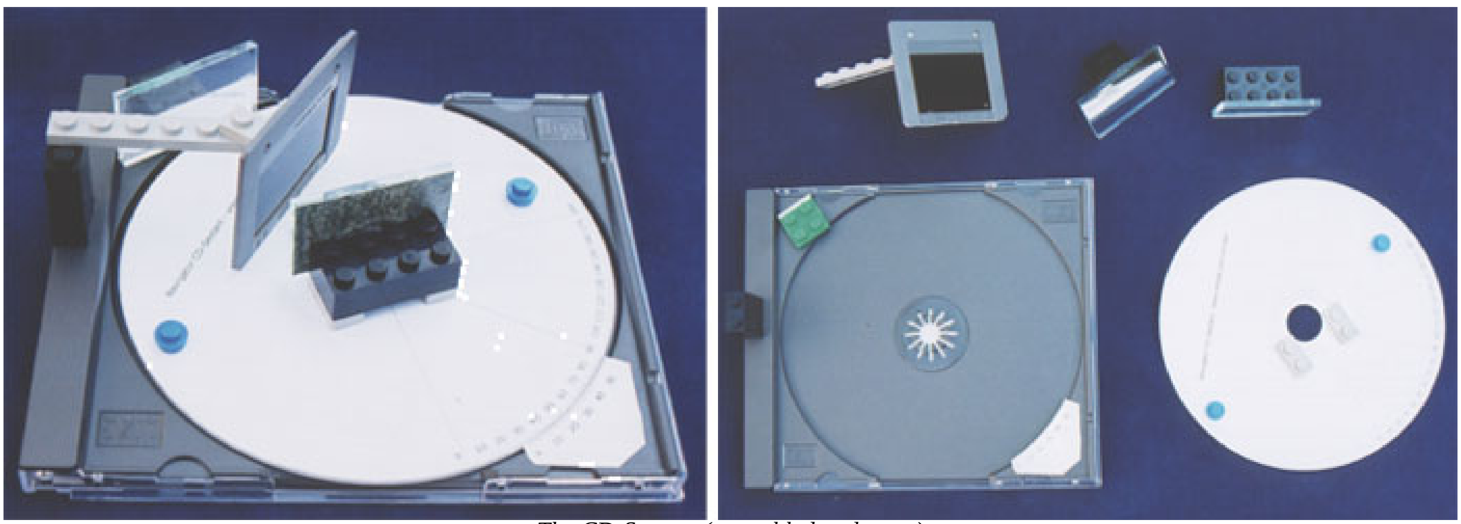
The CD-Sextant

Build your own sextant

One of the obstacles to learn and practice celestial navigation is the price and availability of sextants. Even the simplest plastic models cost between US$ 50 and 150 and can only be found in a few specialized stores, in big centers. This scares many interested people away from celestial navigation.

That's why a few months ago I published the X-tant Project , a "do-it-yourself" octant design. But while that octant is cheap to build, it requires electric tools, some hard to find materials and considerable work.

So I went on to design an even simpler sextant, which I called **CD-Sextant**. This small instrument is built using a CD and box. As in the X-Tant Project, I used a few Lego blocks and glass mirrors. No electric tools are necessary to build a CD-Sextant. It's a good science project.



The CD-Sextant (assembled and parts)

The materials are:

materials

- A CD with box (you can use those free AOL disks).
- A4 Sticker paper (full page, without label cuts. For printing the scale on inkjet or laser printer)
- 2 small glass mirrors (40 mm x 22 mm x 3 mm thick).
- Lego bricks
  - 1 2x4 brick
  - 2 2x1 plates
  - 1 2x2 brick
  - 1 2x2 plate
  - A couple more for the shade support (depends on your design)
- Cyanoacrylate glue (Loctite Superbonder).
- Paper cutter (Olfa cutter)
- Ruler
- Scissors

The design takes advantage of the dimensional precision of CD parts and Lego bricks. The sextant arm is the CD itself and the sextant frame is the CD box. The angle is changed by turning the CD.

Of course the small CD radius gives limited precision to the instrument when compared to larger sextants, but it is enough for celestial navigation practice. Because the instrument is so small, care must be taken in all steps (cutting, sticking etc) to achieve the best possible precision.

The CD-Sextant is not only useful for celestial navigation, but also in coast navigation, using simple trigonometric relations. And it is surprisingly strong (I have dropped mine a couple times, with pieces flying in all directions, and it is still working).

Vernier scale sextants

Minutes of arc are very small and reading them is only possible with a precise scale. There are two kinds of minute scales used in sextants. Modern sextants use a **drum** to trim and read the minutes. One full turn of this drum equals one degree (or 60'). This device requires sofisticated machining to build.

The CD-Sextant uses a **vernier** scale, a simpler but usefull minute scale type. Since the CD-Sextant degrees are small (due to the small CD radius) I used a single 60' vernier (larger sextants usually divide each degree in three ticks of 20').

For more details on **vernier scales click here**.

Printing the Scale

The scale is the most difficult sextant component to do using traditional techniques. Fortunately, most of us have a precise printing equipment right on our desktop: an inkjet or laser printer. These machines can print 300 dots per inch (1200 for laser), with enough precision to print a sextant scale.

Sextant scale printer program

In order to achieve the best results, I wrote a small sextant scale printing program. This will print the sextant scale using vector rendering, for best resolution. This is the same program used in the X-tant project.

XtantScalePrinter - version 1.1 - download **here**

For Windows, 192.874 bytes - This program can be freely used for personal, noncommercial purposes, provided that the credit (name and URL) is not removed from the printed scales.

Mac and Linux users may print this **high definition image** (300 DPI) with similar results.

