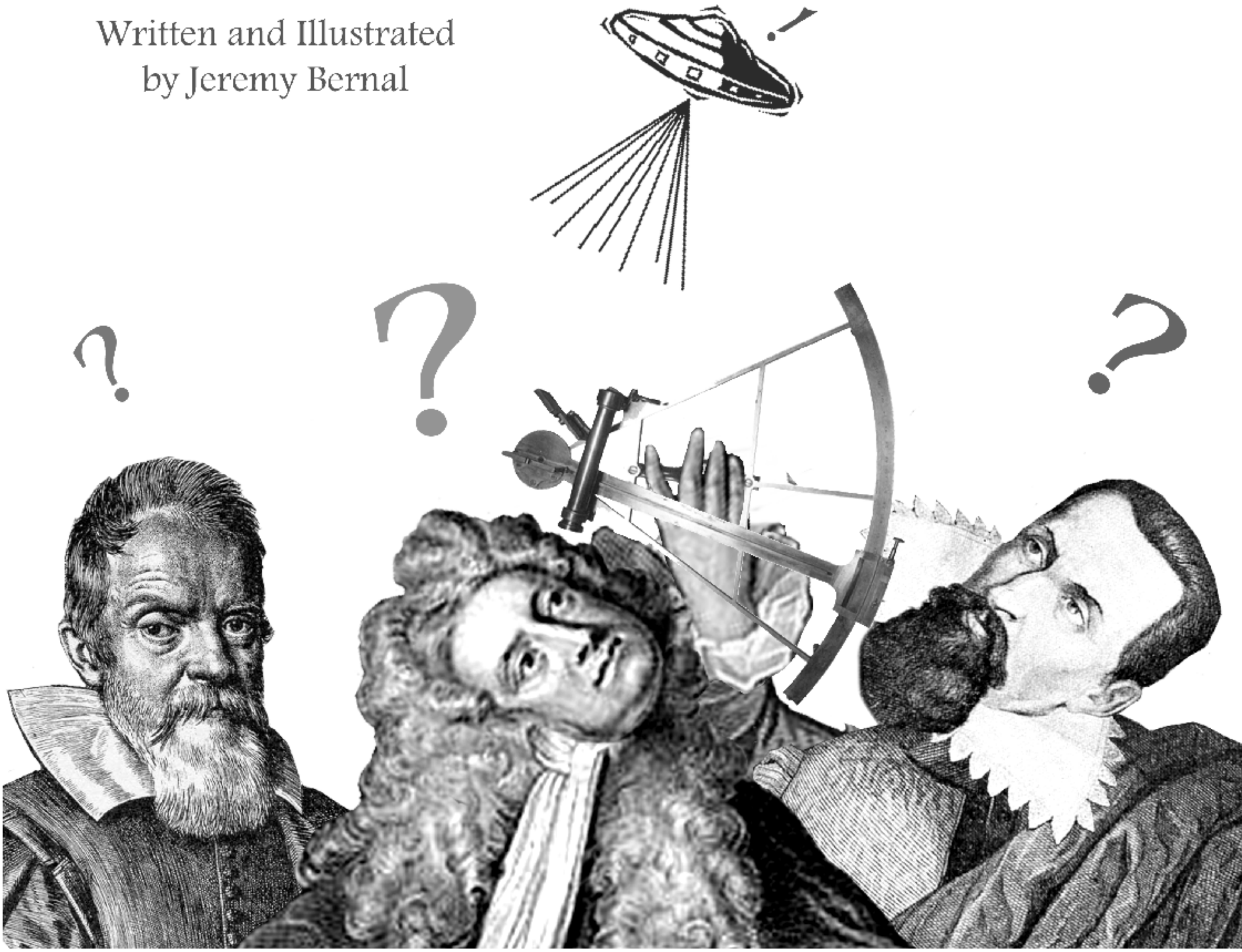
Celestial Navigation for the Clueless

Written and Illustrated
by Jeremy Bernal



Version 9.2

ISBN-10: 1442114355 / ISBN-13: 9781442114357

IMPORTANT:

Before you leave the book store, get a copy of this year's Nautical Almanac. You'll need it. Really. I'm trying to make the whole learning experience easy for you here. It will cost about $25 but you NEED it. You cannot learn or do Celestial Navigation without it.

The tutorials in this book are for the summer of 2005, and all the almanac pages you'll need to follow along are provided. But for you to actually go out and practice on your own, as well as learning the anatomy of the almanac, you will want your own up-to-date copy.

Don't procrastinate. Get it NOW or you'll be really confused and waste time, and have to go back to the book store, back into traffic, etc and your hair will start turning gray like mine is.

If you ordered this book and forgot to get the almanac, then you'll probably be OK learning how a sextant works, up until the part where you actually learn to compute sights. But beyond that, you'll be lost. You'll see. I'd advise ordering your almanac right now and practice using your sextant until your almanac arrives, and then moving on. Otherwise you'll just be extremely frustrated.

Legal Claptrap:

Niether this book, nor the author, can nor should be held responsible if you do something dumb like get lost and/or wreck your boat somewhere, burn your eyes out looking into the sun, injure yourself (brain or body), or fail to follow the common sense that kept your ancestors in the gene pool up until present day. Take some bloody responsibility for your own actions for once, people! It's a shame I have to put this part in here at all. Be a good example to the rest of the gene pool!

Any appearance of dead historical figures is strictly intentional. Any reference to living historical figures is, too, but it's all in good humor so hopefully Margaret Thatcher and Mikhael Gorbachev won't be too terribly insulted.

Now that we're done covering our butts from flesh-eating zombie lawyers, let's get on with the show, shall we?

What this book will do:

I'll teach you just what you need to know as you go. I'm not going to gum up your brain with useless trash you don't need. You learn as far as you want to. Knowing how the universe works is not important at all. You just need to follow step by step instructions, look through tables in a book, and do basic grade-school math. It's wonderfully mindless yet satisfying busy-work!

For more advanced stuff, like plotting lines of position and getting fixes at times other than noon, however, you'll need to learn some spinning planet and time concepts, but that's only if you want to go that far. If you can calculate time and degrees on a circle, then you'll be ok. Even then I've tried to make it as easy as I can, since I'm lazy and like to do things the easy way. The learning curve is steep, but not impossible.

A note on learning and innovation (paraphrased from Heinlein, who probably paraphrased it from some other wise lazy person): The innovators of our society never got ahead by being hard workers. They got ahead by finding better and more efficient ways of doing things so they could stay lazy.

So relax, crack open a beer, and lubricate your brain for the thorough reaming it's about to receive!

Note to Kindle users and other computer geeks:

You can download and print pdf files containing sight worksheets as well as the Almanac pages used in this book's examples at http://www.ncsail.org/publications.html . Scroll to the bottom of the page to the "resources" section, and the links will be there.

For Kristen,
without whom I would be truly lost.

Table of Contents

Foreword:

Honestly, I don't know why the other guys make it so hard to figure out, because it's not. Do yourself a favor—put the other guy's book down and buy this one. I guarantee mine will help you more. Here's why:

I'm no genius, and I've figured it out in a way that is easy to understand, enough that I feel that it's safe to teach YOU, the reader. I am descended from a long line of effective but grumpy bitter teachers (and Chicago bootleggers), so you're in good hands! I believe the reason we are grumpy and bitter is because things are *not* hard to learn, they are just made that way by lousy teachers!

You've probably looked at other books by brainy smarty-pants authors who like to yammer on about Kepler's orbits, Newton this and Spherical Trigonometry that, Sine, Cosine, Tangent, etc. They probably confused the heck out of you. They STILL confuse the heck out of me. They were written by people who know celestial navigation through and through, and they assume you know how to take sights and break them down, and they must also assume that you still remember a single thing from the algebra class you slept through in high school. Let alone trigonometry. Then let alone spherical trigonometry! I can safely say now that all you need to know from those brainy geek books is that YOU DO NOT NEED TO KNOW THAT STUFF! Hopefully you haven't spent money to buy those books like I did.

I read through those books. They confused the heck out of me. I have them here and I'm tearing them to bits finding the few meager useful tidbits of how-to-learn that they contain. They didn't contain much, and the few that did seemed to miss a few concepts that I think are bloody important.

I'm a stubborn guy. When I run into something I do not understand, I go for the problem's throat and bite down until it bleeds its workings out in a clear, concise format. Having run into these horrible books, I felt it was my God-sworn duty to filter through the nonsense for you folks and bring you something you could read and understand the first or second time.

I wrote this book *as* I learned celestial navigation (it started as a notebook and grew out of control). Why? Because in theory, it should give a better step-by-step perspective on just how it works, from the learner's point of view. I've already sorted through a lot of the complaints and grievances I have with the OTHER BOOKS. Yeah, you guys know who you are.

Celestial Nav is like driving a car—you don't need to know how the valves and cylinders and gears work, internal combustion processes, etc—you just want to know how to press the gas pedal to accelerate, the brakes to slow down, why turn signals are good things, and what hand gestures work best to tell others what you think of their driving. If you want to get into the nitty-gritty and tweak your car to give you more, well, Celestial Nav has that option too.

If you've got even the slightest interest in celestial navigation, it's probably good that you learn how to do it, at least on a basic level (Polaris sights and Sun sights) to use it as a backup to GPS.

You're probably a boaty person and you probably go on long trips, and you've gotten caught with your pants down in one way or another in regards to relying on electronic gadgets or battery power. You may dream of crossing an ocean someday, visiting the far-flung third world with all its flavors and culture, and you're afraid Uncle Sam will flip his lid and turn off your GPS signals right when you're skimming through that narrow reef passage halfway across the globe. Or maybe you're a grumpy curmudgeon who hates computers and prefers things that don't crash and fill your view with vague hexadecimal error code messages.

I could cite many an example of beautiful boats meeting their demise on a beach or reef because the captain was looking at his newfangled plotting gps computer program, watching the little boat icon clear the passage perfectly while in the real world he wrecked, and the chainsaw salvagers came out like wolves to the kill.

Well, that's part of my list of reasons for wanting to learn it, and maybe you're not far off, or maybe you are. It doesn't matter, because I'm going to teach you how to un-lose yourself with a sextant, pencil, paper, and basic math. When it's all over, you'll eye your GPS with the suspicious distrust that it so rightly deserves!

Celestial Navigation need not be limited to the sea; it can also be used to navigate on land or in the air.

Why learn Celestial Navigation?

What Celestial Navigation CAN do:

Give you a rough idea of where you are, allowing you to stumble around on the globe from sort of where you started to sort of where you're headed, and have a pretty good chance of getting to your destination. All with a paper, pencil, and sextant. All things not requiring batteries!

