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AGENDA

CONTRAST SEMINARS
WHAT IS PRACTICAL?
SIMPLE EXPLANATIONS
BASIC CELESTIAL THEORY
SIGHT REDUCTION HISTORY
THE INTERCEPT METHOD
METHODS OF SIGHT REDUCTION
EASY SOLUTIONS

PRACTICAL CELESTIAL NAVIGATION

CONTRASTING THE SEMINARS

This seminar differs from the first one BASIC CELESTIAL NAVIGATION in that in the former we showed you how to do celestial navigation anywhere in the world, even without any special tools — but you had to plot your LOP or FIX on a globe instead of a chart. You could always transpose the fix onto a chart, but the basic plotting of it had to be on a globe in order to avoid what is known as “Sight Reduction”. This basic procedure is very easy, and in fact we even developed a class program called “Celestial Positioning as an Earth Science Project “— for fifth graders and up!

In this seminar we will discuss “sight reduction” which allows us to plot directly onto a chart. This sight reduction could be considered the classical “hard part” of celestial navigation. It usually involves using tables and filling in sight forms, and is the process that is usually forgotten if one does not use it often. We are going to discuss various ways to do sight reduction — some easy, and some not so easy. We will also discuss some very easy ways to plot on a chart wothout doing ANY formal sight reduction. These methods will be valuable tools for you to use in the future, and will not be so easily forgotten.

WHAT IS PRACTICAL

What do we mean by Practical Celestial Navigation? Practical celestial navigation is a method of position finding that you will REMEMBER. There are several way to teach celestial navigation. One is what is known as the cookbook method. In this, you learn how to fill in a prepared sight reduction form. You learn where to get the numbers that go in the boxes, how to add or subtract the numbers, and how to convert the final answers into lines of position. You need not understand any theory unless you want to. The trouble with this method is that it is not PRACTICAL. It is not practical because it is easily forgotten. Things that are dull and boring are frequently forgotten. Things easy, interesting, and fun are more easily remembered. So this then, will be our approach to practicality. We are going to talk a lot about sight reduction, in a way that I hope you will remember.

We are going to discuss some very interesting nuances (you could call them emergency tricks if you like) that will be so interesting that you will think about them, and maybe even discuss them with friends long after this seminar is over. In addition, I am going to give you a handout covering all the points of the seminar so you can refresh your memory in that way.

SIMPLE EXPLANATIONS

Lets start with an example that happened to me, and will certainly happen to you if you stay with this subject very long. At my very first boat show exhibiting our sextants, I stood in the booth, having an complete knowledge of celestial navigation, and up walks a fellow that looks like he is reasonably knowledgeable. He says “well, maybe its time that I bought one of these”. He picks up the sextant, turns it upside down and looks through the telescope at a light at the other end of the tent. Then he very slowly turns the micrometer drum. I think to myself “what kind of check is he doing that requires the sextant to be inverted while slowly turning the drum?” “He seems to know what he is doing, and has an optical background — maybe in surveying.” Then he puts the sextant down and says to me “what is it?” “W-why it is a sextant”, I say. “How does it work?” he says? Do you mean how does the sextant itself work, or how does all of celestial navigation with the sextant work?” I reply. “Yeah” he says.

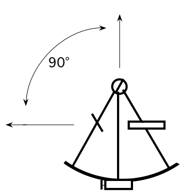
Well, I probably said something like “You look through it and bring the sun down to the horizon. Then you use an assumed position (which may not be your actual position) in order to go into the books to see what your sextant should have read. By subtracting one value from another, you can plot an LOP that you are somewhere on." His eyes glazed over, and he walked away. Now this may not happen to you at a boat show as it did to me, but sure as anything when you get your new sextant home and open it up, your wife, husband, children, grand children or neighbors are going to ask you the same question. "How does it work?" What are you going to tell them?