1) To print the CD-Sextant scale, run the program and check the CD-Sextant checkbox.

2) The CD-Sextant is a vernier sextant (see X-tant Project for more details on Verniers). In the case of the CD-Sextant, the small scale radius makes it impossible to divide the scale degrees into smaller ticks. Set the div/degree property to 1. This will give a scale with ticks only for full degrees and a 60' vernier.

3) Select your favorite font. Use size 7.

4) Press the [Print scale] button.

5) After printing, cut around the scale precisely. Don't cut the CD axis hole yet.

Sticking the scale

Sticking the scale is a critical operation. If the scale is not perfectly centered when you stick, you will probably have to remove it in pieces and print a new one. I did this:

1) Lift an edge of the sticker paper backing, in the scale part.

2) Cut the paper backing edge, to expose a small area of the sticker surface.

3) Position the scale on the CD (use the data side), making sure the scale is perfectly centered. Look against a light source to check if scale is centered in the CD axis hole. Hold the CD and printed scale with both hands, making sure the printed scale is not out of the CD in any side.

4) Once the scale is centered, press the exposed sticker surface against the CD to stick it. This will secure the scale to the CD in the correct position.

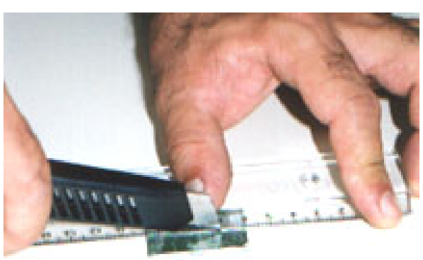
5) Remove the rest of the sticker paper backing and carefully stick the scale, working in one direction, to avoid bubbles and ripples. In the end, the printed scale must be centered and match CD surface perfectly.

6) Use the paper cutter to open the CD axis hole.

Save the printed Vernier. It will be the last thing to be stuck, after the mirrors are positioned.

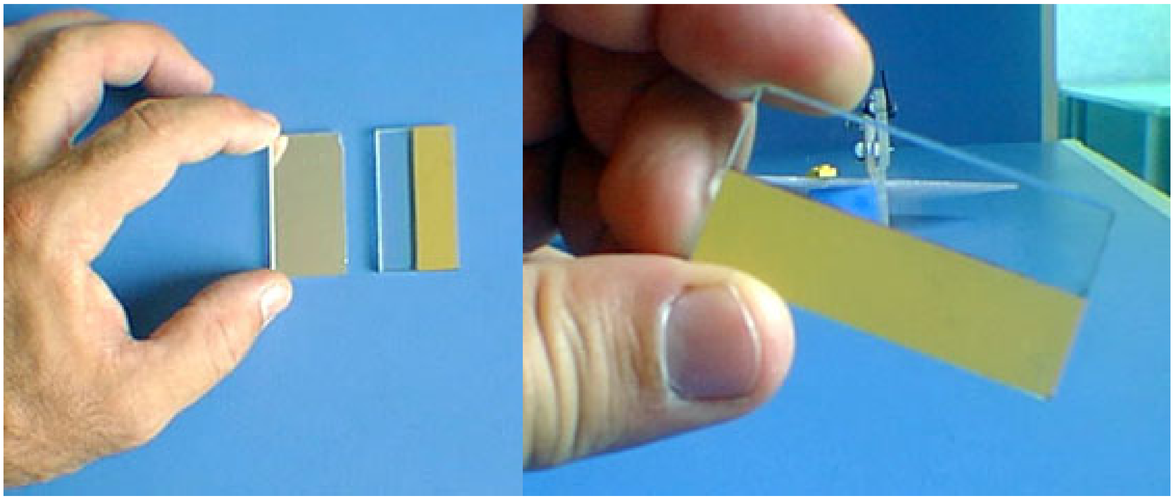
Mirrors

I used 2 equally sized glass mirrors (40 mm x 22 mm, 3 mm tick). Any glass shop will cut these for you. As you know, one of the mirrors must be half silvered. So you must remove half of the mirror silver backing. I used a paper cutter blade for this job (Olfa cutter).



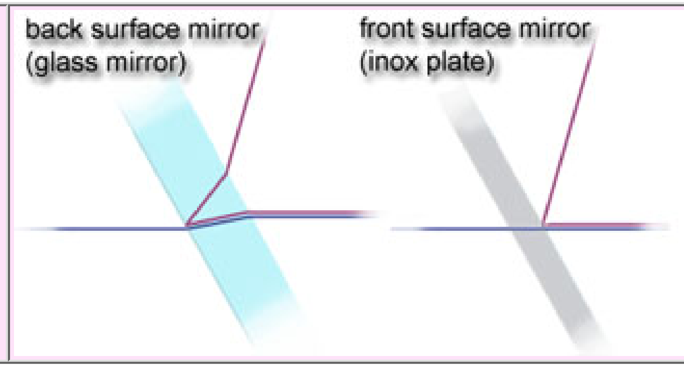
First make a sharp longitudinal cut along the middle of the mirror. Then scratch half of the epoxy protective layer from the back of the mirror, with the blade inclined. The epoxy backing is a hard material, but will come out with patience.

Go easy and don't use any abrasive material or the blade point, to avoid scratching the glass. Once the epoxy is gone, the silver is easy to remove, rubbing with a wet cloth or thin steel sponge (the ones used to clean windows). In the end, the glass must be clear and scratch free (fig. below).



Note: You may be tempted at this point to use a thinner mirror and eliminate the transparent part altogether. Don´t do that. This would introduce a refraction error. The direct (horizon) light ray must pass thru the glass, as the light ray from the star does.

This can only be done if you use a front mirrored surface, such as a polished inox plate.