What Celestial Navigation CAN'T do:

It can't thread you through narrow reefs like a GPS can. It's not fast like a GPS. It's not as accurate as a GPS. It can't provide instant gratification in the way a GPS can. It's slow, cumbersome, and not that accurate. So if you want accuracy, get a GPS. If you want reliable face-first-into-the-waves salty pegleg arr matey "When I spits, I spits tar!" kind of stuff that will get you where you need to go no matter what, then Celestial Nav is for you.

BUT…

Little electronic boxes can tell you all sorts of neat things right away, with no need to think or wait. But as a caveat, little electronic boxes:

- Need batteries to eat.
- Do not cope well with salt water.
- Sometimes have a mind of their own, especially if the above two needs have not been fulfilled.
- Need satellites to see by. Said satellites are owned and operated by the US government, who is extremely neurotic about terrorists these days, and has been known to shut down and/or scramble the satellite signals at a whim. Said satellites also need batteries to run. And though they wouldn't be fired into orbit if they weren't reliable, if they do ever break-- well, they're very far away and won't be repaired quickly, I assure you.

It's the same reasons you shouldn't navigate with purely digital charts. If your computer fails, you're SCREWED. Paper, pencil, and books never crash or run out of batteries, and they are not afraid of people in dynamite vests.

Now I've got nothing against little electronic boxes. They are wonderful inventions. They save me lots of toil, and torment. But when the chips are down, I want something old fashioned and hardcore to rely on. Salty old farts got around with a sextant for centuries, and GPS has only been around for a few decades.

There's also a sense of satisfaction, like sailing itself, that comes from knowing you can get from Point A to Point B with nothing more than a trusty boat, the wind and sky, and your own sheer brain power. It's just good and salty, it is!

Now, I may sound like a hypocrite when I start in on the virtues of the digital wristwatch. Oh well, string me up and prepare the flogs! They are cheap and reliable, and ‘they’ are making ones now that recharge their batteries via mini solar panels. Buy a case of them; they’ll give you better service for half the price of a ‘marine grade’ GPS. If there was just one single electronic thing I could choose out of the whole assortment to go with me on a voyage, it would be a waterproof digital wristwatch.

What do I need to know before I start?

Well, for starters, you need one working hand and one working eye (most pirates worth their salt still have these). You should know how to navigate by a nautical chart. You should have a basic grasp of Latitude and Longitude and how they are measured. You should know how the compass works, and how to chart a bearing on a paper chart using a parallel ruler. You should know basic dead reckoning skills. And you should know how to add, subtract, multiply, and divide. Anyone who’s ever been out on a coastal sail probably knows this stuff. I can’t explain these things to you because that’s what other books are for (I highly recommend “The Complete Sailor” by David Siedman). Fortunately that book is good, otherwise I’d be writing a general sailing book that didn’t suck to go along with my celestial nav book ☺

What are the toughest parts to learn?

Don’t be intimidated by doing math. It’s never harder than grade-school add/subtract/multiply/divide, carrying numbers to make sure 6 hours 100 minutes is really 7 hours 40 minutes, and that when you pass 400º around a circle, you are still only 40º from the point of origin.

The biggest problem I ran into with learning Celestial Nav is that it has seemingly 2 or more names for each concept, measurement, angle, etc and a shorthand abbreviation which may or may not seem related to the real names at all. It’s tough to sort them all out. In time you’ll learn them by heart, but in the meantime please bear with it. I’ve tried to make it as easy as I can.

The Nautical Almanac may seem intimidating at first, but once you’ve used it a few times, it’s completely friendly. There are a myriad little corrections and numbers to look up in the almanac (the most time consuming part of Celestial Nav is looking up those little numbers and corrections!) but if you have a form to fill out (those are included in this book), you’ll never have to remember what they all are; the form will prompt you for everything you need to look up.

What tools do you need to find out where you are?

Not much! These are the basics. We’ll go into them at greater depth below.

1. A clear sky, day or night.
2. A sextant.
3. This year’s Nautical Almanac.
4. An accurate wristwatch.

Let's go over the list in more detail:

1. This should go without saying, but obviously you need a clear sky and horizon, enough to at least see the star or celestial body you are using for your sight. As we all know, Mother Nature is moody, and you just have to hunker down and use your Dead Reckoning skills until she is clear enough to allow you a proper sight.
2. A sextant. It doesn't need to have flashy bells and whistles, but it SHOULD have a set of filters that swing to block the mirrors for sun sights. Otherwise you'll be firing the concentrated rays of the sun directly into your soon-to-be-smoldering eye socket. It is possible to take a sight with a protractor, string, and fishing sinker for the sake of learning, but a real sextant will give you much better readings. It's up to you what your budget is, and how much you want to use your new skills.
3. Nautical Almanac. It's usually blue, with white letters, and available in 2 versions. The commercial version is the same information, just made cheaper because boat-stuff companies place ads in the front and back pages, thereby reducing the cost of publication and passing those savings onto you. No, they don't stuff ads in the middle and make it hard to read—it's all at the very front and back, nice and tidy.
4. An accurate watch. Something digital, waterproof, with a digital readout, date-keeping (with leap years), and preferably a 'dual time' function. If you don't have or can't get a watch with dual time settings, get two watches. Keep one set to your local time, and set the dual time (or second watch) to GMT (Greenwich Mean Time). Synchronize both time settings down to the second. Really. It's important that you do so, so that your readings are as accurate as you can manage. You would not believe the headache that could have been prevented learning this stuff if a SINGLE ONE of these book writers had thought to mention setting a watch to GMT and keeping it that way. It makes it so much easier, trust me. The date-keeping function is nice to have if you're a forgetful idiot like me who often loses track of what day it is.

Not all watches are created equal. Don't cheap out—get a durable one. If you need to get two, get both the same kind. I am not receiving a royalty for this, but I should! I highly recommend the Casio AQ-150W. It has an analog face, with digital readout for 2 time settings, a stopwatch, and good night illumination. Its time setting method also lends itself well to synchronization with timecode and/or the atomic clock. It's waterproof up to 10 bar of pressure, and its cost is around US$25.00, commonly available at WalMart and Target stores. There are a variety of ways to find what the real, honest time is. Radio timecodes, Atomic Clock websites (nist.time.gov), and shareware computer clock-sync utilities are freely available to help you sync up your time.

Quartz movement digital watches are so accurate these days that unless they get frozen, you should not have to worry about them slacking off or running too fast. Just to be sure, though, check and adjust your time before you begin your passage, and you should be ok.

What does a sextant do?

It measures the angles between your eye, the horizon, and any object in the sky.

So how can a sextant be used to find my position?

The Great Geeks of History have done all that work for you over the centuries, and offer it to you condensed into what we call the Nautical Almanac. This book can tell you at any given time where any celestial object will be in relation to the earth's center. Your viewpoint, through the sextant, will give an angle of observation, which, when compared to an angle from a real-world location, tells you how far you are from that location. 2 or more of these angle comparisons can be crossed to give you a 'fix' on your position.

There are many different ways to find out where you are, from easy to hard, and we'll go over them in that order. You don't have to know HOW it works, only that it DOES. Simply following directions on the worksheets included will get you through Noon Sights and advanced Polaris Sights. If you want to learn past that, it's in here too, but I won't fault you if you don't want to.

The first, most basic way to use a sextant is to determine your Latitude by sighting Polaris, the north star (which you don't necessarily need to have the Almanac for unless you're a stickler for details). The second is finding Longitude through a Noon Sight of the Sun. This requires a series of sextant sights and watch set to Greenwich Mean Time. Then we'll do Latitude by Noon Sight of the Sun, which requires the Almanac and data from the same Noon Sight taken for Longitude.

The above stuff is plenty to get you going, and very adequate to get you fixed on just where the heck you ended up at least once every 12 hours. Beyond that, if you really feel like learning, is where it gets more difficult but useful, allowing you to figure your position any time 2 or more celestial objects are visible.

A note on old Nautical Almanacs:

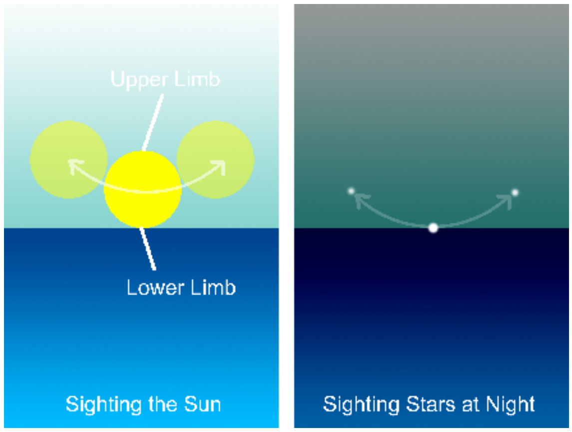
You may want to save your out-of-date Almanacs. Every 4 years, the cycle of numbers starts over for the Sun and Stars, so that data is still good. The Moon and Planets tables, however, do not follow the same cycle and will be useless.

Small post-it notes or stick-on filing tabs from the office supply store make excellent page markers for quick reference.

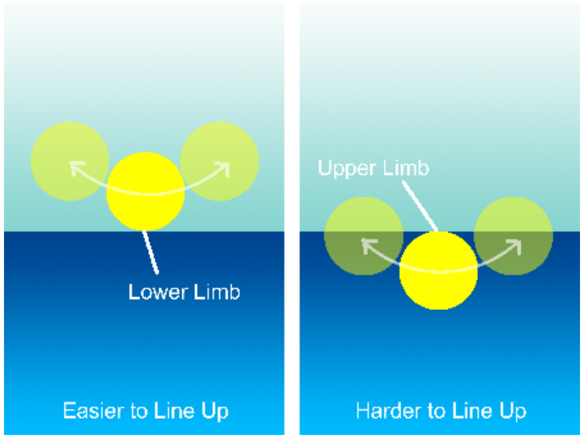
The best reference book in the world! The first one was published by the fifth Astronomer Royal Nevil Maskelyne in 1766, and since 1832 it has been kept up by Her Majesty's Nautical Almanac Office at the UK's Rutherford Appleton Laboratory.

Taking your sight:

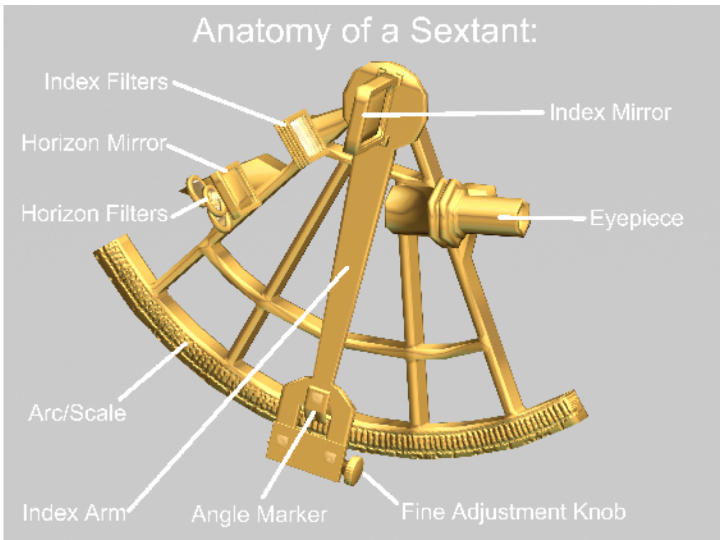
How do I read it?