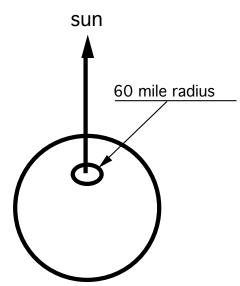
What I tell people today is this: A sextant is a very simple instrument. It has one moving part, the arm, which moves back and forth with a mirror attached to its top end. It has another mirror on the frame, and having two mirrors it lets you see two things at once, kind of like a double exposure, and gives you the angle between them. It could be two people in this room, the top and bottom of a smokestack of known height, or a celestial body above the horizon. It is a simple angle measuring thing. All it does is measure angles. In the case of celestial navigation, the Nautical Almanac tells you where a body (like the sun) is, and the sextant tells you how far out from under it you are. With some simple calculations this can be converted into a line of position for you.

This is a very concise, easy to understand statement that is packed with information. And, I would never have developed it over time, if I had not been faced with the need to answer the simple question posed by my visitor. I would have gone on thinking I was an expert, but not knowing that I didn't have things truely sorted out. So my suggestion to you is that you ask yourselves such questions, and then spend some time thinking about the possible answers.

BASIC CELESTIAL THEORY

Lets say that we are directly beneath the sun. (By the way, we will be talking about the sun as a celestial body, but the same principles apply to the moon, planets and stars. Its quicker to just say "the sun" than to repeat the other bodies too). A flagpole would have no shadow, and the sextant would confirm this by read ing 90° up from the horizon. In this rare case all we would have to do is look up the sun's position in the Nautical Almanac, and that's where we would be! But what if the sun is not directly overhead? Here is the key idea: "if the sun is one degree away from overhead, then you are on a circle of one degree (or 60 miles) radius around where the sun is". If it is two degrees away from the overhead, then you are on a circle of two degrees (or 120 miles) radius around where the sun is, and so forth. The circle you are on is a circular line of position (CLOP). You are not inside the circle, you are on the circle. This is not a fix. You do not know where on the circle you are, but only that you are somewhere on the circle. If you want to know where on the circle you are, you must wait until the sun moves westward, take another observation, and draw another circle. Your position will be at one of the two places the circles intersect. That's the entire theory!





By the way, using a sextant to measure up from the horizon works fine at water level. But a correction called "dip" must be made to allow for the depression of the horizon as your height of eye goes up. There is also a small correction to allow for the refraction of light rays at low angles through the atmosphere.

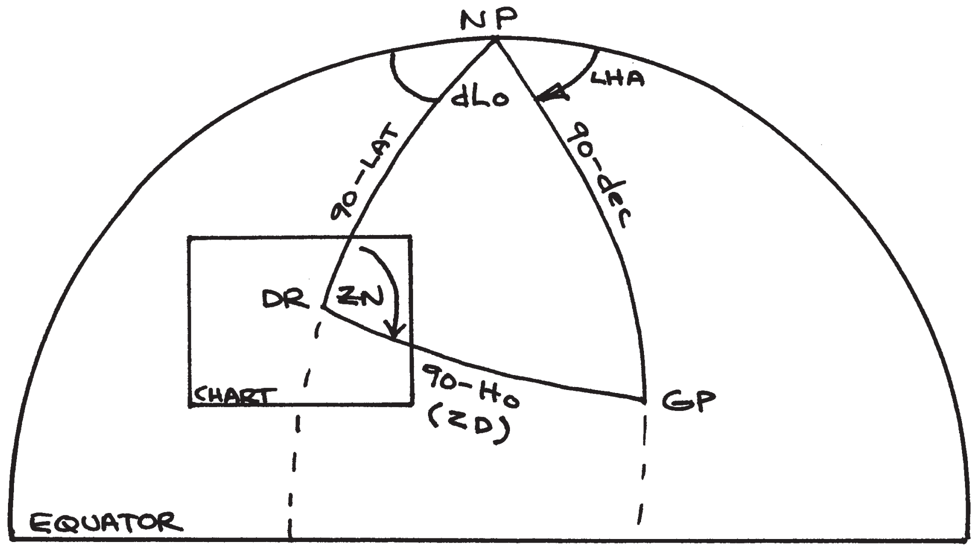
SIGHT REDUCTION HISTORY

Globes The basic idea of any sight reduction operation is to show you how to draw a line of position (LOP) on a chart from a single celestial observation. If you were navigating on a globe you could simply draw the circles we discussed above. But, if you are constrained to a chart there is not enough room to draw such large circles. It is interesting to note that in the 1600s people actually plotted on globes and transposed the fix onto their charts.

