THIS SEMINAR WAS GIVEN BY KEN GEBHART
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AGENDA

WHY DO CELESTIAL NAVIGATION
EASY EXAMPLES
HISTORY
BASIC TOOLS AND THEORY
MORE THEORY
MODERN EQUIPMENT
HOW TO GET STARTED

Introduction

Celestaire is the largest sextant seller in world. In taking orders on our 800 number, and exhibiting at six boat shows per year, I have the opportunity to talk to about 4000 people per year about the problems, successes, equipment developments, and innovations in celestial navigation. I am here as a resource to pass this information to you. Remember, the definition of a seminar is “a giving and discussing of information”. So audience participation is very much desired.

WHY DO CELESTIAL NAVIGATION?

The Agenda above is my idea of what you might like to get out of this short meeting. In order to get you warmed up with audience participation, lets start with making a list of all the reasons one may have for learning about celestial navigation. (Some typical audience suggestions are listed below)

Fun
Challenge
License
Back Up for electronics
Verify correct operation of GPS
Life Raft Situation
Maintenance of Skills
Tradition
Impress others
Get job as Navigator

Many of the answers given are discussed on page 2 of our catalog. These are there not to convince you why you should learn this subject, but instead to supply you with responses for your friends who question your judgement in taking up such an antiquated navigational method. Remember — celestial is the only self-contained, stand-alone, absolute, manual method of navigation in the world.

EASY EXAMPLES

What are some easy examples of how we can use the sky for information without getting too deep into the technical aspects?
Finding longitude by sunrise, sunset.
Finding time during the day by the sun’s position.
Using star Polaris to find north.
Using star Polaris to find latitude.
Using the sky as a map to connect one’s orientation to the Earth.

HISTORY

It used to be (before GPS) learning celestial navigation was compulsory to get a commission, license, or just to survive at sea. Students were a captive audience. Being such an important navigation skill, courses and texts were very thorough, and teachers were not reluctant to use mathematical and geometrical derivations to prove the validity of celestial navigation procedures and concepts. People were proud to complete these courses, and perpetuated a high academic level surrounding the subject. A vestige of this thinking remains today in the form of the prestigious “N” given by the U.S. Power Squadrons to successful graduates of their Celestial Navigation courses. Pride in receiving this N means it shouldn’t be easy to get.

By contrast — today’s sailors do not have to be experts in celestial navigation. Just knowing some basics is much better than nothing. And because we are trying to sell sextants, I want to make the subject as EASY as possible.

To do this, lets start by looking at the older, traditional textbooks. The old texts (mine was called Nautical Astronomy, not Celestial Navigation) started with a description of the celestial sphere and its coordinates, located at infinity, and with terms such as ecliptic, hour circle, zenith, nadir, and celestial horizon defined. Next, it showed a triangle in this abstract celestial sphere, and solved for its sides using spherical trigonometry and logarithims. This enabled you to understand how Sight Reduction tables were written.

These tables required you to use a fictitious position instead of a DR. Then, after learning all 57 navigational stars, you were finally allowed to try using an actual sextant. By this time you had forgotten most of the earlier material, so they gave you a sight form to fill in (you thought an IRS 1040 was bad). It required different entries depending on wether you shot the sun, stars, planets or the moon. Typically, a group of student navigators would come up with results ranging from fairly accurate, to being hundereds or even thousands of miles in error.

You know, I think the best games are those that are easy to start and hard to master. In golf, for example, it is very easy to hit a ball off the tee in the general direction of the hole. As of that moment one is actually playing golf, although not very well. There is the putting, chipping, and driving game to master. The duffer with a score in the 150s can get around the course just as well as the fellow who shoots in the 80s. And he probably has more fun because the latter is too worried about his score. Conversely, the game of Tic Tac Toe is easy to start, but is not hard to master. As a result, it has no lasting attraction as a game or hobby.