When looking through the eyepiece, facing your target sun/star/planet, you find the horizon in one view, while you locate the target object in the opposite view. Finding the angle is as simple as manipulating the index mirror so as to line the target object up with the horizon. Wag the sextant side to side, and 'swing' the object, making sure it just brushes the horizon at its lowest point. Then read the angle off the sextant. Not all sextants are the same, so refer to your owner's manual on how to read the increments on your fine-adjustment knob.



Since it is tough to figure exactly where the center of the sun (or moon) is to line it up, we typically (because it's easier to see) line it up by dropping the bottom edge of said object to where it just touches the horizon. Touching the bottom edge of the object to the horizon is referred to as using the Lower Limb of the object. For the sake of sanity, we'll always do Lower Limb sights.



The sextant should have a rough adjustment for large movements, as well as a fine adjustment knob at the bottom of the index arm. If it has no fine adjustment, don't worry—you can still learn how to do this, there will just be a larger margin of error in your fixes (which is fine!).

When taking sights, it is best to take three sights and average the results. This will make up for minor errors in adjustment, as well as point out if you're making any major mistakes.

A sight consists of 3 parts: an angle, a celestial object, and a time. It helps to have an assistant ready to note the exact time the sight is taken. Once your sextant is aligned, say “Mark”, and have them note the time. Then look at your sextant and tell them the measurement, and what you were looking at (Sun, Polaris, etc).

If you’re on your own, the fastest way to do it is this: Line your sight up. Have a pencil ready. Bring your watch up in view and look at it with your free eye. Note the seconds first. Now put the sextant aside and write down that seconds reading. Then the minutes, then the hours. Mark down the sextant measurement last, as it’s there to stay until you take your next sight.

There are naturally things that will affect your reading. These are:

- Your sextant may need adjustment or may always be off a bit (don’t panic—this is ok, read on).
- Your eye may be at different heights when you take sights.
- The atmosphere acts like a lens and bends light.

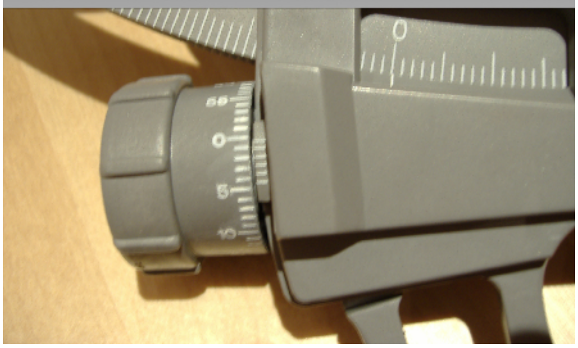
Fortunately, once again, the Great Geeks of History in their vast triangular genius have calculated how to make up for these issues, and the solutions are all in that fantastic Nautical Almanac.

Index Error and Index Correction:

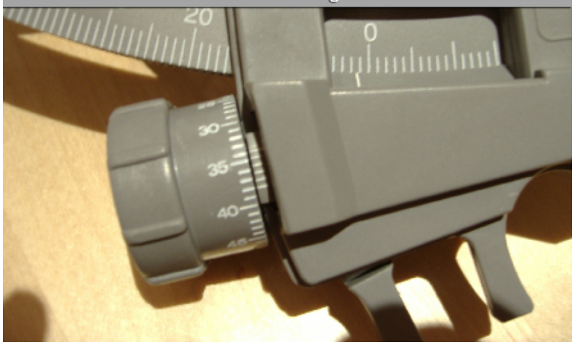
Not all sextants are created equal!

In order to get an accurate reading, you will need to find out the Index Error (so you can correct it with the Index Correction) of your sextant. This is easy to do—go anywhere you can see the horizon clearly in both mirrors, line them up, and see what the sextant reads. This number is your Index Error. No, your sextant is not defective. Every sextant has tiny differences, and their readings can be affected by age, temperature, number of times it's been dropped, etc. This is an important number to know, and you will need to compensate for it in every one of your calculations.

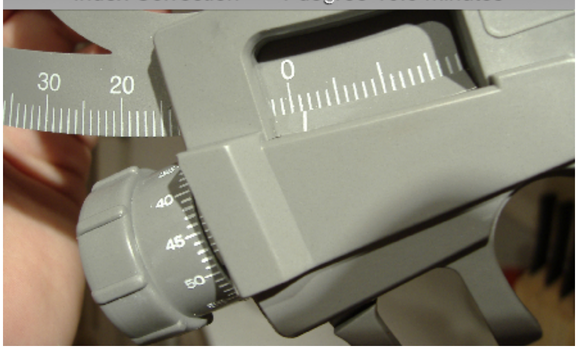
- *Index Error* is the amount "off center" your sextant is.
- *Index Correction* is the number you need to compensate and bring the sextant back to Zero. It is the exact opposite of Index Error. If your sextant is 1 minute in error, then the Index Correction is –1 minute. If your sextant is –2.3 minutes in error, your Index Correction is +2.3 minutes.



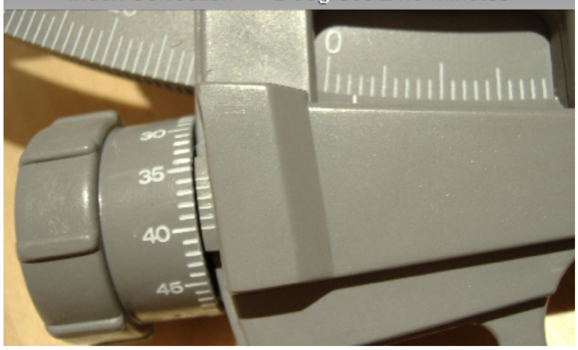
Sextant reads Zero.
Index Error = 0
Index Correction = 0



Sextant reads 1 degree 34 minutes
Index Error = +1 degree 34 minutes
Index Correction = -1 degree 34 minutes



Sextant reads 358 degrees 43.4 minutes
Index Error = -1 degree 16.6 minutes
Index Correction = +1 degree 16.6 minutes



Sextant reads 357 degrees 36.0 minutes
Index Error = -2 degrees 24.0 minutes
Index Correction = +2 degrees 24.0 minutes

Some sextants have adjustment screws on their mirrors that can be used to 'zero' the sextant's measurement thereby removing Index Error from the equation. You should zero your sextant or re-calculate your Index Correction every week or so as the seasons/temperatures change to make your readings the most accurate.

Plastic sextants expand and contract quite a bit depending on temperature. Metal sextants change less, but are more expensive. They still measure the same things; it's just a matter of preference and how you'll be using your sextant. If you only want it as backup, or just to learn, go with a cheaper plastic one. If you are really jazzed about the whole concept of Cel Nav later on, then you may want to invest in a metal sextant.

Helpful hint: While we're at this point where we begin discussing what we call Sight Corrections, write down your Index Correction (not index error) on a card or slip of paper, and tape it to the inside of your sextant case.

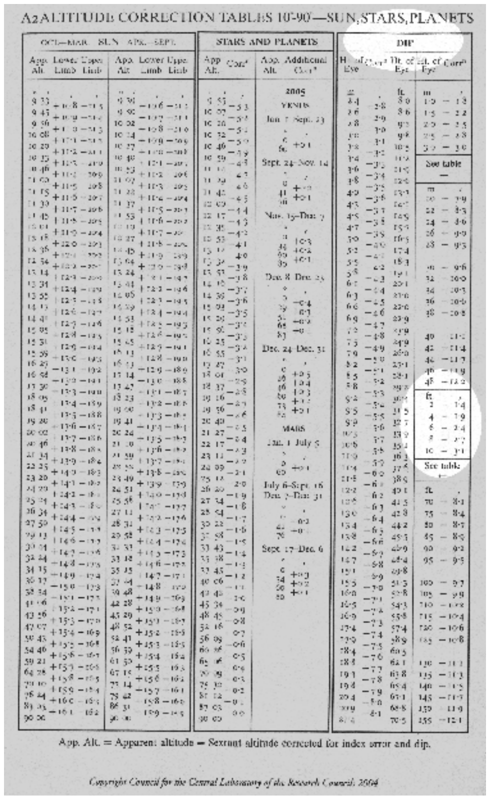
Dip Correction :

Where are you taking the sight from?

Sextant sights are full of little Sight Corrections depending on time of year, atmospheric refraction; the list goes on and on. The higher your eye is above sea level, the larger your angle will be when sighting your celestial target. This needs a correction in your calculations, and this is called your Dip Correction.

The first thing you need to know is how high your eye is from the ground (sea). It should be pretty easy to figure out, and it doesn't have to be super-accurate, just a rough guess. For example, if you're on the deck of a boat that is 4 feet above sea level, and your eye is 5 feet above that, your eye height will be 9 feet.

There is a table in your Nautical Almanac which tells you your Dip Correction based on that height. It should be a yellow page, near the front of the book, and it is usually on a heavier grade paper than the rest of the pages. If you do not have the yellow page, this table will be on page A2 in the front of your almanac.



The top of the page should read "Altitude Correction Tables – Sun, Stars, Planets". It has 3 columns, the right-most of which is "Dip". Find your eye height, and then find your dip correction next to it, in minutes and seconds.

Take a moment to find your 2 common Dip Corrections for, say, standing on your front deck and sitting in your cockpit, and write them down on the paper you taped inside your sextant case.

Dip corrections are ALWAYS SUBTRACTED from your sextant angle.

Apparent Altitude (with semi-important vague geek trivia):

Your sextant sight, corrected for Index Error and Dip, is called "Apparent Altitude." Why it is done this way *before* the Refraction and Semi-diameter corrections were included is beyond my knowledge and understanding, and it is likely that some dead famous Geek of History took the secret to his grave. Nonetheless, you cannot determine your Refraction or Semi-Diameter corrections unless you first have your Apparent Altitude.

Atmospheric Refraction :

The curvature of the Earth's atmosphere bends light.

As light enters the Earth's atmosphere, it bends (refracts), meaning that the source of the light is not really located in the exact direction you are looking at it from. Don't worry—it's easy to figure out how to correct for this. It's all written down in that handy Nautical Almanac.