Mirror supports

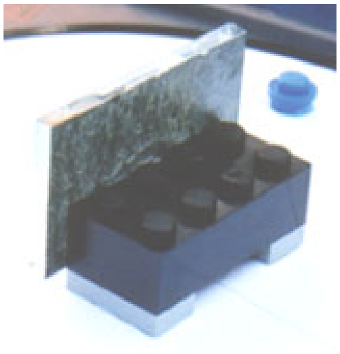
I used Lego bricks to hold the mirrors. They have good dimensional precision and will guarantee a nearly correct 90° angle between the mirrors and CD parts. They will also allow the sextant to be assembled, disassembled, trimmed and parts to be replaced as needed.

Of course other materials can be used if Lego bricks are not available. Try to use dimensionally precise objects, to build the mirror supports with right angles.

Bonding the mirrors

CD Center mirror:

1) Working on a flat surface, bond the center mirror back to the large side of a 2x4 Lego brick. Make sure the mirror is perpendicular to the flat surface.

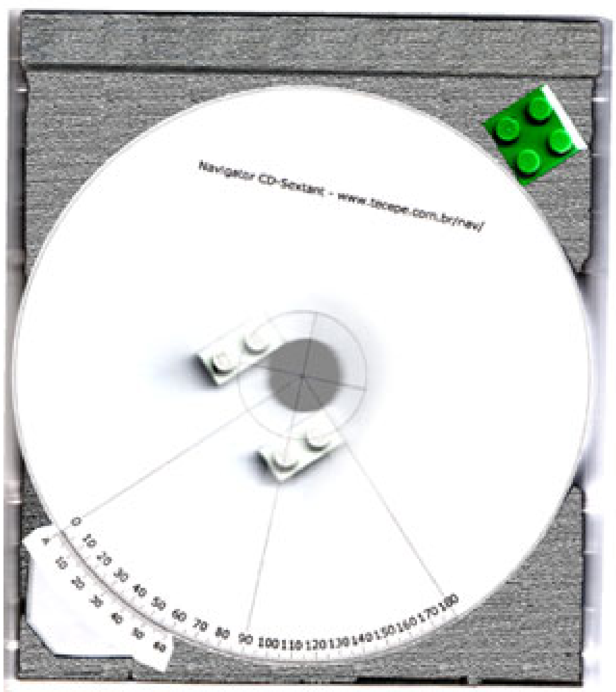


2) Assemble the 2x4 brick over two 2x1 Lego plates (gray ones). The space between the plates will be over the CD axis hole.

3) Bond the mirror assembly to the CD. A few things to watch here:

- Align the the large Lego side to the 180° scale line. This way, the mirror silvered surface (i.e. the back surface of the glass mirror) will be over the CD center.
- Take care to center the Lego plates well. They will be very close to the CD center hole. Don't let them interfere with it.

CD Box mirror (half silvered):



CD-Sextant Layout

> high definition 300 DPI image

I used a 2x2 Lego brick mounted on a 2x2 Lego plate, to hold the CD box mirror. Cut the 4 brick bumps out, because they will be visible thru the transparent part of the half silvered mirror.

1) Working on a flat surface, bond the half silvered mirror to the 2x2 Lego brick. Make sure the mirror is perpendicular to the flat surface.

2) Assemble the box mirror brick to the plate.

3) Position and bond the box mirror assembly in the CD box corner. Make sure that:

- The CD is positioned pointing more or less as shown in the layout to the left, so you will have space to place the Vernier in the other box corner afterwards.
- Place the half silvered mirror assembly parallel to the center mirror. Position it visually.
- Bond the assembly to the CD box.

Sticking the Vernier

At this point, your CD-Sextant is almost done. You must now stick the Vernier in 0° position:

1) Cut the vernier in a triangular form, to fit the CD box corner. I did stick the vernier on a blank sticker paper piece, in order to make the vernier paper ticker. This is important because the vernier edge will be unsupported.

1) Trim the mirrors (see trimming the mirrors below)

2) Turn the CD until the mirrors are parallel.

3) Hold the instrument in observation position, looking thru the half silvered mirror and focus on a far away object. Turn the CD slowly until the reflected image and the direct image coincide. This must be the instrument zero, so....

4) ...Carefully place and stick the vernier in the CD box, reading 0°00'. This means that the vernier tick A most coincide with the 0° scale line. On the other side of the vernier, the 60' tick must coincide with the 59° tick in the scale.

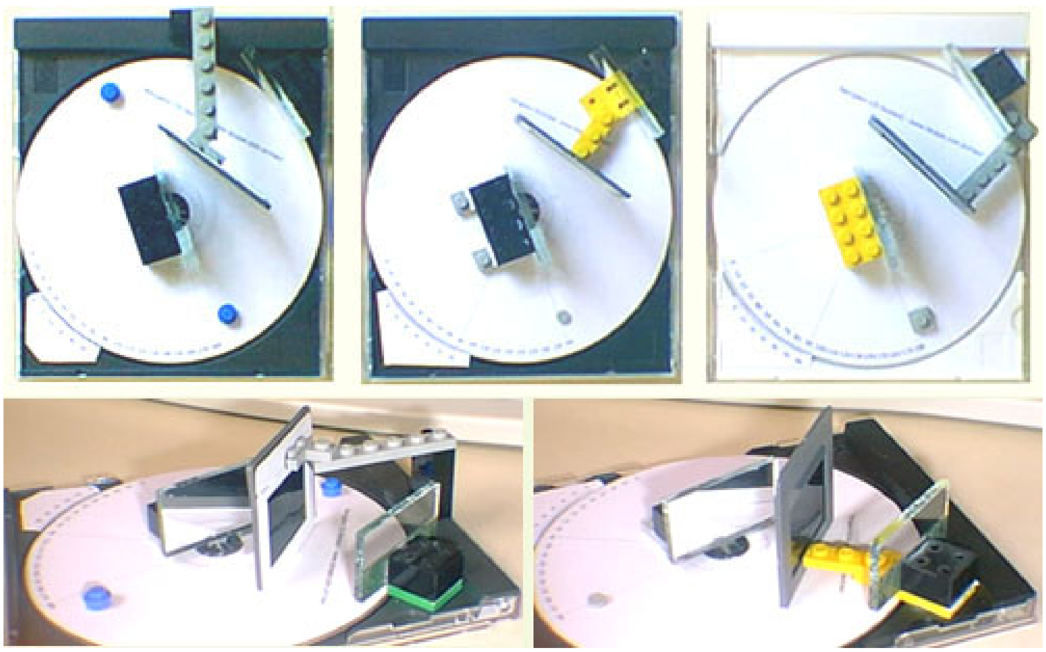
Make sure the vernier and CD scale are very close together. The vernier probably will be a little higher than the CD, and you might want to bend it down a bit.