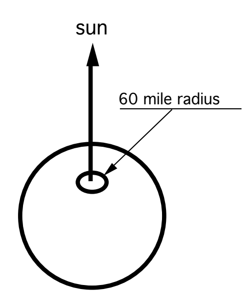
So I introduce celestial navigation in a way that gives immediate results without the math, or difficult phraseology (sort of like hitting the ball off the tee). This is a reversed method of learning — one that begins with using a sextant (or simpler tools as we shall discuss), and working towards the front of the book so to speak.Then we will draw a simple line of position (LOP) using no books, no tables, and no math. You can add skills, techniques and celestial astronomy as you desire to refine your capability. You can quit at any time and keep what you have learned. I am reminded of buying a new VCR. You hook it up and immediately insert a tape to see if it works. You learn to set the clock later — usually much later.

This method has two major benefits: (1) you will immediately be able to use celestial positioning in a way that is interesting, rewarding, and maybe even valuable in an emergency situation; and (2) you will not be as likely to forget the basics of this rudimentary approach as you would one that is preceded by complicated astronomical and linguistic protocol. It is very common to meet someone who learned celestial navigation in the traditional way, but forgot most of it shortly thereafter. (Lets see a show of hands). By the way, there are a couple of chapters that we can remove from the traditional textbooks to make them even less imposing. The concept of time zones has become so commonplace, that a chapter is no longer needed for it. The chapter on chronometers, with care and winding, error rates, and total watch error needed to get the correct GMT is completely overshadowed by the abundance and accuracy of today's inexpensive quartz watches.

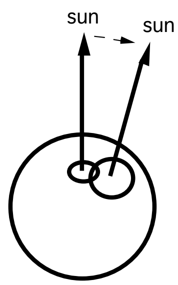
One other aspect bears mentioning — abstractness. The very concept of an earthly position being defined by a sun or star can be difficult to truly understand. I mean you can recite the words, and maybe even explain it to others, but you may still not be perfectly at ease with it. There are two ways to deal with such abstractness: seek new explanations until one finally hits home; or best yet, simply devote some time to think about the bothersome concept. Eventually everything will line up, and the calmness of understanding will be yours.

BASIC TOOLS AND THEORY

Before we begin let me say that for simplicity's sake we will be talking about observing the sun. We do this for two reasons — it is easy to identify, and it casts a shadow. The shadow allows us an additional way to tell were it is and makes demonstrations easier. However, the theory is the same for the stars, planets and the moon. We can tell where we are from these bodies in most of the same ways as with the sun.



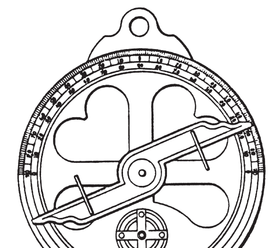
Now how exactly does this thing called celestial navigation work? Lets say that we are directly beneath the sun. And if we knew where the sun was— that's where we would be! When we talk about where the sun is, we mean what point on earth is directly beneath it in terms of latitude and longitude. We call this the sun's geographic position or GP. We all know the sun is 93 million miles away from Earth, but we are concerned with the points that lie beneath it as it races across the surface of the Earth from east to west at over 1000 mph. So, if we are directly beneath the sun we would obviously be at the sun's GP, and it would be a very simple way to get a fix of our position. But how exactly does this work? And how do we know it is directly overhead? And what if it isn't directly overhead? If you have been nodding off up to now it is time to wake up!!! This is the entire theory of celestial positioning in just a few words. If you can accept this one premise, we can bypass a lot of geometry that deals with such notions as "interior angles from the center of earth subtended by parallel rays from the sun, much of the vocabulary of the celestial sphere, and any need for the derivation of the solution of the famous celestial triangle". That's a mouthful, and it is meant to be. Its why this presentation of celestial positioning will be easy for you to understand and, most of all remember. 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.