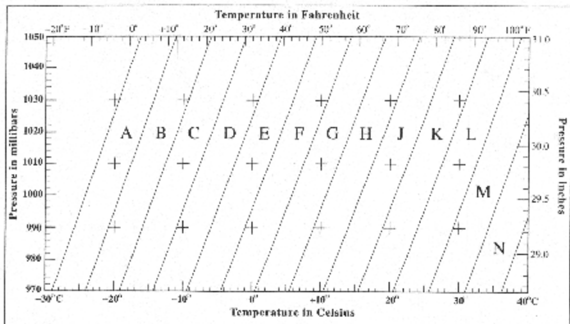
In the front of your Nautical Almanac is a page (page A4) with tables to find your atmospheric refraction correction. The top of the page reads, "Altitude Correction Tables – Additional Corrections"

The top table is for temperature and barometric pressure adjustments. The temperature and pressure should coincide with a letter-coded zone on the chart. If you don't know your barometric pressure, just use the letter in the column for temperature. Keep that letter in mind for the next table.

The chart on the bottom is what is important. Basically, the more atmosphere you have to look through, the more light bends. When you are looking at an object near the horizon, its light is bent the most—you are looking through much more air at the horizon. The light from directly overhead is bent the least.

A4 ALTITUDE CORRECTION TABLES—ADDITIONAL CORRECTIONS

ADDITIONAL REFRACTION CORRECTIONS FOR NON-STANDARD CONDITIONS



App. Alt.	A	B	C	D	E	F	G	H	J	K	L	M	N	P	App. Alt.
° ′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	° ′
00 00	−7·3	−5·9	−4·6	−3·4	−2·2	−1·1	0·0	+1·0	+2·2	+3·0	+4·0	+4·9	+5·9	+6·9	00 00
00 30	5·5	4·5	3·5	2·6	1·7	0·8	0·0	0·8	1·6	2·3	3·1	3·8	4·5	5·3	00 30
01 00	4·4	3·5	2·8	2·0	1·3	0·7	0·0	0·6	1·2	1·8	2·4	3·0	3·6	4·2	01 00
01 30	3·5	2·9	2·2	1·7	1·1	0·5	0·0	0·5	1·0	1·5	2·0	2·5	2·9	3·4	01 30
02 00	2·9	2·4	1·9	1·4	0·9	0·4	0·0	0·4	0·8	1·3	1·7	2·0	2·4	2·8	02 00
02 30	−2·5	−2·0	−1·6	−1·2	−0·8	−0·4	0·0	+0·4	+0·7	+1·1	+1·4	+1·7	+2·1	+2·4	02 30
03 00	2·1	1·7	1·4	1·0	0·7	0·3	0·0	0·3	0·6	0·9	1·2	1·5	1·8	2·1	03 00
03 30	1·9	1·5	1·2	0·9	0·6	0·3	0·0	0·3	0·5	0·8	1·1	1·3	1·6	1·8	03 30
04 00	1·6	1·3	1·1	0·8	0·5	0·3	0·0	0·2	0·5	0·7	0·9	1·2	1·4	1·6	04 00
04 30	1·5	1·2	0·9	0·7	0·5	0·2	0·0	0·2	0·4	0·6	0·8	1·0	1·3	1·5	04 30
05 00	−1·3	−1·1	−0·9	−0·6	−0·4	−0·2	0·0	+0·2	+0·4	+0·6	+0·8	+0·9	+1·1	+1·3	05 00
06	1·1	0·9	0·7	0·5	0·3	0·2	0·0	0·2	0·3	0·5	0·6	0·8	0·9	1·1	06
07	1·0	0·8	0·6	0·5	0·3	0·1	0·0	0·1	0·3	0·4	0·5	0·7	0·8	0·9	07
08	0·8	0·7	0·5	0·4	0·3	0·1	0·0	0·1	0·2	0·4	0·5	0·6	0·7	0·8	08
09	0·7	0·6	0·5	0·4	0·2	0·1	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	09
10 00	−0·7	−0·5	−0·4	−0·3	−0·2	−0·1	0·0	+0·1	+0·2	+0·3	+0·4	+0·5	+0·6	+0·7	10 00
12	0·6	0·5	0·4	0·3	0·2	0·1	0·0	0·1	0·2	0·2	0·3	0·4	0·5	0·5	12
14	0·5	0·4	0·3	0·2	0·1	0·1	0·0	0·1	0·1	0·2	0·3	0·3	0·4	0·5	14
16	0·4	0·3	0·3	0·2	0·1	0·1	0·0	0·1	0·1	0·2	0·2	0·3	0·3	0·4	16
18	0·4	0·3	0·2	0·2	0·1	−0·1	0·0	+0·1	0·1	0·2	0·2	0·3	0·3	0·4	18
20 00	−0·3	−0·3	−0·2	−0·2	−0·1	0·0	0·0	0·0	+0·1	+0·1	+0·2	+0·2	+0·3	+0·3	20 00
25	0·3	0·2	0·2	0·1	0·1	0·0	0·0	0·0	0·1	0·1	0·1	0·2	0·2	0·2	25
30	0·2	0·2	0·1	0·1	0·1	0·0	0·0	0·0	+0·1	0·1	0·1	0·1	0·2	0·2	30
35	0·2	0·1	0·1	0·1	−0·1	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·2	35
40	0·1	0·1	0·1	−0·1	0·0	0·0	0·0	0·0	0·0	+0·1	0·1	0·1	0·1	0·1	40
50 00	−0·1	−0·1	−0·1	0·0	0·0	0·0	0·0	0·0	0·0	0·0	+0·1	+0·1	−0·1	+0·1	50 00

The graph is entered with arguments temperature and pressure to find a zone letter; using as arguments this zone letter and apparent altitude (sextant altitude corrected for index error and dip), a correction is taken from the table. This correction is to be applied to the sextant altitude in addition to the corrections for standard conditions (for the Sun, stars and planets from page A2–A3 and for the Moon from pages xxxiv and xxxv).

Your apparent altitude is what you use to look up this atmospheric correction. Use the columns at either side to find your apparent altitude, then work your way across to the column that coincides with the letter you found in the top (temperature/pressure) table. Write this number down on your worksheet.

Altitude/Semi-Diameter Correction:

The Sun is fat. So is the Moon. Since they consume space in our eyepiece, and because of how the sextant works, we find it easier to match their edge to the horizon, rather than their center. The angle you measure with the object's top edge on the horizon will obviously differ from its bottom edge touching, and this difference is called Semi-Diameter Correction.

Stars and planets, since they are so far away and appear so tiny, do not require semi-diameter correction.

Now, on Pages A2 and A3 in your Nautical Almanac, "Altitude Correction Tables – Sun, Stars, Planets", you will see a column for "Sun" with 2 columns denoting monthly ranges on either side. Find your month's side, and read down the Apparent Altitude column until you find the number closest to your Apparent Altitude. Note that the corrections are listed for ranges of numbers (for example, An Apparent Altitude of 85º during Apr-Sept will have a +15.8 minute correction for the sun, and a –0.1 correction for stars.)

You'll notice that the Sun's correction hovers around +16 or –16, and changes as it gets closer to the horizon (this is due to our old friend Atmospheric Refraction). The "Fat" objects in the sky are the Sun and the Moon. Since the Moon is so close, so fat, and has its own special goofy orbit, it has its own special page of corrections in the back of the Almanac.

A2 ALTITUDE CORRECTION TABLES 10°–90° SUN, STARS, PLANETS

SUN OCT.–MAR. App. Alt.	Lower Limb	Upper Limb	SUN APR.–SEPT. App. Alt.	Lower Limb	Upper Limb	STARS AND PLANETS App. Alt.	Corr^n
9 33			9 39			9 55	
	+10.8	−21.5		+10.6	−21.2		−5.3
9 45			9 50			10 07	
	+10.9	−21.4		+10.7	−21.1		−5.2
9 56			10 02			10 20	
	+11.0	−21.3		+10.8	−21.0		−5.1
10 08			10 14			10 32	
	+11.1	−21.2		+10.9	−20.9		−5.0
10 20			10 27			10 46	
	+11.2	−21.1		+11.0	−20.8		−4.9
10 33			10 40			10 59	
	+11.3	−21.0		+11.1	−20.7		−4.8
10 46			10 53			11 14	
	+11.4	−20.9		+11.2	−20.6		−4.7
11 00			11 07			11 29	
	+11.5	−20.8		+11.3	−20.5		−4.6
11 15			11 22			11 44	
	+11.6	−20.7		+11.4	−20.4		−4.5
11 30			11 37			12 00	
	+11.7	−20.6		+11.5	−20.3		−4.4
11 45			11 53			12 17	
	+11.8	−20.5		+11.6	−20.2		−4.3
12 01			12 10			12 35	
	+11.9	−20.4		+11.7	−20.1		−4.2
12 18			12 27			12 53	
	+12.0	−20.3		+11.8	−20.0		−4.1
12 36			12 45			13 12	
	+12.1	−20.2		+11.9	−19.9		−4.0
12 54			13 04			13 32	
	+12.2	−20.1		+12.0	−19.8		−3.9
13 14			13 24			13 53	
	+12.3	−20.0		+12.1	−19.7		−3.8
13 34			13 44			14 16	
	+12.4	−19.9		+12.2	−19.6		−3.7
13 55			14 06			14 39	
	+12.5	−19.8		+12.3	−19.5		−3.6
14 17			14 29			15 03	
	+12.6	−19.7		+12.4	−19.4		−3.5
14 41			14 53			15 29	
	+12.7	−19.6		+12.5	−19.3		−3.4
15 05			15 18			15 56	
	+12.8	−19.5		+12.6	−19.2		−3.3
15 31			15 45			16 25	
	+12.9	−19.4		+12.7	−19.1		−3.2
15 59			16 13			16 55	
	+13.0	−19.3		+12.8	−19.0		−3.1
16 27			16 43			17 27	
	+13.1	−19.2		+12.9	−18.9		−3.0
16 58			17 14			18 01	
	+13.2	−19.1		+13.0	−18.8		−2.9
17 30			17 47			18 37	
	+13.3	−19.0		+13.1	−18.7		−2.8
18 05			18 23			19 16	
	+13.4	−18.9		+13.2	−18.6		−2.7
18 41			19 00			19 56	
	+13.5	−18.8		+13.3	−18.5		−2.6
19 20			19 41			20 40	
	+13.6	−18.7		+13.4	−18.4		−2.5
20 02			20 24			21 27	
	+13.7	−18.6		+13.5	−18.3		−2.4
20 46			21 10			22 17	
	+13.8	−18.5		+13.6	−18.2		−2.3
21 34			21 59			23 11	
	+13.9	−18.4		+13.7	−18.1		−2.2
22 25			22 52			24 09	
	+14.0	−18.3		+13.8	−18.0		−2.1
23 20			23 49			25 12	
	+14.1	−18.2		+13.9	−17.9		−2.0
24 20			24 51			26 20	
	+14.2	−18.1		+14.0	−17.8		−1.9
25 24			25 58			27 34	
	+14.3	−18.0		+14.1	−17.7		−1.8
26 34			27 11			28 54	
	+14.4	−17.9		+14.2	−17.6		−1.7
27 50			28 31			30 22	
	+14.5	−17.8		+14.3	−17.5		−1.6
29 13			29 58			31 58	
	+14.6	−17.7		+14.4	−17.4		−1.5
30 44			31 33			33 43	
	+14.7	−17.6		+14.5	−17.3		−1.4
32 24			33 18			35 38	
	+14.8	−17.5		+14.6	−17.2		−1.3
34 15			35 15			37 45	
	+14.9	−17.4		+14.7	−17.1		−1.2
36 17			37 24			40 06	
	+15.0	−17.3		+14.8	−17.0		−1.1
38 34			39 48			42 42	
	+15.1	−17.2		+14.9	−16.9		−1.0
41 06			42 28			45 34	
	+15.2	−17.1		+15.0	−16.8		−0.9
43 56			45 29			48 45	
	+15.3	−17.0		+15.1	−16.7		−0.8
47 07			48 52			52 18	
	+15.4	−16.9		+15.2	−16.6		−0.7
50 43			52 41			56 09	
	+15.5	−16.8		+15.3	−16.5		−0.6
54 46			56 59			60 26	
	+15.6	−16.7		+15.4	−16.4		−0.5
59 21			61 50			65 06	
	+15.7	−16.6		+15.5	−16.3		−0.4
64 28			67 15			70 09	
	+15.8	−16.5		+15.6	−16.2		−0.3
70 10			73 14			75 32	
	+15.9	−16.4		+15.7	−16.1		−0.2
76 24			79 42			81 12	
	+16.0	−16.3		+15.8	−16.0		−0.1
83 05			86 31			87 03	
	+16.1	−16.2		+15.9	−15.9		0.0
90 00			90 00			90 00	