Shades

The Sun is known to have destroyed many navigator retinas in the past. **Extreme** care must be taken while observing it, to protect your eye. This means your instrument must have a good Sun filter. I cannot guarantee that the design that follows is 100% safe. Tips:

- Make sure the shade is in place before observing the Sun.
- Avoid observing the Sun for more than a few seconds.
- Never stare at it directly.
- If you feel uncomfortable, stop the observation immediately.
- In this case, consider adding some more filter (i.e. one more film layer).

As shades for Sun and Moon sights, I used 35 mm dark negative photography film (there is one in the end of every film roll). The negatives were mounted in slide frames. I used two layers of dark film for the Sun frame and single for the Moon. Both slide frames are removable and are attached to the instrument frame using Lego pieces. I did trim the lower edge of the slide, to make it thinner. The slide window must match the imaginary "tube" formed by the mirror edges.



In the image to the left we have 3 different shade support designs.

The shade must be positioned between the two mirrors and the filter surface must be orthogonal to the line connecting both mirror centers. This is to avoid introducing a refraction error.

Try to position the slide center in the line connecting the two mirror centers. The Sun observation is made by looking thru the half silvered mirror, below the shade.

Trimming the mirrors

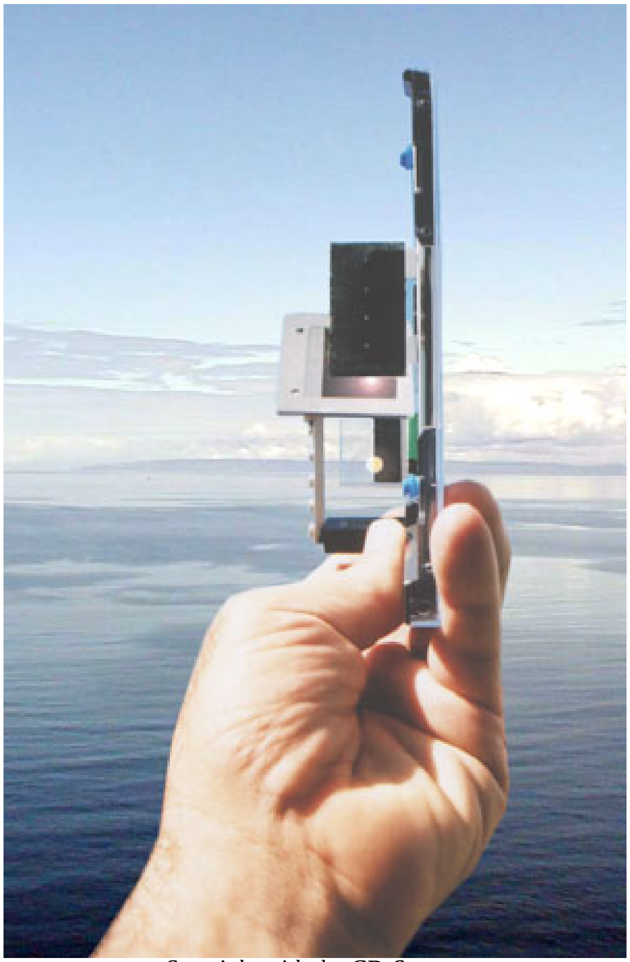
For simplicity, the CD-Sextant is not equipped with screws to trim the mirrors. But the mirrors can be trimmed by inserting small sticker paper pieces between the Lego brick and plates (or by sanding the brick) at suitable positions.

First check the angle of the CD mirror (center mirror). As you look to this mirror, the reflected CD edge must be perfectly aligned with the edge you see outside the mirror (green arrows in the image). This must hold for all directions.

The half silvered mirror can be trimmed by setting the instrument to 0°00', aiming to a far away object and making sure the direct and reflected images coincide.

CD center mirror trim

After this initial trimming, the Lego bricks will hold the trimming surprisingly, even after disassembled. Of course you must read the index error after each set of observations, as with all sextants.



Sun sight with the CD-Sextant

Final touches

Bond a round 1x1 Lego piece to the CD surface, to use as a turning knob (the blue piece).

The CD may be hard to turn. In this case, rub the CD hole with a pencil. The graphite is a good lubricant, and will make turning the CD easier. This is important for fine adjustments.

I made 8 such sextants. I will be publishing test results here soon. Stay tuned.