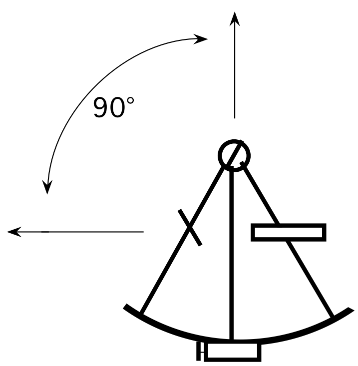
Your position will be at one of the two places the circles intersect. That's the entire theory!

So now to do celestial navigation we have talked about two things: (1) measuring how far away from the overhead the sun is so we will know how big a circle to draw; and (2) calculating where the sun itself is so we will know where to center the circle. If we can do these two things, we will OWN celestial navigation.

Measuring away from the overhead. So how can we measure how far away from the overhead the sun is? The easiest thing that comes to mind is that we could measure the length of a **shadow** cast by you, a flagpole, or any other vertical object. What other tools could we use? Well, if we had a **protractor** or course plotter with a plumb bob (a string with a weight on the end) attached through the center hole; and then sighted the sun along the top edge, the device would read the angle. A handy way to use this device is to glue a small dowel on one end, and a small cardboard square on the other end to serve as a screen to show the shadow of the dowel. Another tool might be the ancient **astrolabe**. This is similar to the protractor except that the whole device hangs on a string, and has a movable sighting vane which can also be used to cast a shadow. With the sun directly overhead, the astrolabe will read 0°. Lastly we come to the marine **sextant.** Aboard a boat, sailors had a hard time to measure shadows since as the boat moved, the shadows changed in length. Likewise the plumb bob kept swinging as did the astrolabe. So, the sextant was developed to measure the angle upwards from the horizon, and to subtract its reading from 90° in order to get the angle away from the overhead. It is very simple instrument with one moving part (the arm), and two mirrors which allow you to see two things at once. The sextant simply gives you the angle between any two things that you see. So, by moving the arm in order to see the horizon in conjunction with the sun when it is directly overhead, the sextant gives the angle of 90° as you would expect. So, now we have 4 ways to tell how far away from the overhead the sun is: shadows, protractor and plumb bob, astrolabe, and sextant. 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.

