you are away from the GP, the star is lower. As you move toward the GP, the star would get higher, until you are precisely at the GP, at which it would be overhead. And remember, too, our model: the earth is not rotating, so the sky is permanent.

If we happened to be about half way up Vancouver Island, BC, when we stopped the earth, then one star that might have stopped right overhead is Alkaid, on the tip of

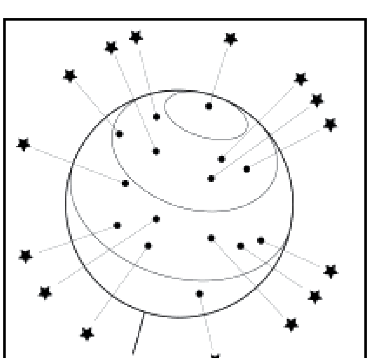


Figure 10.1-1 *Stars marking Geographical Positions on the earth.*

Figure 10.1-2 *Section of a star globe showing Big Dipper.*

Chapter 11
In Depth...

This chapter gathers special topics so they do not distract from the basics. There is no particular order to the topics. All are related to successful ocean navigation on some level. Some are fine points not covered earlier, others are just more practice or expanded coverage of earlier topics.

11.1 Bowditch and other References....124
11.2 Taking Your Departure....125
11.3 Electronic Navigation....126
11.4 Mercator Charts.... 131
11.5 Time Keeping in Navigation....132
11.6 Dip Short 136
11.7 Solar Index Correction 138
11.8 Optimizing Plastic and Metal Sextant Sights 141
11.9 Longitude from LAN 144
11.10 Ocean Plotting Sheets....146
11.11 Ocean Dead Reckoning 147
11.12 Practice with Time Prediction 151
11.13 Practice Choosing the AP 151
11.14 Practice with Pub. 249 Vol. 2, 3....153
11.15 AM to PM Running Fixes....154
11.16 An Ocean-going Nav Station 155
11.17 Offshore Navigation Checklist.... 157
11.18 Checking a Sextant with the Stars....158
11.19 Artificial Horizons.... 161
11.20 Storm Warnings at Sea 164
11.21 Compass Checks at Sea....165
11.22 Great Circle Sailing....166
11.23 Rhumb-line Sailing 169
11.24 Optimizing Celestial Fixes.... 174
11.25 Star and Planet ID 178
11.26 Emergency Procedures....183
11.27 Pub. 249 Vol. 1, Selected Stars 184
11.28 Computed Solutions....189
11.29 NAO Sight Reduction Tables 191
11.30 N(x) Table....196
11.31 Nuts and Bolts of Ocean Navigation 199
11.32 Most Likely Position from Three LOPs.... 202

New Terminology

- artificial horizon (AH)
- departure
- fit slope method
- GPS, WAAS, COG, SOG, VMG
- great circle sailing (GC)
- International Date Line
- local mean time (LMT)
- Mercator chart
- Mercator sailing
- mid-latitude sailing
- parallel sailing
- rhumb line (RL)
- set and wait method
- small angle rule
- solar index correction
- standard time
- WWV and WWVH
- zone time (ZT)

Appendix 1

Glossary

These definitions are in the terminology of this book. Standard terms and abbreviations are used throughout, although the interpretations of some are simplified or expanded for clarity. This glossary includes content details expanded in some cases beyond the presentation in the text. A list of ***Abbreviations*** *alone is at the end of the Glossary.*

a-value — Same as Altitude Intercept. Called the "a-value," it is the difference, found in the last step of a sight reduction, between the calculated height (Hc) and the observed height (Ho) of a celestial body. It is used for plotting the LOP. It is labeled A (away) if Hc is greater than Ho, or T (toward) if Hc is less than Ho. In physical terms, "a" tells if we are closer or farther from the GP than the assumed position is. An a-value of 20' T, for example, means your true position is 20' (20 nmi) closer to the GP than the assumed position is.

Accuracy — The difference between your true position and the fix position found from a round of celestial sights. Generally this is better thought of as the uncertainty in your fix, which, with good procedures and a good sextant, should be less than 3 or 4 miles routinely. This can be improved to about 0.5 miles, but this requires special care, especially when moving. Anything over about 10 miles indicates some problem with procedures or equipment. A rough way to judge your accuracy is the size of the triangle of crossed lines of position, assuming that each side of the triangle represents the average of several sights of the same body. The most accurate fix comes from sights of 3 bodies, bearing about 120° apart. See Sextant Sights and Fix.