-x-x-x-x-x-

Bibliography

>> **"The American Practical Navigator "** by Nathaniel Bowditch
ISBN 0781220211 - 1200 pages

buy from **Amazon**

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Navigator SOFTWARE

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Web services

- Star Finder
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- Interactive Sextant

Software

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- Chart Library and links

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- Celestial Navigation
- Using Navigator
- Stars & planets
- Navigator methods
- Build your sextant
- The CD-Sextant

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Cartoon

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> Sextant Corner

The CD-Sextant

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The interactive Sextant - *Flash* movie

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Chart library

Vector charts for the registered edition. **Links** for raster chart images in the Internet.

Navigator for DOS

For old DOS machines and HP LX 95/100 palmtops. Free. Service release 1.3 available.

star finder

your *guide* to the navigation sky

- sky map in any position and time
- stars, constellations and planets with complete positional data.
- specify position or choose one of 300 listed cities
- requires a Java enabled browser
- printer friendly results
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Theory

Celestial navigation fundamentals

English › Français › Português

Identification of stars and planets

keeping the time...

object distances and Lunar calculation.

Navigator calculation **methods**

Practice

How to find your position using Navigator

- Navigator 4 User Manual
- How to find your position using celestial navigation.
- How to scan, import and use existing paper charts.
- Tips for improving results.

Navigator screen shots

Texto em português

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- **Star Finder, for easy star** identification.
- **Meridian Passage** and artificial horizon support.
- **Leg calculator** (Great circle and rhumb lines).
- Print **Nautical Almanac** pages.
- Secure online registration.
- Register, download and install in minutes.
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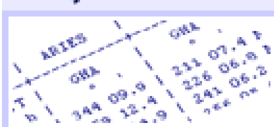
The Online Nautical Almanac



Perpetual online Nautical Almanac

free web service

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Navigator software download

> **Navigator 4** - for Windows 95/98/Me/NT/XP/2000

>> buy **Navigator 4.1 online**

- Check the list of **extended features**

> **Navigator Light free** shareware version 1.0 for Windows 95/98/Me/NT/XP/2000

Note: This is an old 97 trial version which I no longer support. I'm working on a new reduced feature version of Navigator, for free download. In the mean time, use this one as-is or register as a version 4 user (see above). The same goes for the two programs below. Check the known issues

> **Navigator Light 16** free shareware version 1.0 for Windows 3.1 - For older machines...

> **Navigator for DOS** and HP 95 LX - freeware version 1.3 - For even older machines...

Download and installation instructions for shareware versions

1) Download to a temporary directory (p.e. c:\windows\temp).

2) After the complete download, run the program (click 'open' or double click the file in the Windows Explorer) . This will automatically install the software in your system.

Shareware versions features

The shareware versions do all the calculations needed for celestial navigation, including:

- Automatic altitude corrections, including Index Error, Parallax, refraction and height of the eye.
- Full astronomical calculations for Sun, Moon, 4 planets and 56 stars.

- Nautical Almanac calculations, from 1950 to 2050.
- Full information for all celestial objects used in celestial navigation (rise, set, transit and twilights)
- List of visible stars with polar chart. Select the best stars to observe using the mouse.
- Calculation of Lines Of Position (LOP)
- Transport and edition of Lines of Position.
- Calculation of the astronomical position - Your position.
- Easy-to-use user interface.

Navigator 4 registered version features

The registered version includes all features found in the shareware, plus:

- A redesigned Star Finder.
- Chart viewer, with support for vector and raster charts.
- GPS interface - Connect a GPS and plot your position. And save your track.
- Improved celestial navigation. Better meridian passage.
- Automatic LOP transport, when calculating the astronomical position.
- Nautical Almanac pages printer. For navigation in the traditional way.
- Leg calculator, for great circle and rhumb line calculations.
- ChartMaker program, for creating vector charts and importing GIF and JPG chart images
- Extensive printer support. Even if you are not taking the computer on board, Navigator can help you, printing nearly all the necessary navigation data and charts.

>> Buy Navigator 4.1 online

Click **here** for more Navigator details

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Navigator software purchase

Registration benefits - You receive:
1- Latest version of Navigator software.
2- E-mail support for two years.
3- Software upgrades for two years.
4- Many extra features, not available in the shareware version >> read more...
5- No shareware nag messages.

Current version is 4.1 for Windows 95/98/Me/NT/2000/XP

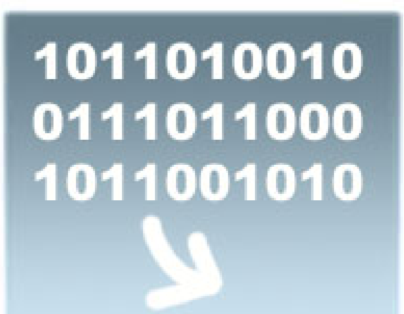
What to expect from Navigator ?
1- Complete celestial navigation module.
2- Powerful star finder for celestial navigation.
3- Useful chart tools, specially for those willing to roll their own charts or scan existing paper charts.
4- Simple GPS interface, to plot the position and save the track in real time.

What *not* to expect ?
1- Navigator is *not* compatible with any commercial electronic chart format. Only the custom vector chart format and popular GIF/JPEG raster image formats are supported.
2- Navigator accepts NMEA GPS messages, but does not implement any proprietary or model specific features, such as waypoint uploads or instrument setup.

2 payment methods:

Online - Credit card, money order and US check registrations. Handled by authorized resellers (RegNow and Celestaire)
Cash Orders via regular mail to the Author - All currencies accepted. See below.

2 media options:



Navigator - Internet download version Software and documentation downloaded over the Internet (a 2.7 MB file).

US$ 35.00 Buy now Register Now

buy from RegNow, an authorized electronic reseller. Credit card, money order or US check accepted. Secure server.