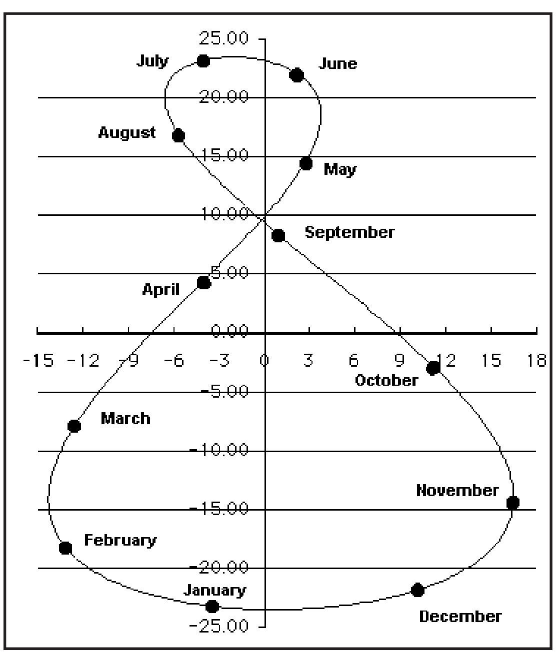


The Astrolabe

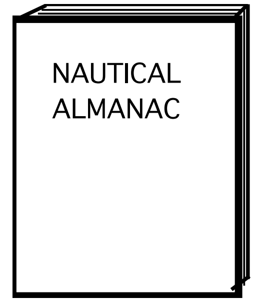


The Sextant

Calculating where the sun is. Well, as we said earlier, if the sun is directly overhead, that's where we are! But where is the sun? A rough idea of the sun's position can be figured in the following way: We know that the sun moves up to about 23.5° N. Latitude in the summer, and down to 23.5° S. Latitude in the winter. If you draw a circle and put June 21st at the top, Sept 23 on the side, Dec 22 on the bottom, and March 21st on the other side, and divide the radius into 23.5 equal parts (for the degrees); you will have a diagram for finding the declination (or latititude) of any intermediate date you construct on the circumference. We call this a **declination circle**. We also know that the sun passes roughly south of Greenwich England at noon, and that Greenwich is at 0° longitude. Since it takes 24 hours to go the 360° around the earth, that works out to 15° per hour. Thus at 1300 GMT the sun is at 15° W. Longitude, at 1400 GMT it is at 30° W. Longitude, etc. The reason you only get a rough idea with this system is that the sun actually goes a little faster during part of the year, and a little slower at other times. This means that the sun is not always due south of Greenwich at noon. Sometimes it is a little east, or sometimes a little west of that direction. This variation has the forbidding name of "the equation of time", and is not as easy as declination to account for. However, it is pictorially represented by a curious figure 8 type diagram shown on some older globes, and usually placed in the Pacific Ocean. It is called an "**analemma**". You might look this up in a dictionary. It has dates printed all over it just like the circle we drew for declination. In fact, the vertical dimensions are the same as for our circle of declination. The difference is that the horizontal dimensions show how much the sun lags behind, or is ahead of its average (or mean) position. So, with an analemma (see yahoo for analemma), you can quite accurately plot the sun's position at any time using simple arithmetic, and without using a Nautical Almanac.



The Analemma



The traditional and simplest way to plot the sun's position is to go to the **Nautical Almanac**. It lists the position of the sun for every hour of every day of the year. There is a minor language problem though— the Almanac gives the sun's longitude as "GHA", and its latitude as declination or "dec". GHA (Greenwich Hour Angle) is the same as longitude except that it goes all the way around the earth, from 0 to 360° instead of stopping at the date line (180°) and reversing as East longitude. Declination is exactly the same as latitude. So, the Nautical Almanac is a straightforward way of finding the sun's position throughout the year. Of course, interpolation will be necessary to find its position in between the hourly listings.

<u>To review</u>: To find out where you are from the sun, you simply carry out the steps we have described.. For example, if you measure that the sun is 30° away from your overhead, do the following things: (1) For the time of observation plot the sun's position on a globe by using using a declination circle, analemma, or Nautical Almanac. (2) Draw a circle on the globe about this point with a radius of 30° (or 30x60= 1800 miles). Bear in mind that using the 30° directly is easiest, because you can measure this directly between latitudes on the globe itself. The resulting circle should go through your true position. You may combine this circular line of position with another to produce a fix position.

<u>An Experiment.</u> When we give this seminar at boat shows in warm climates, we can actually take a break and go outside to measure the length of a shadow of some convenient object like a yardstick. While holding it vertical, someone marks the end of the shadow with their finger. We lay the yardstick down and measure the shadow length, lets say it is 20 inches. Then going to a chalk or marker board we draw a vertical line of 36 inches, and from the base of this line we draw a 20 inch line (if the board is small, you can halve these numbers) We then connect the end points as the hypotenuse, and with a protractor we measure the angle at the top as 30°. Going to a globe, we plot the position of the sun at the time of measuring the shadow length. We usually use a Nautical Almanac but always check that the result is reasonable. For example, near noon the sun should plot south of our position, and its latitude will be north or south of the equator in accordance with the time of year. Next, we take a string and establish the length of it from the equator up to 30° latitude. Holding a dry erase marker at one end, and holding the other end at the sun's position, we draw a circle around the sun's position. We note that the circle goes right through our boat show location.

At each stage of this experiment, we let members of the audience participate in taking the measurements, recording the time, plotting the sun's position on the globe, and drawing the circle. The impact of this is that each person sees how easy it is to perform the steps of finding their position from a simple sun observation, and they are likely to retain it for a very long time.