Time Sights But for greater accuracy, it is desirable to plot an LOP directly on a chart. So, how do we draw this LOP? Its good that you ask, because until 1837 we didn't know how to draw it. Instead, people used a "time" sight. This was bourne out of the fact that latitude was traditionally easy to find (in ways that we will discuss later). Then when reliable clocks were invented they were quick to use them to find the longitude. They drew the modern celestial triangle, but made different assumptions about it. This triangle is usually drawn in the celestial sphere which contains such exotic astronomical names as zenith, nadir, celestial horizon, hour circles and the ecliptic. But it is just as easy, and just as accurate, to draw the triangle on the surface of the Earth; call it the terrestrial triangle; and avoid much of that language. The triangle is drawn from the north pole down to the point on the Earth directly beneath the sun. We call this the sun's GP, or geographic position. We get this position from the Nautical Almanac which lists the positions of the sun, stars, moon and planets for every hour of each day of the year, in terms of Greenwich Mean Time (GMT). But it doesn't use latutude and longitude, instead it uses the astronomical terms Greenwich Hour Angle (GHA) and declination (dec). GHA is the same as longitude except it goes all the way around the Earth instead of reversing at the dateline. Declination is the same as latitude.

Next it goes from the pole to your position (DR), then finally from the DR to the GP. Even though it is a spherical triangle, which is much different from a plane triangle, we can still solve it if we know all three sides, or any two sides and the included angle.

To do a time sight, the navigator solved the triangle in order to obtain the difference of longitude angle (dLo) at the top. The sides he knew about were as follows: From the pole to the GP the length is 90°-declination. From the pole to our DR latitude the length is 90°- Lat.. The remaining side is measured directly by the sextant and subtracted from 90° (90°-Ho). Once he got the dLo, he subtracted it from, or added it to, the sun's GHA to get his longitude. But remember— he used his DR latitude which was not always accurate. So, what it came down to was "IF my latitude is that,THEN my longitude is this.



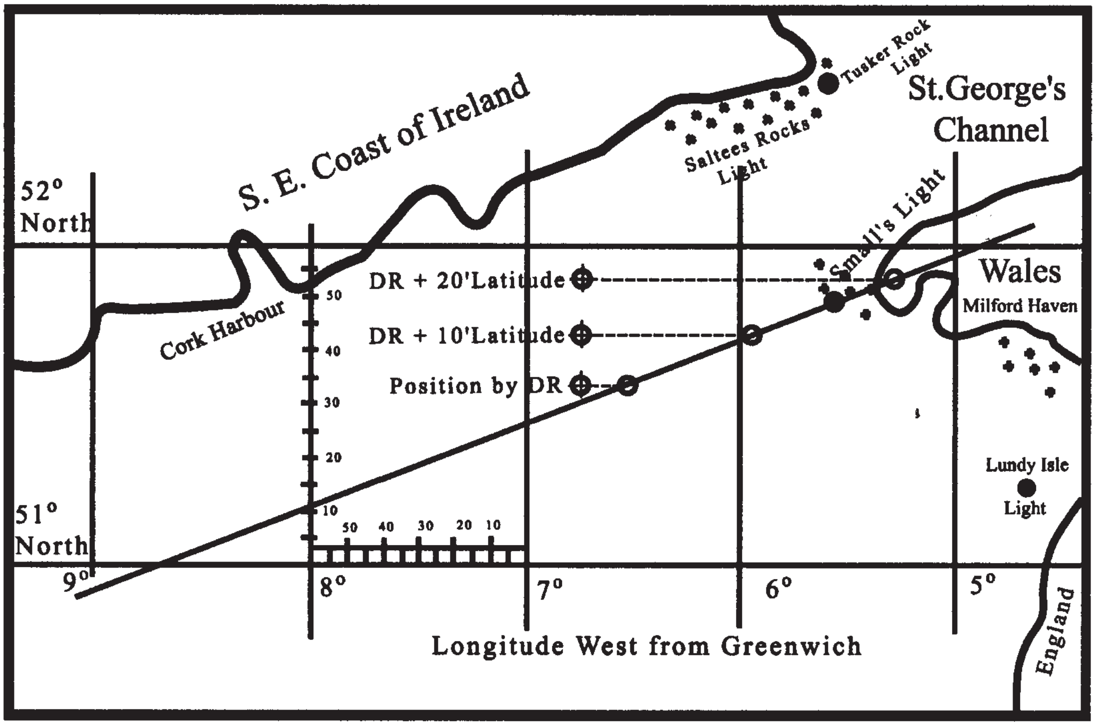
The Celestial (Terrestrial) Triangle

<u>The Sumner Line</u>

In 1837, Capt. Thomas Sumner discovered how to construct a line of position. In his own words, the discovery took place in this manner:

> "Having sailed from Charleston, S.C., 25th November, 1837, bound to Greenock, a series of heavy gales from the westward promised a quick passage. After passing the Azores, the wind prevailed from the southward, with thick weather; after passing longitude 21° W., no observations were had until near the land, but soundings were had not not far, as was supposed, from the edge of the bank. The weather was now more boisterous, and very thick, and the wind still southerly.
>
> Arriving about midnight , 17th December, within 40' by dead reckoning of Tuskar light, the wind hauled S.E. (true), making the Irish coast a lee shore. The ship was then kept close to the wind, and several tacks made to preserve her position as nearly as possible until daylight, when, nothing being in sight, she was kept on E.N.E. under short sail, with heavy gales. At about 10 A.M. an altitude of the sun was observed, and chronometer time noted; but having run so far without any observation, it was evident that the latitude by dead reckoning was liable to error and could not be entirely relied upon. "
>
> However, the longitude by chronometer was determined using the uncertain D.R. latutude, and the ship's position fixed in accordance. This put the ship 9 miles east of the D.R. which was in tolerable agreement; but feeling doubtful of the latitude, the observation was computed using a latitude 10' further north. This placed the ship E.N.E 27 miles of the former position. For good measure, another latitude 20' north of the D.R. was used, which placed the ship another 27 miles E.N.E. It was noticed that all three positions lay in a straight line which also happened to pass through Small's light.
>
> The conclusion arrived at was "that the the observed altitude must have happened at all three points, at Small's light, and at the ship at the same instant of time". The deduction followed that, though the absolute position of the ship was doubtful, yet the true bearing of Small's light was certain, and the ship was somewhere on the line, provided the chronometer was correct. The ship was therefore kept on her course, E.N.E., and in less than an hour Small's light was made bearing E.N.E 1/2E., and close aboard.
>
> The D.R. position was found to be in error by 8' too far south, giving a longitude error of 31'-30" too far west. The result to the ship might have been disasterous had this wrong position been adopted.

As a result of Capt. Sumner's discovery and publication of his method, navigators henceforth solved two time sights at different latitudes for each observation, and constructed an LOP through them. This was, in effect, twice the work of a simple time sight, but yielded a more useful product.



Sumner's First Line of Position

THE INTERCEPT METHOD (Marcq St. Hilaire)

In the late 1800s, a fellow named Marc St. Hilaire made a major breakthrough when he discovered that if you assume a value for your DR latitude and your DR longitude as well, you have the dLo angle by simple subtraction of the sun's GHA from your DR longitude. This gives you side-angle-side of the triangle, and you can solve the celestial triangle for the (90° - Ho) side. Renaming Ho (height observed) to Hc (height computed)You may compare it with your sextant reading (Ho) to get a line of position directly. If Ho is greater than Hc by say 1°, we would go 1° (or 60 miles) toward the body, and draw a perpendicular line.This line is part of the large circle around the body that we could draw on a globe, but not on a chart because it is too small. This is called the "intercept method". The beauty of this method is that it is quick, and works no matter how much your DR is in error.

The equation that solves for Hc is the law of cosines for spherical triangles which is:

$$\sin(Hc)=\sin(dec)\sin(lat)+\cos(dec)\cos(lat)\cos(dLo)$$

So lets put this all together. We have a DR lat and longitude from our chart. We have the sun's GHA and dec from the almanac. The dLo is simply the DR longitude minus the GHA. So, we have everything to solve the triangle for computed height or Hc. Lets say the Hc of the sun is predicted to be 31° at 1030 in the morning. What do we do with this number? We grab our sextant, go out on deck and wait for 1030. Then we measure the actual height (Ho). If this is 31° as its supposed to be, we have no adjustments to make to our DR. But, what if it is 31°-10'. We saw the sun actually higher in the sky (by 10 minutes) than it was supposed to be. So, we must be 10 miles closer to underneath the sun than we thought. So we mark off 10 miles in the direction of the sun and plot our LOP perpendicular to it. Again, this is part of the big circle that we could not otherwise draw on our chart.