STARS AND PLANETS — App. Alt. / Additional Corr^n

2005

VENUS

Jan. 1–Sept. 23

App. Alt.	Additional Corr^n
0	
	+0.1
60	

Sept. 24–Nov. 14

App. Alt.	Additional Corr^n
0	
	+0.2
41	
	+0.1
76	

Nov. 15–Dec. 7

App. Alt.	Additional Corr^n
0	
	−0.3
34	
	−0.2
60	
	−0.1
80	

Dec. 8–Dec. 23

App. Alt.	Additional Corr^n
0	
	+0.4
29	
	+0.3
51	
	+0.2
68	
	+0.1
83	

Dec. 24–Dec. 31

App. Alt.	Additional Corr^n
0	
	+0.5
26	
	+0.4
46	
	+0.3
60	
	+0.2
73	
	+0.1
84	

MARS

Jan. 1–July 5

App. Alt.	Additional Corr^n
0	
	+0.1
60	

July 6–Sept. 16
Dec. 7–Dec. 31

App. Alt.	Additional Corr^n
0	
	+0.2
41	
	+0.1
76	

Sept. 17–Dec. 6

App. Alt.	Additional Corr^n
0	
	+0.3
34	
	+0.2
60	
	+0.1
80	

DIP

Ht. of Eye (m)	Corr^n	Ht. of Eye (ft.)
2.4		8.0
	−2.8	
2.6		8.6
	−2.9	
2.8		9.2
	−3.0	
3.0		9.8
	−3.1	
3.2		10.5
	−3.2	
3.4		11.2
	−3.3	
3.6		11.9
	−3.4	
3.8		12.6
	−3.5	
4.0		13.3
	−3.6	
4.3		14.1
	−3.7	
4.5		14.9
	−3.8	
4.7		15.7
	−3.9	
5.0		16.5
	−4.0	
5.2		17.4
	−4.1	
5.5		18.3
	−4.2	
5.8		19.1
	−4.3	
6.1		20.1
	−4.4	
6.3		21.0
	−4.5	
6.6		22.0
	−4.6	
6.9		22.9
	−4.7	
7.2		23.9
	−4.8	
7.5		24.9
	−4.9	
7.9		26.0
	−5.0	
8.2		27.1
	−5.1	
8.5		28.1
	−5.2	
8.8		29.2
	−5.3	
9.2		30.4
	−5.4	
9.5		31.5
	−5.5	
9.9		32.7
	−5.6	
10.3		33.9
	−5.7	
10.6		35.1
	−5.8	
11.0		36.3
	−5.9	
11.4		37.6
	−6.0	
11.8		38.9
	−6.1	
12.2		40.1
	−6.2	
12.6		41.5
	−6.3	
13.0		42.8
	−6.4	
13.4		44.2
	−6.5	
13.8		45.5
	−6.6	
14.2		46.9
	−6.7	
14.7		48.4
	−6.8	
15.1		49.8
	−6.9	
15.5		51.3
	−7.0	
16.0		52.8
	−7.1	
16.5		54.3
	−7.2	
16.9		55.8
	−7.3	
17.4		57.4
	−7.4	
17.9		58.9
	−7.5	
18.4		60.5
	−7.6	
18.8		62.1
	−7.7	
19.3		63.8
	−7.8	
19.8		65.4
	−7.9	
20.4		67.1
	−8.0	
20.9		68.8
	−8.1	
21.4		70.5

Ht. of Eye	Corr^n
m	′
1.0	−1.8
1.5	−2.2
2.0	−2.5
2.5	−2.8
3.0	−3.0
See table ←	
m	′
20	−7.9
22	−8.3
24	−8.6
26	−9.0
28	−9.3
30	−9.6
32	−10.0
34	−10.3
36	−10.6
38	−10.8
40	−11.1
42	−11.4
44	−11.7
46	−11.9
48	−12.2
ft.	′
2	−1.4
4	−1.9
6	−2.4
8	−2.7
10	−3.1
See table ←	
ft.	′
70	−8.1
75	−8.4
80	−8.7
85	−8.9
90	−9.2
95	−9.5
100	−9.7
105	−9.9
110	−10.2
115	−10.4
120	−10.6
125	−10.8
130	−11.1
135	−11.3
140	−11.5
145	−11.7
150	−11.9
155	−12.1

App. Alt. = Apparent altitude = Sextant altitude corrected for index error and dip.

So why do we even need Upper Limb? Well, if the sun or moon's Lower Limb is obscured by clouds (or if you can't see the Moon's lower limb due to its current phase), you can still measure it by its top edge.

Find where your reading falls in the column, and add that number to your now full-grown list of onerous corrections.

Parallax:

While learning, you may find references to “Parallax Correction”. Parallax defined is the angular difference in direction of a celestial body as measured from two points on the earth's orbit. You shouldn’t have to worry about it with stars, since they are tiny points in the sky, *very* far away and therefore the measurements are microscopically negligible. It is an issue present with the sun and moon, however, since they are close to us. Modern almanac data includes this amount in the Semi-Diameter corrections for the Sun. The Moon has its own page of Parallax corrections in the back of the Almanac.

So don’t get worried; just know that it’s there, hiding—this explanation is just so you don’t panic, thinking you are forgetting to calculate something.

Complete Sight Summary:

1. Take your sight.
2. Add Index Correction (if applicable).
3. Subtract Dip correction.
4. Add Refraction correction.
5. Add Altitude/Semidiameter (SD) correction
6. Add Parallax correction (if applicable)
7. All done!

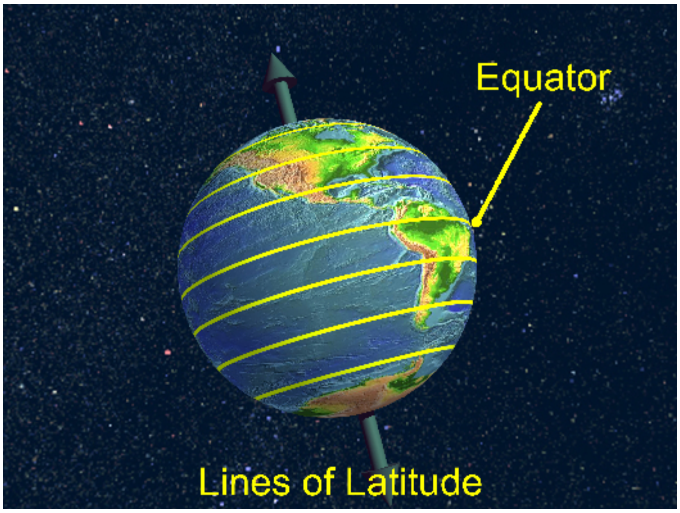
Beginners’ tips for getting the aim right:

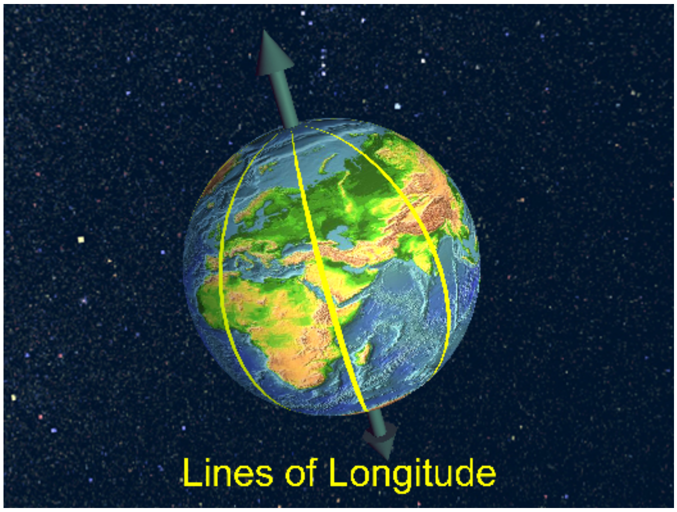
You may find it hard at first to get your target object lined up in the mirrors. It’s a lot of sky to scan and small mirrors to fit it into. Don’t worry, I had that problem too, still have it sometimes.

Set your sextant to 0º, with the horizon in both views. Then, with both index and horizon filters on, look up directly at the sun. If it’s too bright, flip down some more filters until it’s easy to see but not burning holes through your skull.

Now hold the index arm steady, and tilt the sextant instead. Slowly tilt the sextant down while opening the angle, keeping the sun in your index mirror as you bring the horizon into view. If you have to stop halfway to get the horizon filter out of the way, it’s ok. Voila! Much easier.

How the Earth is Measured:





The Earth is divided top-to-bottom by horizontal lines of Latitude (like a sandwich), and cut into vertical wedges by lines of Longitude (like an orange). The diameter of Latitude sections varies, while diameter of Longitude remains the same.

The Equator is 0º Latitude. Counting from there, each degree of Latitude increases, until it reaches each of the poles at 90º, North and South, respectively.

Longitude lines split the Earth vertically into wedges, like the segments of an orange.