MORE THEORY

"Wait a minute" you say. "Something isn't quite right here. You've shown how to plot the sun's position on a globe, and to draw a circular line of position around it, but what about doing it on a chart like we normally use? I can see that if the sun were nearly directly overhead, I could draw a circle around it, but what if it were, say, 30° away from the overhead? The circle would have a 30x60 or 1800 nautical mile radius, and that wouldn't fit on my chart".

This is true! But we call this more of a charting problem than a celestial navigation problem. It helps to keep celestial navigation a simpler subject. But in practical terms we cannot avoid coming to grips with the need to plot on a chart instead of a globe. The method needed is called "Sight Reduction". We only care about the part of the large circle that lies near us, and sight reduction lets us reduce the large circle to a segment of the circle that we need. Usually the circle is so large compared to our chart, that the segment appears as a straight line of position, or as we will refer to it in the future, an LOP. There are several ways to get this LOP, among which are: dedicated computers, computer software which will run in a non-dedicated computer, a simple scientific calculator, and the traditional "tables". Although using computer programs are the easiest, they in some way defeat the idea of having a truly manual backup system. So, we will confine our discussion to these Sight Reduction Tables.

There are several kinds of tables, and some have multiple books, each dealing with a different latitude zone of the Earth. But they all work in much the same way. If you will permit me to pretend one of these books could speak to you— it would say this: "Tell me where you <u>think</u> you are; tell me where the sun <u>is</u>; and I will tell you how high the sun should be". Actually, these are called "entering arguments" and how you use them is covered in the instruction section of each book. They are also covered as a separate chapter in all celestial navigation textbooks. They are also the part of celestial navigation which is the most difficult to understand because they tell you not only how to use the tables but also how they were devised — something you do not need to know at the beginning. They are also the part of celestial navigation which is most easily forgotten. Now let's look at what the book is telling us in more detail.

"Tell me where you think you are. " This is simply the latitude and longitude of where we think we might be. It doesn't have to be accurate, just someplace on our chart, not too close to the edge. "Tell me where the sun is." (simply the latitude and longitude of the sun taken from the Nautical Almanac as dec and GHA, or one of the other methods discussed earlier), "and I will tell you how high the sun should be". This is as simple as it sounds. It is called Hc (for Computed Height), and is what your sextant should read if you are where you thought you were. If we told the book our estimated position was the same as the sun's, then the book would give us a computed height (Hc) of 90° up from the horizon.

As we change our estimated position to be farther away from the sun's, the book would give us a progressively lower Hc. What do we do with this Hc? We check it with our sextant (or astrolabe, or other tool). Here's the way it works:

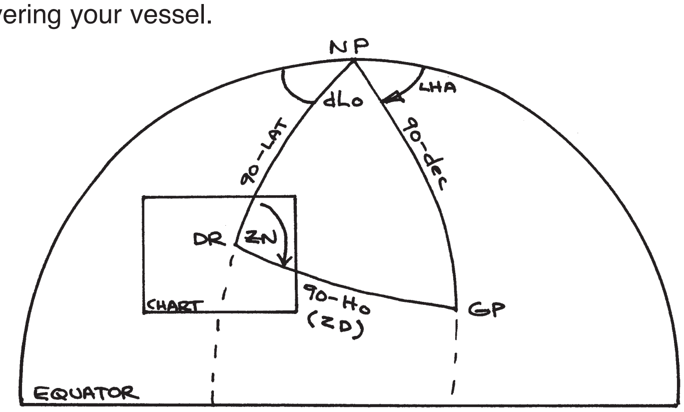
Let's say we give the book our estimated position and the sun's accurate position at some particular time in the future, say at 1030 GMT. The book tells us that under those circumstances the sun should be 30° high. So we grab our sextant, and run outside to check. At 1030 we see the sun at exactly 30° just as predicted! This means that our estimated position was actually quite correct with respect to being on the large circular line of position around the sun, even though we could not draw it on our chart. But what if we saw the sun at 31° instead? Logically, if we see something in the sky higher than expected, we deduce that we are closer to being underneath it. In this case the difference between 30° and 31° is one degree or 60 miles. So, on the chart we go 60 miles towards the sun, and draw an LOP perpendicular to this direction. This is really a segment of the big circle we could not draw on our small chart.