And since we solved the whole triangle, we can also get the accurate bearing to the sun (Zn) for plotting purposes by the following equation:

$$\cos(Zn)= \sin(dec) - \sin(lat)\sin(Hc)/\cos(Hc)\cos(lat)$$

But there is an ambiguity: Zn might be 360° - the above value, if Sin LHA is >0
LHA? This brings up the final definition. Local Hour Angle (LHA) is the angle from our position westward to the celestial body. If the body is west of us LHA will be the same as dLo, but if it is to the east, we must go all the way around the world to the west to get it. Knowing LHA is necessary when using sight reduction tables.

METHODS OF SIGHT REDUCTION

Scientific Calculators

All the theory in the world won't help you if you don't know how to put something on the chart. So, what are the best ways to find the needed Hc? There are several ways, but the most direct way is probably to use a scientific calculator (one that has sin, cos, and tan keys on it) and solve the equation directly. Simply write down the values needed ie. DR lat, dec, and dLo, and plug them into the calculator. This is not very difficult, and I urge you to go home and try this. You will need an almanac to get GHA and dec, and the calculator itself which you can buy for under $10.

Concise Tables

There are several such tables that will solve the equation. One such table is actually located in the back section of the Nautical Almanac. There are others listed in our catalog.All of these tables use logarithims to solve the equation, although you are not necessarily aware of this fact. All you know is that you are directed to find lots of numbers that you must add or subtract in order to wind up with the answer.

Standard Sight Reduction Tables

These tables known as Pub 229 or Pub 249 are also called "inspection" tables. They are pre-printed solutions to the equation, which are readily looked up. However, since the equation has an infinite number of answers, only those values of whole numbers of latitude and LHA are listed. This means that you cannot use actual DR values of lat and long, but must use a fictitious "assumed" position in order to have the required whole numbers. This introduces an abstractness to the process which is an impediment to learning and retaining knowledge of their use.

Pre-Programmed Calculators

Various preprogrammed calculators are on the market from time to time that make easy and quick work of sight reduction. They ask you to input sight time, sextant reading, and the body observed. They then supply you with the intercept value for plotting, and if more than one body is observed will combine the LOPs to give you a Lat and Long readout directly.

Computer Programs

These work the same way as pre-programmed calculators

EASY SOLUTIONS

Having enumerated the various methods of sight reduction above, they will admittedly require you to make the ultimate effort of study and practice. You should give some of these methods a try, but remember that you can always go back to plotting on a globe instead. Or, you can use the following methods which allow you to plot on a chart, but do not require formal sight reduction

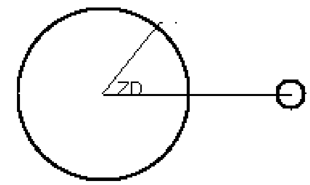
Longitude by Sunrise- Sunset

As you travel in a westerly direction you will notice that the sun rises and sets later in the day with respect to GMT. So, it is a simple leap to say that if it rises for you at 0900 GMT and rises for the folks in Greenwich at 0600, then you are 3 hours times 15° west of Greenwich, or at longitude 45° W. But it is not exactly that simple. You must consider your <u>latitude</u> as well. An example is that in mid summer above the artic circle the sun never sets — but it does for those in Greenwich. To compensate, you need to have the table in the daily pages of the Nautical Almanac which list the times of sun set and sun rise on the Greenwich meridian for all latitudes. Then you can directly convert the time difference to a longitude difference from Greenwich for your latitude, based on 15° per hour. How simple! No sight reduction tables needed. Not even a sextant is needed. By the way the Nautical Almanac also lists moonrise and moonset, so you can do that too!