Navigator - Packaged version
CD-ROM and User´s Manual (68 pages illustrated booklet).

US$ 59.95 Buy now

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Notes:
> Both licenses include the same versions of Navigator and ChartMaker programs.
> Single user license. See license details **here**.

Or send **cash** orders to:

Omar Fontana dos Reis
R. Dr Alberto Seabra, 448
05452-000 Sao Paulo - SP - Brazil

If sending cash:
> Wrap securely in opaque envelope.
> Post me an **e-mail** message. I'll email the download instructions ASAP, so you don't have to wait for the snail mail latency.
> Remember to include a card with your name and e-mail address (and regular mail address for the packaged version)
<Please> don't send checks directly to me. If you want to pay with a check, use the online registration above. > All currencies accepted. Use the current exchange rate to USD price.

Registration and installation steps - Internet version

1- Register using either credit card, money order, US check or cash.

2- After registering you will receive an e-mail with the download location (URL) and a registration code. The location points to the Navigator software **installer** file. Click the link start the download. Choose to save the file.

3- Save the file to a temporary directory.

File size is 2,7 MB. 8 minutes, with a 56k modem.

4- After the download is finished, run the file. This will install the software in your computer.

5- Type the registration code when prompted for a password. Proceed until the installation is complete.

6- Remember to backup the installer file (and the password) for future installations. Only the original installer can properly setup the software components on a new computer. No hacking with directories is recommended.

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Contacting the Author

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R. Dr Alberto Seabra, 448
05452-000 Sao Paulo - SP - Brazil

Bug reports

Please report bugs in this form. This makes sure that they get "in" the system.

In order to identify and correct the bug, I need to reproduce the problem here. That's why it's important that you give a full description of the conditions and test data associated with the problem.

Feedback/Bug Report form

Your name :

email address:

Navigator version: * choose one

Windows version: Windows 95

1) Feedback text or ..
2) Bug description and test data:

Send

About the author

My name is Omar Fontana dos Reis. I'm 43 years old and live in São Paulo, Brazil. I'm married to Monica and have two kids: Raul (5) and Renato (3).

The dog in this 1996 picture was called Tonel. After a friendly life, he passed away. I have another now called Rex , a very funny B&W Border Collie.

I'm a mechanical engineer, graduated in 1982. But have been programming PCs since 85, mostly software for the financial information market.

I'm partner and chief developer of Enfoque Sistemas Ltda, a real-time financial information company. I also write airport information software.

this is how I would look, if I tried to climb the Everest...

I sail since I was 16. Started with a Hobie Cat 14'. Currently I sail Laser and J/24 in Ubatuba, SP. Also enjoy drawing.

I Started the *Navigator* **project in 1992, first as a hobby. The first version was for DOS and old HP LX palmtop computers, still available for download.**

In 96 I started this website, after translating the Navigator to English and Windows, the globalization languages.

I enjoy communicating with users. You are welcome to e-mail me telling how you use the Navigator (fun, navigation, training, educational tool), what features should be added, removed or changed. And bug reports, of course.

I apologize for English errors, which - I suspect - are present in most of my texts. I would appreciate any error report or clarification request.

I hope this web site and software have increased your knowledge and interest for navigation.

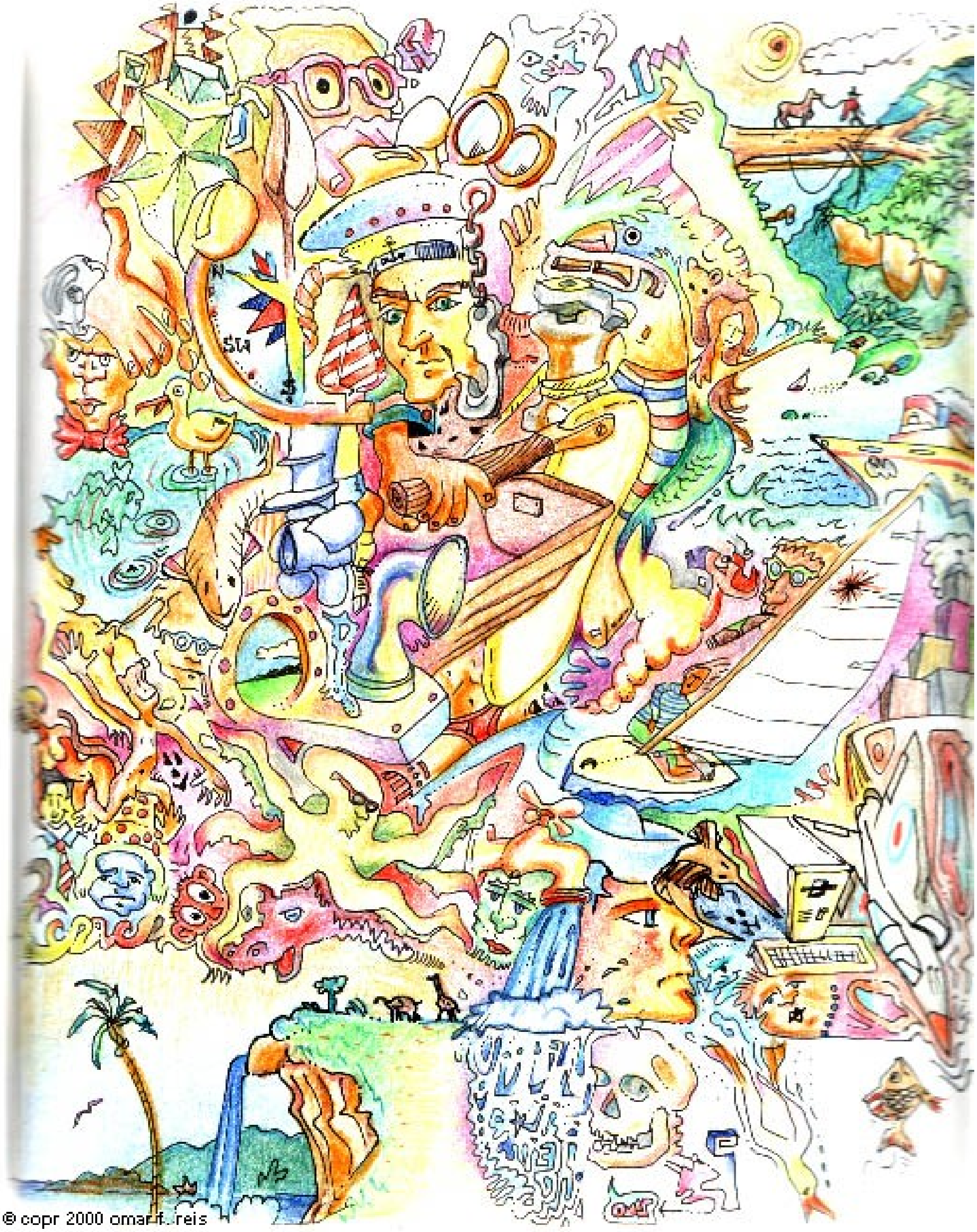
Why Celestial navigation ?