So, now we have solved the problem of drawing the circle (or part of it) on our chart. Sure, there were a few extra steps to do, and we have to learn how to make the entering arguments in the book, but these are just details left for another time. The important thing is that we see how it works, and that it is a very logical system. Even more important is the knowledge that should we not want to deal with this, we can always go back to drawing circles on a globe, and navigate happily (but not as accurately) around the world.

Lets talk for a second about accuracy. There are several corrections to be made such as refraction and dip (or height of eye) if we really want to be accurate. Refraction accounts for the bending of light from a body downward as it enters the atmosphere, particularly at low angles below 30°. Dip is the error you incur because the sea horizon becomes depressed the higher you go above the water. Accuracy to be expected from a metal sextant, and making these corrections is from 1 to 2 miles. Using a plastic sextant degrades this to from 3 to 10 miles. If you use simple tools such as a protractor with plumb bob, or an astrolabe, your accuracy is about 30 miles. Measure the sun's shadow, and plot it on a globe, and you get about a 60 mile accuracy. So what are we talking about here? The difference between a novice using crude tools and a pro with a sextant is 60 versus 2 miles. It is not about being lost! The important thing in navigating is to know what accuracy you are dealing with so you can allow for it in maneuvering your vessel.

MORE THEORY (OPTIONAL)

This part is strictly optional, but just in case you find the idea of the sight reduction books a little bit fuzzy (another word for abstract), this might help you to put it in perspective. It is about how they wrote the sight reduction books! This subject usually takes up a chapter in formal textbooks, and is nice to know. It also contains some language that will impress your friends. It is certainly not something you must thoroughly understand, nor even need to remember. It is the notorious "celestial triangle".



The Celestial (Terrestrial) Triangle

The computed height (Hc) given by the sight reduction tables is merely the solution of a spherical triangle which 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. Next it continues to your estimated position (DR), then back to the north pole. Even though it is a spherical triangle, which is much different from a plane triangle, we can still solve it if we know any two sides and the included angle. The side we want to know the length of is the one between our DR and the sun's GP. The length of this side is the same as the distance in degrees that the sun is away from being directly overhead. Or, if we want instead to measure up from the horizon (Hc), it is (90° - Hc). The sides we know about are the other two. From the pole to the GP the length is 90°-declination (the latitude of the sun). From the pole to our DR the length is 90°- Lat. (our latitude). The angle (dLo) between these two sides at the pole is simply the difference between the two longitudes (the sun and ours). The equation that solves for Hc is the law of cosines for spherical triangles which is:

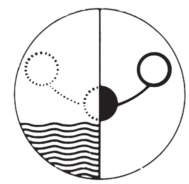
sin (Hc)=sin(dec)sin(lat)+cos(dec)cos(lat)cos(dLo)

Knowing this solution opens up another avenue for you to do sight reduction— on an inexpensive scientific calculator. You may want to give this a try.

MODERN EQUIPMENT

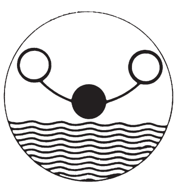
Something should be said about the modern devices which enhance your enjoyment and ability to practice and perform celestial navigation. Discussion of these is rare in existing texts. Foremost among these are improvements to the sextant itself.