Accuracy in dead reckoning is the difference between your fix position and your DR position at the time of the fix. With calibrated instruments and careful dead reckoning this should be no worse than about 15 percent of the distance run since the last fix, although this depends very much on the conditions present. See Dead Reckoning.

Additional Altitude Correction — Used only in the sight reduction of the moon, Mars, or Venus (the three closest celestial bodies), this correction accounts for the parallax of their light rays—that is, since each of these bodies is so close to the earth, the light ray we see it with is not strictly parallel to the light ray from it that passes through its geographical position (GP). The theory of celestial navigation assumes that the distance along the earth's surface between the observer and the GP is equal to the zenith distance (z) of the body, but this is only true if these two light rays are parallel. So for these three close bodies this extra correction is required. See Parallax.

Another, completely different, type of Additional Altitude Correction is also discussed and tabulated in the Table A4 of the *Nautical Almanac*. These are additional corrections for non-standard refraction in unusual atmospheric conditions. In principle, these corrections apply to all sights, but from a practical point of view they can be neglected. The corrections are very small for all sights except those near the horizon (which should be avoided anyway if possible). There is no space for this type of additional correction on the Starpath work forms. It is recommended that this atmospheric correction just be ignored, but bear in mind that any sights within some 5° of the horizon will be uncertain by plus or minus 5' or so. See Refraction.

Advanced LOP — A Line of Position that has been shifted on the chart or plotting sheet to correct for the boat's motion since the time of the sight. Section 11.24 includes a method of numerically advancing an LOP by adjusting the a-value. See Running Fix.

Air Almanac — A questionable alternative to the *Nautical Almanac* that some very few marine navigators prefer. It is not as convenient to use, nor as complete, nor as easy to obtain. As of 2008, only available on CD. It is not recommended.

Altitude — Same as Height. A general name for the angular height of a celestial body above the horizon that is determined from a sextant measurement or sight reduction. Angular height is often called "altitude" in other textbooks. When a body is right on the horizon, its height is 0°; when a body is overhead, its height is 90°. The term is used more precisely depending on the number of corrections that have been made to the sextant measurement. See Sextant Height, Apparent Height, Observed Height, and Calculated Height.

Altitude Correction — When doing a sight reduction, this is the final correction to the sextant height needed to get the observed height. This term actually describes

Appendix 2

ANSWERS

Examples with Full Work Form Solutions*					
Sight	*Body*	*Date*	*DR*	*Exercise*	*Solution*
Sun #1	LL	25 Oct 78	44 50 N, 139 15 W	68	68
Sun #2	LL	26 Jul 78	44 40 N, 123 00 W	72	226
Sun #3	LL	24 Jul 78	44 50 N, 123 36 W	72	226
Sun #4	LL	25 Jul 78	45 26 N, 134 30 W	73	227
Sun #5	LL	25 Jul 78	45 26 N, 134 30 W	73	227
Sun#6	LL	27 Oct 78	45 53 N, 131 24 W	79	229
Sun #7	LL	27 Oct 78	45 53 N, 131 24 W	79	229
Sun #8	LL	26 Jul 78	45 21 N, 122 39 W	104	241
Sun #9	LL	11 Jul 86	25 13 N, 147 15 W	279	279
Star #1	Altair	24 Jul 78	45 30 N, 126 27 W	85	85
Star #2	Arcturus	24 Jul 78	45 30 N, 120 58 W	85	234
Star #3	Altair	24 Jul 78	44 36 N, 122 14 W	86	234
Star #4	Antares	24 Jul 78	44 36 N, 122 14 W	86	236
Star #5	Arcturus	25 Jul 78	44 40 N, 126 27 W	87	237
Star #6	Regulus	27 Mar 81	45 21 N, 130 03 W	87	237
Star #7	Hamal	26 Oct 78	45 05 N, 160 25 E	98	238
Star #8	Sirius	25 Jul 78	45 30 S, 033 40 W	98	239
Star #9	Arcturus	26 Oct 78	45 05 N, 160 25 E	105	243
Star #10	Rigil Kent.	2 Sep 86	31 09 S, 157 48 E	281	281
Planet #1	Venus	27 Oct 78	44 50 S, 015 10 E	96	96
Planet #2	Jupiter	26 Oct 78	45 05 N, 160 25 E	97	238
Planet #3	Venus	25 Jul 78	45 30 S, 033 40 W	97	239
Planet #4	Venus	2 Sep 86	31 09 S, 157 48 E	282	282
Moon #1	UL	25 Oct 78	44 50 N, 40 20 W	103	240
Moon #2	UL	26 Jul 78	44 58 N, 122 24 W	104	241
Moon #3	UL	26 Oct 78	45 05 N, 160 25 E	105	243
Moon #4	LL	27 Mar 81	45 16 N, 140 20 W	106	244
Moon #5	LL	11 Jul 86	25 13 N, 147 15 W	281	281