Latitude by Polaris

As we know, the star Polaris lies almost directly over the north pole. Therefore, however high it is, that's your latitude. Trouble is, it is not exactly over the north pole, and a small correction is needed to adjust its reading. The correction varies from plus to minus 45 miles, and is listed in a handy one page table in the Nautical Almanac. No other sight reduction required.

Latitude by Noon Sun



Sometime before noon (local time), or when the sun approaches due south or north of you, watch through the sextant as the sun climbs higher and begins to level out. As it reaches its maximum height, and begins to start down, note the highest reading taken. First find the zenith distance (ZD) by subtracting the sextant reading from 90° (90 - Ho)Then it is a simple matter to combine ZD and dec to obtain your latitude without the need for sight reduction tables. Draw a circular diagram showing you, the equator, and the sun to see whether ZD should be added to, or subtracted from dec. to get your Lat. Some examples are: if the sun passes north of you then Lat = dec - ZD, and if it passes south of you then Lat= dec + ZD. (Lat and dec are minus values in the southern hemisphere, and + in the north).

The Noon Sight

This is the grandaddy of them all. Many sailors claim to navigate around the world using just this method, and not having to use standard sight reduction methods. Here's how it works. Sometime before local noon take a sextant sight and record the time and reading. Then take a short break and set up to do Latitude by noon sun as discussed above.

After that, re-set your sextant to the earlier reading and wait for the sun to come down to it. Record the time when it does. Now, half way between the first and last recorded times is when the sun crossed your meridian. At that time your longitude was the same as the GHA of the sun as listed in the Nautical Almanac. So now you have both components of your position — latitude and longitude — and all without doing any sight reduction. You can do it on a cocktail napkin!

Stop the World Method

If I told you it was possible to navigate by the stars without having a Nautical Almanac, sight reduction tables, the time of day, and without even knowing the names of any of the stars — what would you say? It sounds impossible, but it does work, and is an excellent way to look at celestial navigation from a different perspective. Its greatest practicality is in giving you a dramatic insight into the beauty of St. Hilaire's intercept method. Here's how it works.

Most of you are familiar with the stroboscopic effect. That's why the flashing light makes the dancers seem to be frozen, or at least to have jerky movements. We check the timing of motors with a flashing strobe which makes the rotating timing marks seem to stand still. Well you can do the same thing with the stars. They move through the sky so regularly that every 23 hours 56 minutes and 4 seconds, each star is back in the same place as the night before. This means that if you laid on the ground facing up, and every 23h 56m 4s you opened your eyes for a moment, the stars would appear to be stationary in space, always in the same place. If you took a round of sextant readings on any of the stars you cared to keep track of (you can give them any names you wish), the readings would be the same night after night, as long as you did it every 23h 56m 4s instead of every 24 hours. The readings would remain the same — unless you moved! If you move between the readings, your movement will be reflected in changed readings — one minute of arc for every mile you moved. If a star's reading increases by 23' for example, then you must have moved 23 miles in its direction. Its handy to have a compass with you when taking readings, so you will know what direction to plot the new line of position. You simply plot a line from your previous position in the direction of the star, measure 23 miles (the intercept) and plot a line perpendicular at this point. This is your new LOP. Do the same for several other stars, and you have a new fix.

An advantage of this method is that it is incredibly easy to do. You don't even have to correct for refraction or dip. Even if your sextant has an error, it won't matter.

The disadvantage is that each position depends upon the previous one, so that small errors may build up to be large ones. If you are on a long voyage, you may find that the original stars are no longer visible at a time when they are useful. Before this happens, you will need to pick some new stars, and take a double round of sights — one for the fix, and one to establish a basis with the new stars.

SUMMARY

Have fun trying out some of these ideas. As we have discussed, the Nautical Almanac does a lot more than just list GHA and dec of the celestial bodies. It gives sunrise, sunset, and moonrise, moonset; and gives corrections for Polaris. Get one of these and a simple basic book on celestial navigation. As you go through the book, you will meet many of the old friends we have discussed here. But you will be way ahead of the game. You will have a previous acquaintance with the concepts, and how they fit into the big picture. As you now know, there are many ways to do the same thing. Pick the ones you like, and go with them. Add others if and when you want.

Finally — the basic questions you should now be able to answer are: (1) what does a sextant do? (2) how does celestial navigation work? and (3) what is the purpose of sight reduction?