Plastic or metal Until about 1985, your choice in sextants was mostly governed by your pocketbook. Inexpensive plastic sextants were available, and made excellent spare or back-up sextants. You could sail around the world with these — if you were good at making frequent adjustments, and were experienced in allowing for their inherent inaccuracies. These were characteristics that trained navigators could handle, but were not always suitable for students. Inaccuracies deprived students of consistent feedback to know that they were otherwise doing everything correctly. Higher quality metal sextants cost 20 times as much as plastic models, which put them out of range for many beginners. Today, inexpensive but good quality metal sextants are available for about 2 to 4 times the cost of plastic models, and are thought by many to be the best “first” sextant to buy.



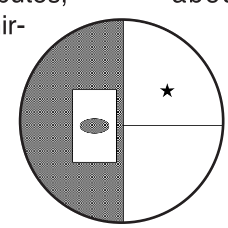
Traditional

Sextant mirrors offer more choices too, with the introduction of the “whole horizon” mirror. Other brand names for this mirror include: univision, allview, transflex, and beam converger; but they all are essentially the same. Since they are offered as options on all sextants you should know how to make this choice. But first, some background on the sextant. If you line up, say, the sun with the horizon, you may notice that if you point the sextant a little higher or lower the whole scene moves up or down as expected, but the sun does not detach from the horizon. The double mirror arrangement of the sextant self-compensates for this motion. It is very good news for boaters that you don’t have to hold a sextant steady to use it! While true for vertical motion, it is not always true for lateral or side-to-side motion. **Traditional** sextant horizon mirrors have silvering on the right side, and clear glass on the left. The silver side reflects the sun or star to the observer, while the clear left side allows the horizon to be seen through the glass. This arrangement requires that the sextant be aimed accurately at the sun in order that the horizon and the sun be seen together. If the sextant is moved too far to the left, the sun appears on the right side and the horizon cannot get to it. If the sextant is moved too far to the right, the sun moves onto the clear portion and is not well reflected. The **whole horizon** mirror replaces the half silvered design with a film on the glass which both reflects the sun’s image and allows vision through the film to see the horizon. Since this shows the horizon all the way across the glass, lateral motion (within the field of view) is now possible. Having both vertical and lateral freedom to move the sextant is appreciated by boaters on a moving platform, and by beginners. A deficiency of the whole horizon mirror is that by using a reflective film you have neither 100% reflection nor 100% transmission of light. Under certain conditions of haze or ambient light, the reflective coating tends to mask fainter stars, so that only the bright ones are usable. Low contrast horizons are less distinct. Although this amounts to a trade-off between good and bad attributes, about 80% of the new sextants sold today have the whole horizon mirror installed. Some sextants allow mirrors to be interchanged, thus hedging against the possibilities of disappointment.



Whole Horizon

Bubble horizons which fit right onto the sextant have long been available for practicing ashore and for inland surveying purposes. Today GPS provides unparalleled accuracy for the latter. Practice requirements are amply met by inexpensive bubbles which attach to most metal sextants, so that backyard observations are possible for everyone .



Bubble Horizon

HOW TO GET STARTED

The aim of this seminar was to show you that this is not a difficult subject, and that it can be taken in steps rather than mastered all at once. To this extent the many books available on this subject should cover anyone’s needs. Please do not think that you need to take a course or class in order to learn this stuff. I personally feel that a class is more of a social experience than a learning necessity, and one that you should avail yourself of only if you are so inclined. Professional seminars are offered periodically, and from what we hear are reasonably effective, although somewhat pricey. Training cruises are quite popular, and we have only glowing reports on these. It is surprising how many community colleges offer courses on celestial navigation. Many planetariums do likewise, and these include the Adler in Chicago, and the Hayden in New York. The Mystic Seaport Museum in Connecticut has an excellent course and I expect other maritime museums may be good possibilities too. Although not in their charter, several Coast Guard Auxiliary units offer courses, and of course the U.S. Power Squadrons offer courses leading to the coveted JN and N awards as we mentioned earlier. Lastly, you may find that a local person may be giving a class in your area, possibly in a chandlery or bookstore. Ask around.