* *Over the years we have learned that having this indexed list of fully worked examples is helpful for cross referencing. Please note the list is here and use it as called for. The last example of each body is in the Instructions to using Work Form 104 in the Appendix. On the right are the page numbers.*

9.5 Moon-Sun Running Fix, Moon #2

1

WT	7 h	50 m	07 s	date	26 July 1978	body	UL Moon	
WE +S -F			-13	DR Lat	44° 58' N	log	852.0	
ZD +W -E	+7			DR Lon	122° 24' W	HE ft	16 →	
UTC	14 h	49 m	54 s	UTC date / LOP label	1449 July 26 UL Moon		C 335T S 7.8 Kt	

Hs	51°	25.2'
index corr. + off - on		0.0'
DIP -		-3.9'
Ha	51°	21.3'

2

GHA hr.	126°	00.2'	v moon planets	12.1	Dec hr	N 8°	40.8'	d +/-	+9
HP moon	56.6								

3

GHA + m.s.	+ 11°	54.4'
SHA + or v corr.	°	+ 10.0'
GHA	137°	64.6'
	138°	04.6'
a-Lon -W+E	- 122°	04.6'
LHA	16°	00´ W / 60´ E

stars or moon, planets			
d corr.	+/-	+ 7.4'	
Dec	N 8°	Dec min	48.2'

tens d		d upper
units d		d lower
dsd corr.	+	dsd ←
d. corr. Pub. 229		

additional altitude corr. moon, mars, venus	+3.3'
altitude corr. all sights	+45.9'
upper limb moon subtract 30'	-30.0'
Ho	51° 40.5'
T	
Hc A	51° 15.2'

4

LHA	16°	
Dec deg	8°	N
a-Lat	45°	N

5

tab Hc	50°	29'	d +/-	+ 57	Z 155
d. corr. Pub. 249		+ 46.2'	Dec min	48.2'	
Hc	50°	75.2'			

6

a =	25.3' T
Zn =	205°
a - Lat =	45° N
a - Lon =	122° 04.6' W

The plot of these sights are on the following page.

9.6 Moon-Sun Running Fix, Sun #8

1

WT	11 h	05 m	19 s	date	26 July 1978	body	LL Sun	
WE +S -F			-13	DR Lat	45° 21' N	log	876.4	
ZD +W -E	+7			DR Lon	122° 39' W	HE ft	16 →	
UTC	18 h	05 m	06 s	UTC date / LOP label	1805 ☉ July 26		C 335T S 7.8 Kt	

Hs	51°	53.6'
index corr. + off - on		0.0'
DIP -		-3.9'
Ha	51°	49.7'

2

GHA hr.	88°	23.3'	v moon planets	—	Dec hr	N 19°	23.9'	d +/-	-0.5
HP moon	—								

3

GHA + m.s.	+ 1°	16.5'
SHA + or v corr.	—°	—'
GHA	89°	39.8'
	—	—
a-Lon -W+E	- 122°	39.8'
LHA	-33°	00´ W / 60´ E
	+360°	

stars or moon, planets			
d corr.	+/-	-0.0'	
Dec	N 19°	Dec min	23.9'

tens d		d upper
units d		d lower
dsd corr.	+	dsd ←
d. corr. Pub. 229		

additional altitude corr. moon, mars, venus	—
altitude corr. all sights	+15.2'
upper limb moon subtract 30'	—
Ho	52° 4.9'
T	
Hc A	52° 34.9'