Many people ask me "why do you care about celestial navigation, an obsolete technology ?" - Mostly for the fun. And it is a niche software market, not in the sight of larger software companies.

And why should you care about celnav ? Of course the GPS system is great. In fact, it is the single most important navigation technology of the 20th century. It' s very precise and reliable. But still, there are a few reasons to know celnav, if you are going to high seas:

- **If you love the sea, you probably like that no-strings-attached feeling. And GPS dependency is a huge string.**
- **Celnav is fun and will bring you closer to the Nature and other navigation concepts.**
- **Some areas may sometimes be subject to GPS jamming. Remember that GPS is a great service but is also a military system.**

Another common question is "how much conventional celnav one must know to attempt a large passage? At least the meridian passage, which is simple and requires a single table.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Navigator Star Finder shows the celestial bodies used in celestial navigation (most visible stars (56) and planets (4), Sun and Moon). For more details on calculations and abreviations, check the FAQ. For a more powerfull celestial navigation application, visit the Navigator software website. Access to this service requires a Java enabled browser.

Choose a city from one of the listboxes...	..or input your position. In this case, follow these examples:
Africa: * choose Americas: * choose Asia: * choose Australia: * choose CIS(ex USSR): * choose Europe: * choose Middle East: * choose Pacific: * choose	• Lat: for **23°45.6'N** type **23.456** (use negative values for South) • Lon: for **53°35.2'W** type **53.352** (use negative values for East) Latitude : 00.000 Longitude: 00.000
Use GMT time in the format "hh:mm:ss" GMT Date (dd/mm/yy): 3/9/2004 GMT Time (hh:mm:ss): 06:04:50	☐ Printer friendly Submit! Clear

e-mail **Navigator Star Finder 2.0 ©Copr 97-2k Omar Reis**

The Online Nautical Almanac

Navigator SOFTWARE

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This service generates "Nautical Almanac" like daily pages.
Date range: between 1950 and 2050
Parameter: initial date of a 3 day period.

Generated data includes:
- Star position table (SHA and declination).
- Sun and Moon hour tables, complete with increments and Semi diameter.
- Planets hour tables, with increments.
- Aries hour table.

A few tables are **not** included:
- Twilights, Sun and Moon rise and set.
- Sun E.T. and meridian passage.
- Moon meridian passage, age and phase.
- Correction tables (yellow pages) - Tables from an old Almanac can be used instead.

While not intended to substitute the Nautical Almanac, this information is enough to do celestial navigation using the traditional methods.

Other celestial navigation stuff in this site:

> Navigator Software - Theory and practice in celestial navigation. Software for Windows.

> Navigator Star Finder - Polar chart of the sky in a given time and position.

Questions? check Online Nautical Almanac tips

Date [mm/dd/yyyy] : 09/03/2004 Go get it

Navigator Light® Almanac Pages
http://www.tecepe.com.br/nav
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Navigator 4.1 user manual

Table of contents

Celestial Navigation links

1. New to celestial navigation? To understand how it works, go to the **Fundamentals** page.
2. Other Navigator **screen shot**
3. Navigator software Homepage

Version 4 new features

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Version 4 of the Navigator software has many new features and improvements.

In the celestial navigation side, I implemented several features suggested by users and Brazilian Navy School officers. I'm proud to announce that the program was adopted by this school, for use in celestial navigation classes.

These are the new features:

Star Finder
The star finder was improved, particularly the printed results.
> Now the star chart and table are printed in a single sheet of paper.
> Boat course indication, for easy orientation.
> Improved celestial object identification in the chart . Now all planets have their own icons, for easy identification. The most visible stars (mag<3.0) are also indicated by a larger star icon.

Celestial Navigation
> Checkbox do select/deselect LOPs, for Astronomical Position calculation. Now you don't have to delete a LOP that is either wrong or nearly parallel with other LOP. Just deselect it and recalculate the position.
> Automatic LOP transport. In the prior versions, to calculate a running fix, it was necessary to transport each LOP by hand. In version 4.0, you can specify the boat course and speed; and the LOPs will be automatically transported (either to current time, LOPs mean time or last LOP time) when calculating the astronomical position. This feature makes calculating running fixes as easy as normal twilight positions.
> Better Moon position calculations (version 4.+).