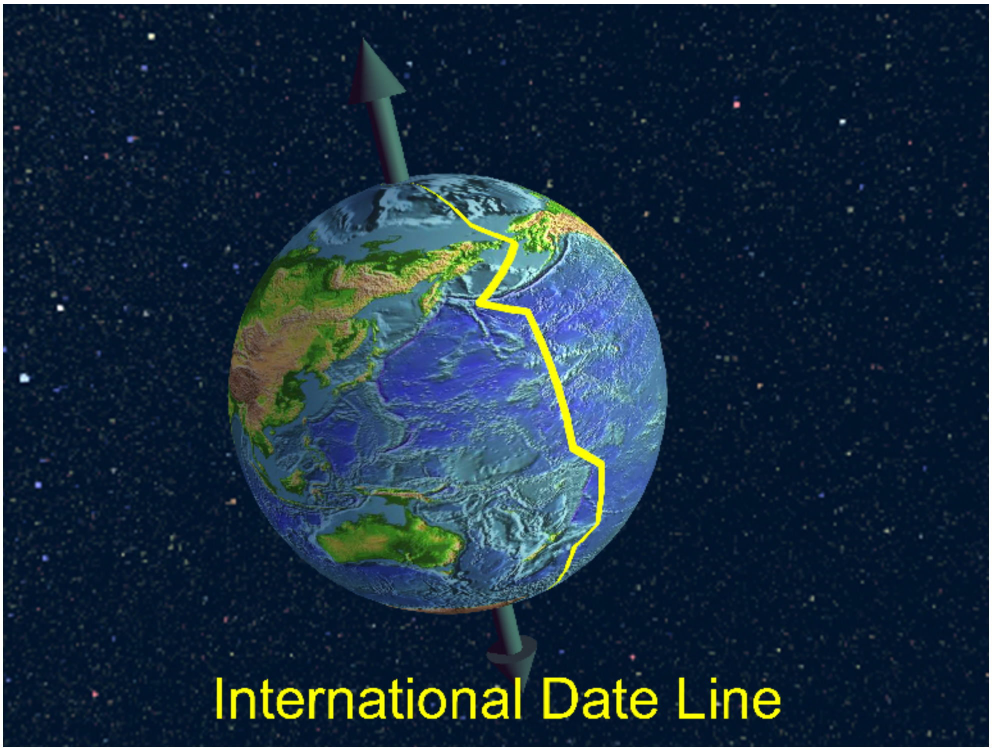
Counting the lines is slightly more complex than Latitude: Since the lines branch from the poles, how do we determine where the counting should "start" from? We need a zero, a point of origin, known as the Prime Meridian. Who decides where it is?

Back in the old days of early exploration, every country had its own idea of where the Prime Meridian ought to be located. Eventually they all got tired of running their expensive galleons up onto the rocks halfway across the world so they all jumped on the bandwagon with the British, who declared that their Prime Meridian, 0º, is at Greenwich. And there it lies to this day.

Except for the stubborn French, big surprise, who finally gave in only 150 years ago and changed their Prime Meridian from Paris to Greenwich.

Starting from that point in Greenwich, the wedges of Longitude count to 180º East or West respectively, where they meet at the opposite side of the Earth at the International Date Line.

As the lines of Longitude approach the poles, they get mashed closer and closer together. Lines of Latitude, however, always remain the same distance apart no matter how close to the poles you are. Thus, the actual counting of distance East to West decreases the farther North or South of the Equator you are traveling. Keep this in mind for chart navigation as well as advanced celestial navigation later on.


International Date Line


Prime Meridian

Basic Latitude Fix:

Beginning with the easiest,

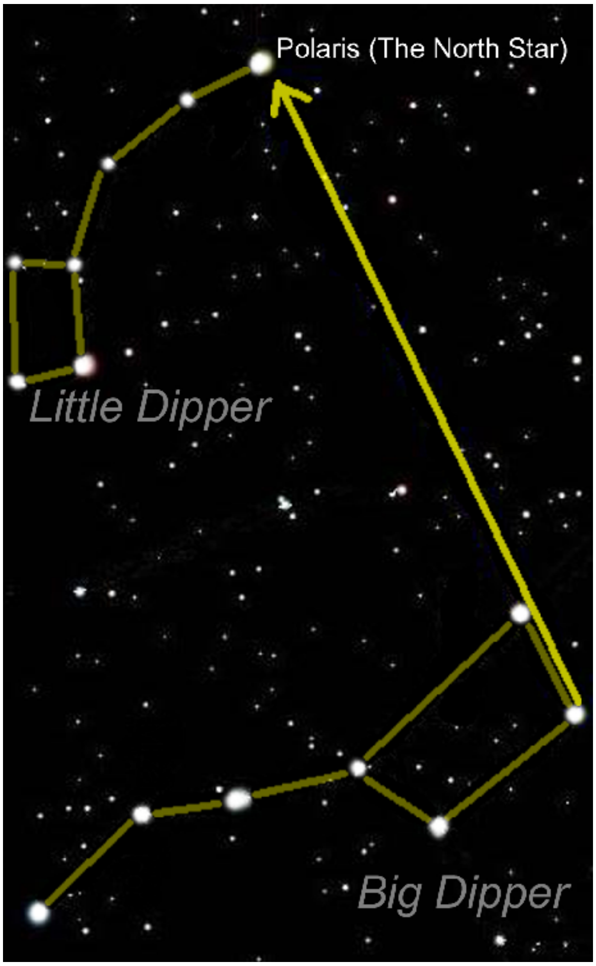
Latitude by Polaris (generic format)

Remember the rhyme Lat is Fat! The sandwich stacking concept might help nail this one into your brain.

Your Latitude, the lines that fatten at the equator, splitting the earth into 'horizontal' discs, is the easiest fix to figure out with a sextant sight. Fortunately, there is a star (Polaris) that is almost perfectly aligned with the polar axis of our planet Earth, and if you can see it, you can measure your latitude. You don't even need to know the time.

You can only do this easy sight, however, if you are in the Northern Hemisphere, i.e., north of the Equator, as Polaris is otherwise hidden by the curvature of the Earth.

The easiest way to find Polaris is to find the end of the Little Dipper's handle. Or, trace a line from the pouring edge of the Big Dipper. Imagine it is pouring a perfect straight line upward (from the bottom to the rim). The imaginary line will run right into Polaris. The Big Dipper spins around Polaris, so be prepared to see the following diagram in any position.



How to find Polaris

To make the most generic of generic celestial sights, line up Polaris with the horizon in your sextant. Add (or subtract) your Index Error and Dip Error, and there you have it. This number is your general Latitude, and should be accurate to an average of 55 miles. This is how they did it in the old days before timepieces, when voyaging ships would travel north or south first, lining themselves up with the known Latitude of their destination, and then sail east or west until they arrived.

But a whole 55 miles of error! Possibly more!?! Well, it's enough to keep ancient mariners from running into most charted islands (give 'er a good wide berth there, matey!), and enough to get them reasonably close to the port they wanted. Beyond that, like Captain Ron navigates, if they needed to know where they were, they just stopped somewhere and asked directions, or skewered the locals with rusty cutlasses until they pointed the way.

Until the age of clocks and Isaac Newton and the Great Geeks of History, though, you were pretty much stuck with Polaris and its potential error margin. Here's why: Polaris isn't 100% perfect. Even though it's closely aligned to the Earth's pole; It has a slight wobble which can be corrected for in more advanced sighting calculations, which we will cover later (If Polaris were attached to the Earth, it would be about 47 miles from the North Pole). But for now, hopefully you understand the basic concept of Latitude by Polaris and how your sextant measures the angle of a celestial object.

Polaris is lined up nearly perfectly with Earth's axis.

The Noon Sight

Longitude by Noon Sight.

Finding Latitude by a star that “never moves” is easy enough, but how do we figure out Longitude when the planet is spinning and there is no object in the sky around our equator that “holds still?” Fortunately for the lost souls of the world, the sun is absolutely guaranteed be overhead once every 24 hours for the next few hundred million years. Well, unless you are stuck at the North or South Pole in winter. Your choice, not mine!

One benefit to the Noon Sight is that you don’t need any Dead Reckoning or Assumed Position (explained later on) in order to build a fix. You can be absolutely 100% lost; so long as you have the correct date and time, you can take a noon sight and un-lose yourself.

Let's give good old Galileo another spin in his grave! It’s much easier to understand just about all of Celestial Navigation if you abandon hundreds of years of science and physics, and think of the earth as the center of the universe, with the sun and stars spinning around it. We’ll speak in these terms to keep it easy.

Every 24 hours, the Sun “orbits” around the Earth one time. The earth is divided into 360º of Longitude. Divide 360º by 24 hours and you find that the sun passes 15º around the earth for every hour. The old guys in funny wigs discovered that if you had an accurate way to measure time, you could find out your Longitude by calculating where the sun passes over. But how do we find the time if noon happens 24 hours a day anywhere on earth wherever the sun is directly overhead (and like Alan Jackson and Jimmy Buffett sing, “It’s 5 o’clock somewhere”)??? We need some point of reference to time things by. This is why, in the beginning, I stressed the importance of having a watch set to…

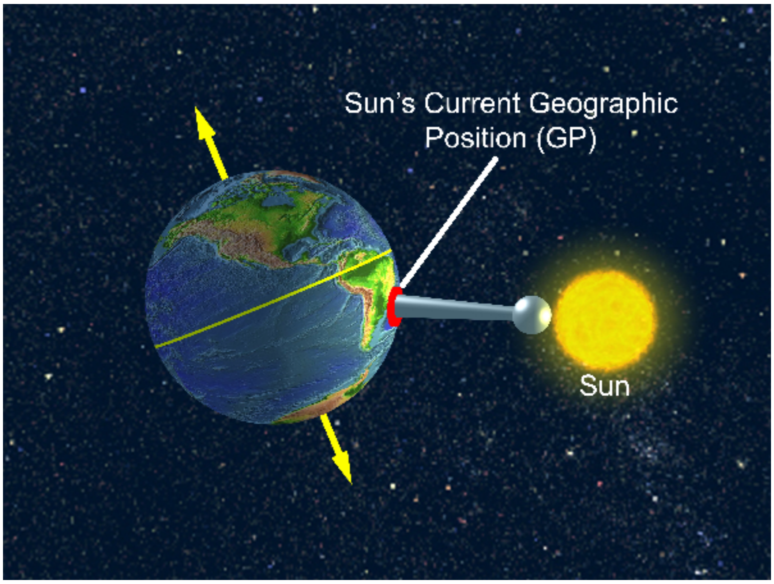
Greenwich Mean Time:

At some point, the old guys in funny wigs decided that the Royal Observatory in Greenwich (London) ought to be that reference point: the standard for true Noon, because hey, if we’re figuring out all this stuff, the center of our observations may as well be right where the geeks are doing the research. It’s not important how or why, really, only that a center point had to be decided and it’s been declared that Noon at Greenwich is “True Noon”. Noon at Greenwich is 12:00 GMT (Greenwich Mean Time). This line of Longitude where Greenwich lies is also called the Prime Meridian, or Zero degrees. On the opposite side of the earth, 180º away or 12 hours of the sun’s passage, is the international date line: 24:00 hours and 0 hours simultaneously.