4

LHA	327°	
Dec deg	19°	N
a-Lat	45°	N

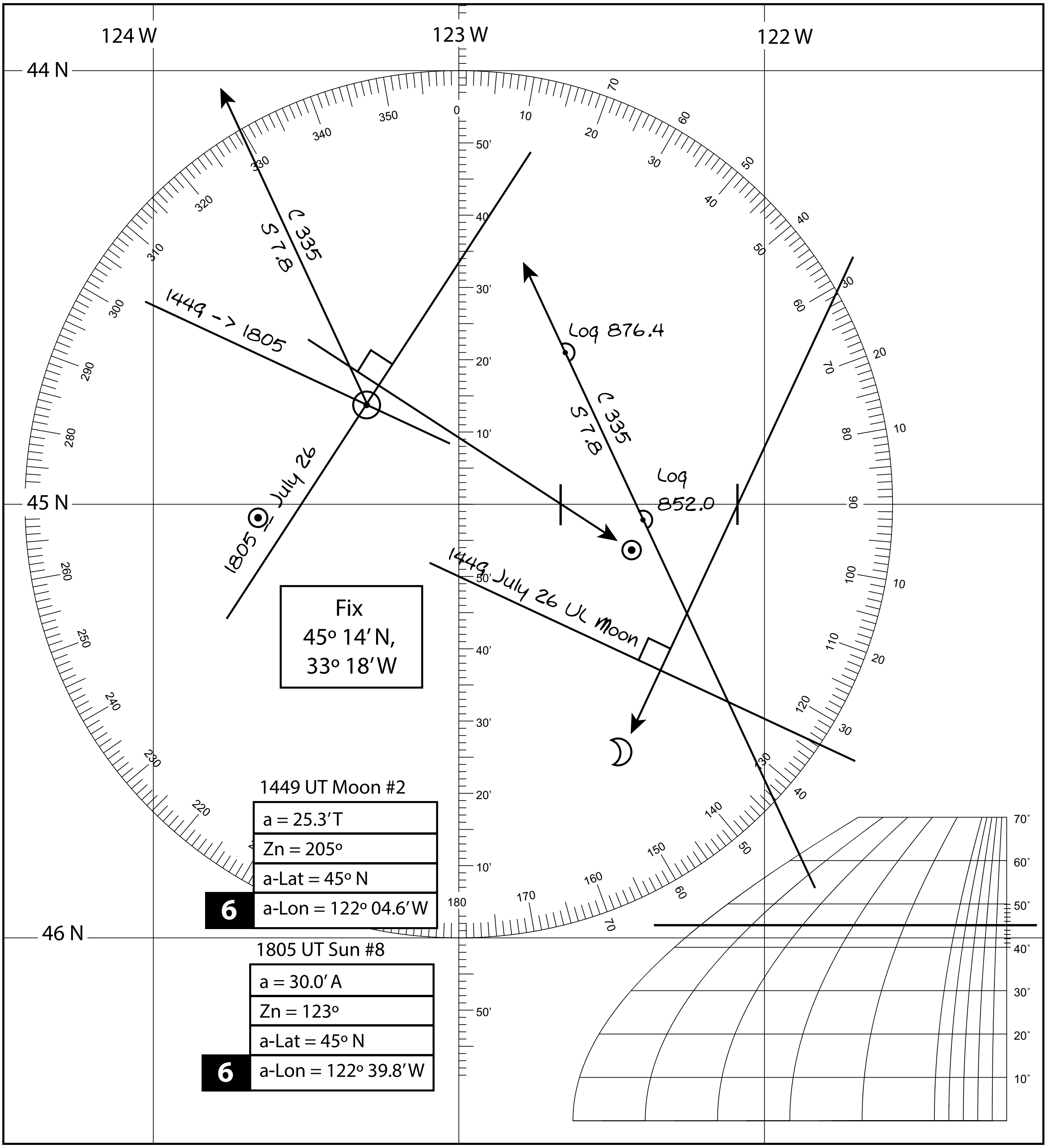
5

tab Hc	52°	16'	d +/-	+ 47	Z 123°
d. corr. Pub. 249		+ 18.9'	Dec min	23.9'	
Hc	52°	34.9'			

6

a =	30.0' A
Zn =	123°
a - Lat =	45° N
a - Lon =	122° 39.8' W

Plot of Moon-Sun Running Fix, Moon #2, Sun #8



Appendix 3

Table Selections

CONTENTS

The notation "T-1," "T-2," etc, is for easy cross reference within this book or classroom only. This notation is not used elsewhere in navigation, and it does not appear in the *Nautical Almanac*. These Table Selections are available as a free pdf download from www.starpath.com/celnavbook, if it might be more convenient to have them separate from the book.

T-1 *Nautical Almanac* 1978, Jul 24, 25, 26 planets and stars...............244
T-2 *Nautical Almanac* 1978, Jul 24, 25, 26 sun and moon...................245
T-3 *Nautical Almanac* 1978, Oct 25, 26, 27 planets and stars 246
T-4 *Nautical Almanac* 1978, Oct 25, 26, 27 sun and moon...................247
T-5 *Nautical Almanac* 1981, Mar 26, 27, 28 planets and stars 248
T-6 *Nautical Almanac* 1981, Mar 26, 27, 28 sun and moon..................249

T-7 Conversion of Arc to Time 250
T-8 Altitude Corrections Sun, Planets, Stars 251

T-9 Increments and corrections 4m and 5m 252
T-10 Increments and corrections 6m and 7m..253
T-11 Increments and corrections 48m and 49m.....................................254
T-12 Increments and corrections 50m and 51m......................................255
T-13 Altitude Corrections Moon, 35° to 90°...256
T-14 Altitude Corrections Moon, 0° to 35°...257

T-15 Pub. 249, Vol 2, Lat 45, Dec (0-14), Same Name.............................258
T-16 Pub. 249, Vol 2, Lat 45, Dec (0-14), Contrary Name 259
T-17 Pub. 249, Vol 2, Lat 45, Dec (0-14), Contrary Name 260
T-18 Pub. 249, Vol 2, Lat 45. Dec (15-29) Same Name 261
T-19 Pub. 249, Vol 2, Lat 45, Dec (15-29), Same Name 262
T-20 Pub. 249, Vol 2, Lat 45, Dec (15-29), Contrary Name......................263

T-21 Table 5. Pub. 249 Corrections to Hc for Minutes of Declination......264
T-22 Polaris Corrections..265

T-23 Pub. 249, short sections (for problem 6.6)......................................266
T-24 Pub. 249, short sections (for problem 6.6)......................................267
T-25 Pub. 249, short sections (for problem 6.6)..................................... 268
T-26 Pub. 249, short sections (for problem 5.7)......................................269

T-27 Starpath N(x) Table for Emergency Sight Reduction 270
T-28 Emergency Almanac for the Sun 271

Appendix 4

Work forms

Contents

Overview of Starpath Work Forms....272
Sun Sights with Form 104....273
Moon Sights with Form 104....275
Star Sights with Form 104....275
Planet Sights with Form 104....277
Form 104 (2 Up)....278
Form 106 for NAO Tables, with Short Instructions....279
Form 106 for NAO Tables (2 Up)....280
Form 108 Combined Forms 104 and 106....282
Form 107 for LAN....283
Form 109 for Finding Index Correction by the Solar Method....284

Overview of Starpath Work Forms

Not all celestial navigators use work forms to help with the paper work, but I think it fair to say that most do. Or at least most—even very experienced navigators—like to have the forms at hand just in case they are needed. There are a lot of steps in the process, and we may have to do the work when very tired and not feeling well, as the boat rocks around in the seas. Having a guide that takes you step by step, with little thought required, can be a blessing. So even if you do not use them routinely, it is good to add them to your checklist and have at least one of each type tucked away in the almanac. Also, these days we rely mainly on GPS, so we might be rusty when we need to do the sights. For those who want to use them routinely, you can copy the ones in this book, or download from www.starpath.com/celnavbook.

The course presented in this book proceeds by giving annotated step by step instructions for filling out the forms. That we might think of as the *first pass* through the materials—the place you learn it and practice it. The detailed form instructions (to follow) is a summary of the process. So these form instructions are a *second pass* through the process.

The *third and final pass* is the set of forms themselves. After you have worked a few examples, you will find that the form itself, without any further instructions, will guide you through the process for each of the celestial bodies.

We have heard back many times from navigators who have been away from the subject for a long time, who told us how easy it was to recall the paperwork with the use of these forms. This was, of course, an intention of the forms, along with the main design criteria that they be such that all sights are done essentially the same way. Another goal was to have a place to write in every step of the process, and to have some reasonable element of smooth flow though the process. Alternative designs that one sees are typically vertical strip forms that usually do not meet any of these criteria.

The Form 106 that we have for the NAO Tables is especially valuable because the original instructions for the process given in the *Nautical Almanac* are difficult to follow. As a result of that problem, these valuable tables have not been used as much as they deserve. Some instructors go so far as to ridicule the NAO Tables for their complexity, driving new users away before they even get to try them. Misguided magazine articles have not helped. Our Form 106 makes the process very simple, and with just a few samples worked you will be doing them automatically.