Other books will tell you all sorts of tricky stuff about calculating time to account for Longitude differences, but it’s all 100% garbage and you can throw it all away if you set a watch to GMT. All your calculations are going to be based on GMT, so why add the burden of extra math? Save your brain!

Geographic Position (GP):

If the sun were attached to the earth on a stick, like the knob at the top of a flagpole, the base of that flagpole would be its GP, or Geographic Position (the actual pole part, for you trivia geeks, is called the Zenith). In our simple Geocentric model of the universe, of course, the sun spins around the earth, so the flagpole's base is going to move. And since the earth is on a tilt and doesn't exactly sit straight, the sun's 'base' will be at different places at different times of the year, different Latitudes and Longitudes. This is why we have the Nautical Almanac—it tells us when and where the base will be at any given hour, minute, and second during the year. This flagpole base/GP also tells us on what meridian (Longitude) Local Noon is, since the sun is at its highest point overhead.



Since we have a base of standard time to go by (Greenwich time), we know the sun was directly overhead there at 12:00 GMT. Now suppose we're halfway across the globe, in uncharted seas, and we have no idea what our Latitude is. We've got a clock set to GMT. All we have to do is find out our Local Noon, and compare it to Greenwich's noon, and the difference will tell us our Longitude.

The Sun isn't the only thing with a GP. Every celestial object spins "around" the earth, each attached to its own 'flagpole', the base of which is that object's GP. The GP of each of these objects for every day, hour, minute, and second can be looked up in the Nautical Almanac.

Finding Local Noon:

How do we find Local Noon? Easy, with the sextant and our trusty clock (which is set to GMT). Using your sextant, start taking sights around when you think noon will be, say, every 5 minutes, for about 30 minutes before and 30 minutes after. Your measurements should rise, then plateau, then begin to decrease again. Your highest sight will be the moment Local Noon occurred (or close enough to it to get a fix within a few miles of your actual location), and should have a time written next to the sight. Now you know your Local Noon.

For figuring out Local Noon, it's not even important what your sextant reading *is*, so much as that you know which time you took your highest measurement. You can do this by measuring shadows if you like. If you're ever marooned on a desert island with a single tree for shade and your GMT watch, you can at least figure out what your Longitude is, so you have something logical to scream out over the empty ocean.

OK, so now we have this sight of the Sun from Local Noon- with angle and time. What do we do with it?

How to break it all down into a Longitude measurement:

The measured angle is not important right now except for knowing that it was at its highest, which marked noon. We'll use the actual measurement later to find your Latitude.

There are two ways to go about calculating Longitude from our current information. Both have their mathematical and conceptual caveats. The fastest way is the method of finding Longitude by time differential, which I will discuss first. The second way, which is slower due to more calculations and more book-looking in the Almanac's tables, is just about as accurate. Both involve learning some brainbending concepts.

Longitude Calculated by Time Differential:

What did your GMT clock say? Let's suppose it said 04:55:30. This means there is a 7 hours 4 minutes 30 seconds difference between Local Noon and Greenwich Noon. It's easier to break it all down to minutes to do the math.

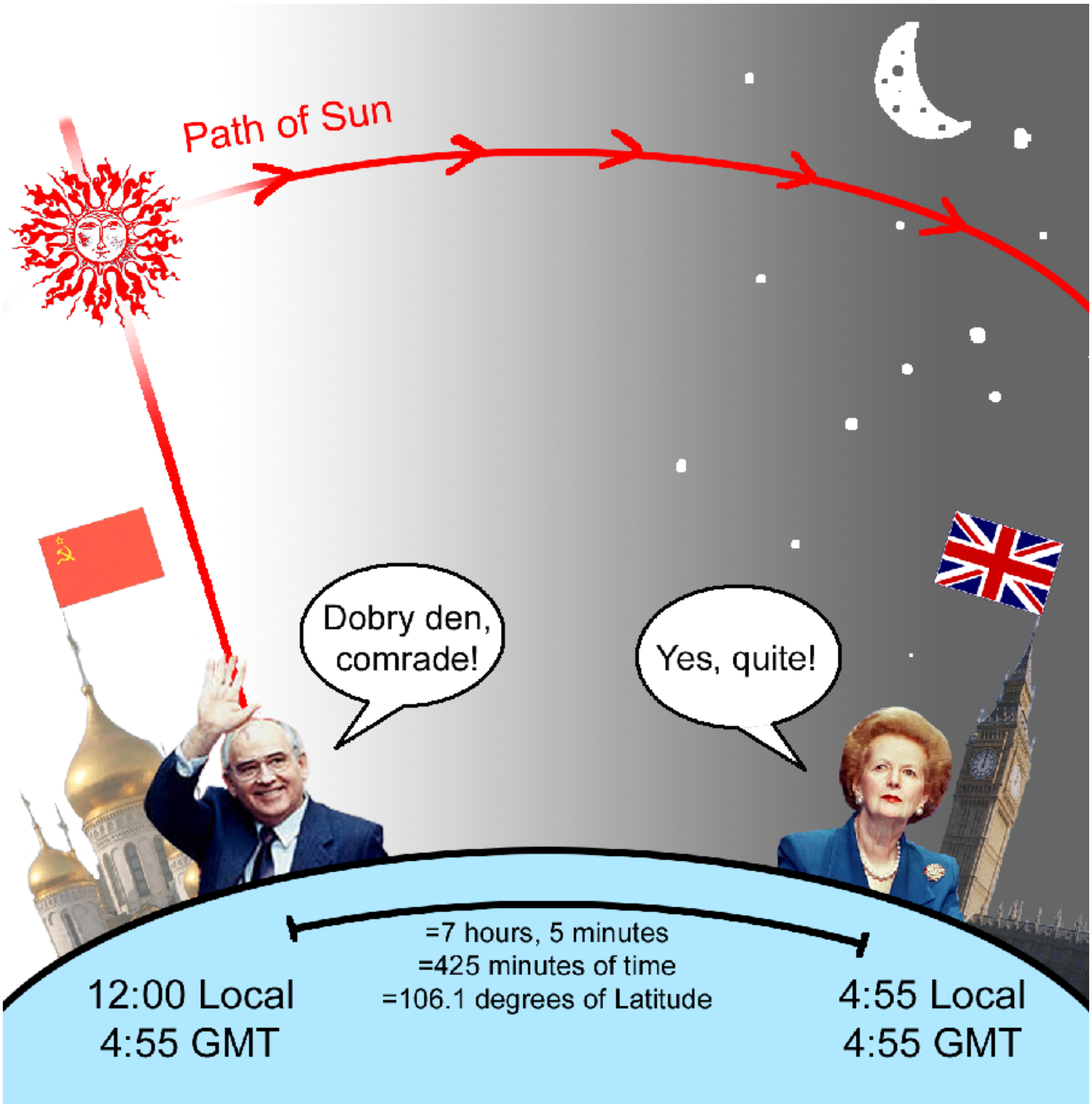
How many minutes away is Greenwich noon?
7 hours = 420 minutes
4 minutes = 4 minutes
30 seconds = .5 minutes.
Total = 424.5 minutes until Greenwich Noon.

Always use GMT Noon as your reference point for noon sights—it's much easier this way! If you took your noon sight *after* GMT Noon, then count backward to find out how many hours it was since then.

The sun passes 15º of Longitude for every hour in orbit.
15º / 60 minutes = 0.25º per minute = 15 minutes of Longitude arc per minute of time

In essence, for every minute of time, the sun travels across the sky 15 minutes of Longitude. Yes, this is a little confusing, comparing minutes of time to minutes of Longitude. Just keep in mind that Time Minutes are not the same as Longitude Minutes. They are not related in any other way than that they share the same name. Those old guys in funny wigs liked to confuse people.

424.5 *minutes of time* **x 15** *minutes of arc per minute* **= 6367.5** *minutes of arc from Greenwich.*
6367.5 *minutes of arc* / **60** *(minutes/degree conversion)* **= 106.125º** *longitude from Greenwich.*
.125º x 60 = **7.5** *minutes of longitude.*



In a logical world, our Longitude ***would*** *come to* ***106º, 7 minutes, 30 seconds****. But it* ***doesn't!*** *Read on to find out why!*

The universe isn't perfect and it's determined to foul up the accuracy of your reading, which can be a long way off. Here's how to fix it and why--

The Equation of Time Correction

"Why are you telling me this NOW?" you ask. Because to understand the concept of Equation of Time, you need to first understand how time relates to the turning of the earth and its measurements of longitude. Which we just covered on the preceding pages. Now for the shocking truth that will ruin your day and make you second-guess the orbital stability of your home planet:

Just because it's noon at Greenwich does not mean the sun is always at its highest point in the sky there. The Earth's orbit isn't a perfect circle; it's egg-shaped. And I hate to break it to you, but the sun doesn't follow you around; he's on his own curved path across the sky and he doesn't care about you. At all. This tremendous cosmic apathy causes noon to shift early or late up to 16 minutes depending on the time of year.

Longitude is, theoretically, sort of set up like a clock. As the Sun "spins around" the Earth, the lines of Longitude tick away. Or so your brain would make you think. Averaged out over the long term, it makes sense. To understand this concept, the easiest way to think of it is that we have a Sun with a split personality. One is the Good Sun, and one is his evil twin, the Mean Sun.

The Story of the Mean Sun:

Long ago in a Happy Land with rainbows and world peace, the Good Sun passed overhead at Greenwich every day at 12:00GMT, without fail. Clocks were set to the Good Sun. Everyone cheered and held ticker-tape parades, beer was always cold, there were real virgins to sacrifice, and life was good and wholesome.