We postpone the use of NAO tables till the end of the course simply because they do introduce a few extra steps at a time you are already learning a lot of new tables. Once you have had the experience of sight reductions with Pub 249, however, it takes just 20 minutes or so to master these new ones. These tables have a great virtue these days when cel nav is often just a back up to GPS. Since there is a full set of the NAO Tables in every *Nautical Almanac*, you just need buy one book to have a complete solution. Pub 249, and especially Pub 229, are large, heavy books when it comes to stowage on a small boat at sea. Also if you choose to do cel nav by computation, then the NAO Tables, as part of the Almanac are a natural back up.

Index

A

accuracy
- defined 203
- of a sextant 158
- of celestial fixes 7, 10, 174, 213
- of dip short 136
- of GPS 126, 129
- of plastic sextants 141
- of sextant sights 19, 26, 176, 214
- of time 199
- of watch time 135, 218

advanced LOP 75, 177, 203
Air Almanac 203
altitude correction 34–38, 36, 39, 66, 84, 88, 91, 94, 100–102, 164, 183, 186, 203
- additional altitude correction 100, 203

altitude intercept (a-value). *See* a-value
amplitude 204
antenna 129
apparent height 34, 204
approach cone 201
arc to time conversion 31, 32
Aries 83–84, 178, 182, 204
artificial horizon 161–163
assumed latitude (a-Lat) 47, 63, 73, 80, 204
assumed longitude (a-Lon) 47, 63–64, 80, 151, 204
assumed position (AP) 49, 63, 204
automatic identification system (AIS) 126
a-value 47, 49, 204, 205
a-Value 67
azimuth angle (Z) 65, 119, 204, 273
azimuth line 49, 52, 70, 118, 204, 275
azimuth (Zn) 47, 204, 273

B

bearing 12, 14, 47, 49, 75, 77, 205
Big Dipper 110, 179–185, 204, 205
Bowditch 19, 43, 124, 125, 137, 169, 171, 172, 173, 191, 205, 214

C

calculated height (Hc) 66, 205
calculators 8, 10, 14, 157, 191, 205
celestial body 59, 75, 130, 165, 205
celestial navigation 2, 3, 7, 205
chronometer 6, 135, 205
chronometer log 59, 134, 135, 205, 273
circle of equal altitude 117–120, 205
circle of position 193, 205, 208, 218
circumpolar stars 180, 205
civil twilight 58, 83, 184, 205
closing suns 163
compass checks 165, 205
compass rose 9, 45, 49, 183, 205–206, 212–213
computed solutions 119, 189–190
computer navigation 44
contrary name 38, 206
course 206
course over ground (COG) 127–130, 206
cross track error (XTE) 128

D

daily pages 36, 60
Davies Tables 191, 206. *See also* NAO tables
daylight saving time 132, 133, 182, 216, 219
d-correction 39, 61, 65–66, 84, 94, 206, 275
dead reckoning (DR) 206
- accuracy 43
- ocean 147–150
- plotting 9
- update the DR plot 217

declination 29–30, 36–38, 60, 206
declination increment 206, 277
departure 125, 128, 158
deviation 197, 205, 206
dip correction 22, 34–35, 136–137, 206
dip short 20, 136–137, 159, 161, 175
dividers 45, 47, 49, 80, 155–157, 206, 212
drift 5, 76–77, 157, 207, 214
DR position 206, 207
DR Track 207
Dutton's 124
d-value 206

E

easy LAN rule 30, 39, 42, 207
ecliptic 207
electronic charting system (ECS) 129, 146, 167
electronic compasses 129
elevated pole 204, 207
ellipsoidal distance 167, 201
Emergency Navigation Card by David Burch 158, 183, 196, 271
EPIRB 207
equation of time 43
equation of time (EqT) 32, 33, 207, 241
equinox 29, 39, 43, 59, 144, 181, 182, 207, 216–217

F

fast position plotting 127
fix 2, 5, 6, 174, 207
fluxgate compass 130
full-view mirror 22, 158, 207, 208, 215

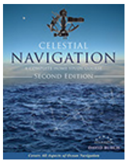
G

geographical position (GP) 29, 109, 114, 115, 119, 207
global positioning system (GPS) 59, 75, 125, 126–130, 132, 157, 161, 191, 207
great circle 166–169, 189, 207, 209, 213
great circle charts 168
Greenwich hour angle 62, 207
Greenwich hour angle (GHA) 208
Greenwich meridian 11, 31, 43, 113, 134, 208

STARPATH

This is the end of the sample.

To continue reading, please return to one of these options to purchase to the book.



Printed version

Adobe pdf ebook

Adobe epub ebook

elibra ebook

Kindle ebook

Apple iBook