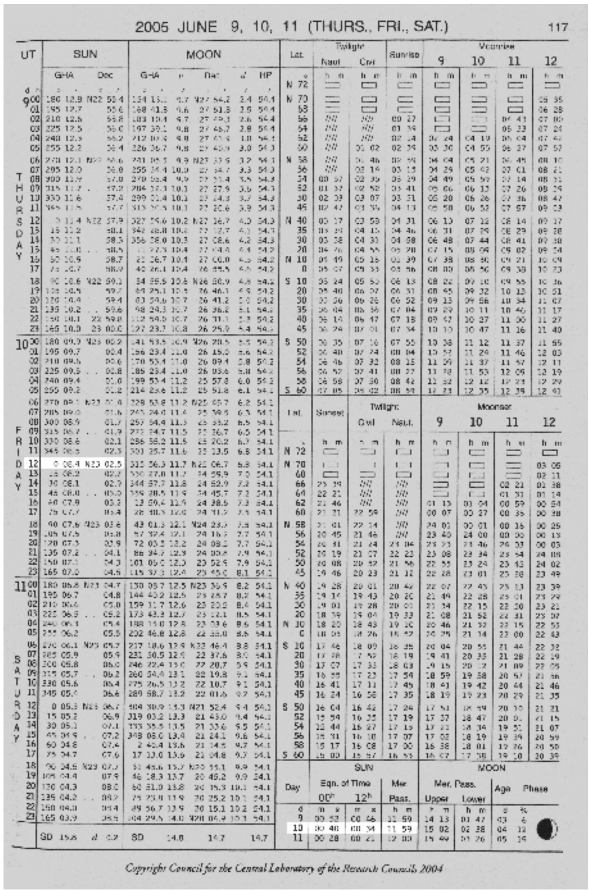
But then evil struck Happy Land! Their leaders invented income tax and the forms to go with it, and spoiled Happy Land for good. The planets fell out of alignment, the Earth's perfect circular orbit became egg-shaped, and the Sun turned Mean! He shaved his head, wore a leather jacket, and became a chronic underachiever: always late or always early, and he only arrives right on time a few days every year. To this day, though, we still keep our clocks accurate in the hopes that the Mean Sun will see the error of his ways and become the Good Sun again. The only consolation is that the Mean Sun's fashionable lateness or earliness is very predictable, and his habits are kept track of in the Nautical Almanac.

Our time is based on where the Good Sun should be. The Good Sun would be the equivalent of a clock. We can't follow that clock around in the sky, though. Cruel reality dictates that when you are finding Local Noon, you're finding the Local Noon of the Mean Sun. Since the Mean Sun is always late or early, and you are following the Mean Sun with your sextant, you will be as late or early as he is too. Naturally this will throw off your Longitude fix.

The Great Geeks of History, in their vigilance to rid the Earth of fashionably late rebels who woo their girls away, have figured out how to shape up the Mean Sun's mistakes and the corrections are in the Nautical Almanac. The Equation of Time correction makes up for the difference in how early or how late our Mean Sun is, and therefore makes up for the fudge in your Longitude. It is measured in units of time, not units of Longitude.

Nerdy notes for geeks: Just as time ticks away perfectly at Greenwich (Greenwich Mean Time or GMT), time ticks away in its own little separate universe for the Mean Sun (called Solar Mean Time, and why his name was changed to "Mean Sun").

Where do I find the Equation of Time?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Let's say today is June 10, 2005. Open your Nautical Almanac to that page. In the lower right hand corner of each page is a small square area with the Sun, Moon, and Equation of Time. We have the date in the left column, and three more columns under the Sun of 00h, 12h, and Mer.Pass (Meridian Passage).

Let's talk about the Meridian Passage first. A Meridian Passage happens when any particular celestial object passes directly overhead (or over your meridian). In this case, the Equation of Time is referring to the Prime Meridian, and what time it was in Greenwich when the sun was directly overhead.

The 00h column displays how many seconds early or late the sun was passing International Date Line. It varies from the Meridian Passage. The numbers may be, and usually are, different. Really. The Earth stumbles drunkenly through the Solar System!

The 12h column represents the difference in time between Greenwich apparent noon and the Sun's real position overhead at 12:00 GMT.

So on the 10th of June 2005, we see that Greenwich's Meridian Passage (Local Noon) is 11:59, the 00h difference is 40 seconds, and the 12h difference is 34 seconds. The sun is moving fast, making it directly overhead early in Greenwich, at 11:59:26 (34 seconds ahead of schedule, like the table says). If the clocks in Greenwich were running 34 seconds ahead of schedule, they might be able to catch the Mean Sun and tell him what a jerk he is for not showing up on time. Thanks to those brainy historical Geeks, we know just how to time it so we can! Our sight time also needs to catch up to the Mean Sun, and this is why the numbers are there in the almanac.

But which of those corrections do we use? 00h or 12h? The difference between the two in this particular example is 6 seconds of time, and that can account for 1.5 nautical miles in error! Well, dear reader, we can easily solve this dilemma.

The logical answer is to use the one that is closer to your actual position (as if you knew what that was-- it's why are you reading this book after all). If in doubt, go by this: If your sight time is between 6am and 6pm, use the 12h adjustment. If your sight time is between 6pm and 6am, use the 00h measurement. If you are right at 6am or 6pm, and feeling saucy, you can average them, in our case to 38 seconds.

Helpful Hint: *Numbers in grey boxes are times when the Mean Sun is late, so you need to subtract from your sight time to slow yourself down. Numbers with no shading (white) are when he is speeding, so you need to add to your sight time to catch up.*

Breaking it Down:

Time: 04:55:30.
+ 0:0:40 (equation of time)
= 4:56:10
How many minutes away is Greenwich noon?
7 hours = 420 minutes
3 minutes = 5 minutes
50 seconds = .83 minutes.
Total = 423.83 minutes until Greenwich Noon.

423.83 *minutes of time* **x 15** *minutes of arc per minute* **= 6357.45** *minutes of arc from Greenwich.*
6357.45 *minutes of arc* / **60** *(minutes/degree conversion)* **= 105.96º** *of longitude from Greenwich.*
.96º x 60 = **57.6** *minutes of longitude.*

Your Longitude comes to ***105º 57.6'***

Now, is that East or West Longitude? If you don't know what half of the globe you are on, you need some serious help. But fortunately, you can still figure it out with simple logic. Your local noon was before Greenwich's noon. Since the sun rises from the East and sets to the West, this means you are in the Eastern Hemisphere, and naturally your Longitude is E 105º 57.6'. Had your local noon been after Greenwich's noon, your Longitude would have been West.

Longitude by Time Differential Review:

1. Take sights until you catch local noon.
2. Find the proper Equation of Time in the Almanac.
3. Apply Equation of Time correction to sight time.
4. Determine local time difference from 12:00 GMT.
5. Convert time to distance.
6. Determine hemisphere.
7. Celebrate!

Longitude Calculated by GHA:

This method works just as well as Longitude by Time Differential, but it requires a few more pages of thumbing through the Almanac and has a potentially wonky math part at the end.

GHA is an abbreviation for Greenwich Hour Angle, meaning the angle the object's longitude represents using Greenwich as its point of origin. Think of it as GHA being parallel to the passage of time, only that it is measured in *360º circular* degrees, minutes, and seconds instead of *time* hours, minutes, and seconds. *(see also page 52 for explanation of GHA)*

However-- it varies from traditional navigation degrees because GHA is measured from 0º to 360º; it does not stop at 180º and start counting back down again like the lines of Longitude. 0º and 360º represent the Prime Meridian; they are the same point as far as measuring GHA are concerned.

We shall use the same sight time from the Time Differential example, 4:55:30 GMT. If you look in your Almanac under June 10, 2005, down the Sun's GHA column, you will see, at 4:00, a measurement of 240º 09.4'. Write this down.

Now the Almanac only displays where the Sun was at exactly 4:00 GMT. We need to account for the remaining 55 minutes and 30 seconds. Flip to the grey-edged pages in the back of your Almanac, and find the page with 55 minutes. At the left side of each minute's column of numbers is a square labeling “55m”. Under it you see an “s” and a column of numbers from 00 to 60. These represent seconds within that particular minute. The numbers across represent the increasing values for planetary rotation for that particular second.

Trace down until you find 30 seconds. Note that the measurement for Sun/Planets is 13º 52.5'. Write this down under your previous GHA Sun measurement. Now we add them together. Remember that every 60 minutes adds another degree so you may have to carry numbers up.

GHA Sun:	240º 09.4'
55:30 correction:	+ 13º 52.5'
=	= 253º 61.9'
= (carry numbers)	=**254º 01.9'**

If this number was 180º or less, you would have your Western Hemisphere longitude already. However since it is greater than 180º we have to do some math. And you cannot simply subtract 254º from 360º and be done with it, because as you count back down from 180º to 0º in the Eastern Hemisphere, the minutes and seconds are also counting down, not up.

Just as our Time Differential calculation represented the time until Greenwich Noon, this number represents the distance to the Prime Meridian. So we need to subtract that 245º 01.9' *from* 360º. This kind of math can be tricky and cause problems because you will be doing number-carry-style subtraction in 2 to 3 columns of numbers:

Prime Meridian:	360º 00.0'
carry numbers:	= 359º 60.0'
subtract GHA Sun:	- 254º 01.9'
=	= ***105º 58.1'***

You will notice this varies slightly from our previous fix of ***105º 57.6'***, a variation of .5 miles. This is considered an acceptable margin of error. The GHA method does have an advantage in that it is generally more accurate than Time Differential.

If we analyze the how and why, 4am is closer to 6am than 12am, so if we had used that averaged 38 seconds worth of Equation of Time in the previous method example, it would account for the 2 second/.5 nautical mile disparity. Close counts not only with horseshoes and hand grenades, but also in Celestial Navigation.

The reason I preach using the Time Differential method as superior is that it takes into account the distance to or from the Sun's Meridian Passage, and the way the math is structured it processes the east-or-west measuring of the Longitude for you. Plus the Time Differential method requires you only find one page in the Almanac. The GHA method only counts in one direction and so needs to be converted at the end if it is an Eastern Hemisphere sight, and the style of math can cause problems in getting it right. In the end it's up to you, I just find it easier to use the Time Differential method.

It should be noted that you do ***not*** use Equation of Time in a GHA sight. The reason is because GHA is a measurement already based on the Sun's position in this case and is for all intents and purposes already corrected for his irregularities.

Longitude by GHA Review:

1. Find GHA Sun on Almanac date page.
2. add Increments and corrections from back of Almanac.
3. If more than 180, subtract from 360º and remember to carry numbers correctly.
4. Celebrate!

That wraps it up for Longitude by Noon Sight. Below is a worksheet for Longitude by Time Differential that will make the work flow much more organized and sensible. Feel free to make copies.

Noon Sight Longitude Worksheet

		Deg/Hrs	Min	Sec		
Working in units of Time:						
	Date					
	Time (GMT) of Local Noon					*in 24:00 format*
subtract		-12	|	|		
	H/M/S difference from 12:00 GMT					*may be a negative number*
			+ -	+ -		
	Equation of Time Correction					*from Almanac (number is negative if almanac box is grey)*
	=					
h/m/s conversion: multiply by 60, carry min & sec unaltered		X 60	X 1	X 1		
		min	*min*	*sec*		
condense minutes		\	|	*/ by 60*		
			min	. *decimal*	=	*total minutes (in decimal form) between Local Noon and True Noon*
multiply by 15			x 15	x 15		
Now working in Degrees:					=	*total minutes of longitude between current position and Prime Meridian*
divide by 60			/ 60	/ 60		
carry secs and mins into Degrees					=	*Longitude of Local Noon (current position)*