Chart Navigation
Perhaps the most dramatic usability improvement is in the chart navigation area. For a long time I have been looking for a way to import electronic charts into the program's chart viewer. I have considered many "popular" electronic chart formats, but was always confronted with same problems:

- Proprietary formats - Most electronic chart formats in use today are proprietary, and there is little or no documentation on how parse these chart files. Many chart vendors sell charts and viewer software, and are not interested in releasing chart format documentation.
- Low availability and high price - Electronic charts are sometimes more expensive than printed versions and not available for all areas in the world, as printed charts are.

For the reasons above, I choose to implement plain raster chart import directly from popular image formats (.bmp, .gif and .jpg). This has the following advantages:

- Scanners today are very cheap. One can buy a good A4 page scanner for less than US$100.
- Gif and jpg are very popular image formats in the Internet. There are many charts available in these formats on the Internet.
- Most users already have paper charts on the areas of interest. That is, they have already paid for the license to use these charts.
- Some satellite images can also be used .
- Allows the flexible 'do it yourself' approach.

Also:

> Fixed strange chart scrollbar behavior.
> Changed the help format from Windows help to html.

The access window

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Both **Navigator** and **ChartMaker** programs have access windows. These are the main menus of these applications. From the access window you choose the module you want to work with.

For **Navigator** you have the following options (buttons):

- Chart Navigation
- Celestial Navigation

- Star Finder

For **ChartMaker**:

- Make vector chart
- Import chart image

Take some time to read the License Agreement and disclaimer (click "important information"). Closing the access window will terminate the program.

Chapter 1 - Celestial Navigation

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The goal of the celestial navigation is to find the **astronomical position**, the position of the boat. In this section we will see how this can be done with the help of Navigator software. As we have seen in the fundamentals, crossings of two or more Lines of Position, taken for two or more celestial objects, define this position.

Preparing the sky

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But before you start taking altitudes of celestial objects, you must be able to find them with the sextant. Trying to find a star with the sextant on a rocking boat is not easy The eyepiece has a relatively small angle of view and the sight is twisted by the sextant mirrors.

One technique to find a star is to turn the sextant upside down, point it to the star, and bring the horizon by adjusting the arm.

Better yet is to know the approximate altitudes and azimuths of the stars you are going to observe. This is known as **preparing the sky**.

The twilights

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Navigators wake up early. They do so to take advantage of the two times of the day when the sky is in best condition for celestial navigation: the **twilights**. In the civil twilights - times when the sun is 6° below the horizon - it's dark enough to see the stars and planets, and light enough to see the horizon. This happens before sunrise and after sunset.

The first step of the sky preparation is to determine the time of the twilights.

To calculate the times of twilights do:

- Select the **Sun** in the celestial objects listbox.
- Set the date of the observation. Since you are probably going to prepare the sun in the night before, set the date to the following day.
- Set the assumed position (Latitude and Longitude). It's the position you think you are going to be in the time of the observations.
- Select the tab "Other calculations"
- Press "Object data" button.

The last two lines show the time of twilights. Like this:

```
dawn civil twilight: 9:13  GMT
Set  civil twilight: 20:46  GMT
```

Selecting stars and planets

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Now that we know the twilight times, you can select the celestial objects you are going to observe. At any time, **Navigator** gives you more than 33 celestial objects to choose from. Of course you will only need 4 or 5. To select stars and planets you will observe, follow these guidelines:

- Select stars and planets that you are most familiar with.
- Select the brighter objects. Planets are easier to spot, because they are very bright. Some stars are also very bright and easy to find. Some constellations have distinct look and are easier to locate.
- Select objects with altitudes between 30° and 60°. Less than that you result in greater atmospheric refraction error,

which is not easy to correct (because it depends changing on atmospheric conditions). And altitudes higher than 60° are more difficult to measure.

- Do not select stars that have similar azimuths or that are in opposition. The resultant Lines of Position will be nearly parallel, which is undesirable.

To **prepare the sky** do:

- Set date and twilight time of your next observation.
- Set the assumed position (Latitude and Longitude).
- Select the tab "Visible stars".
- Press the "Calculate" button.

Now choose the stars in the spreadsheet or chart. To see the name of star in the chart, click the mouse over it. The name will show in a "hint label". Or select the star in the spreadsheet. A circle will show around the correspondent star in the chart.

If a printer is available, Navigator can print a convenient sky preparation (one page), with visible objects table and polar chart.

Input tip: When unsure about how to enter a value (date/time format, number format or number unit), place the mouse cursor over the input box. A hint will show with the field name, input format and/or example.

Taking altitudes

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Now lets take the actual measurements. Take the following items to the deck of the boat:
1) Sextant.
2) Watch.
3) Pencil.
4) Paper with your sky preparation. Attach the paper to a board, so it's easy to take notes and your work will not be carried away by the wind.

Try to establish a routine to handle these items. You will be observing two numbers (altitude and time) at once, possibly on a rocking boat, so don't let these items make things difficult in the critical time. You might want to use preprinted tables to organize your data, like the one below. Save them as the documentation of your work.

Date:		twilight time:		assumed lat:		assumed lon:		
index error:		watch error:		time zone:		Obs:		
celestial object		**sky preparation**		**observations**		**results**		
LOP	**Name**	**Altitude**	**Az**	**Time**	**Hi**	**Delta**	**Dir**	**Az**
1								
2								
3								
4								
5								
6								
Astronomical position for ____ LOPs				Lat:		Lon:		

-> Click here to open this table in a new window, to print some copies

When taking an observation, set your sextant to the expected altitude and point it to the expected azimuth (from your "preparation"), using a hand compass. The celestial body will probably show in your view.

- Adjust the sextant to the correct instrumental altitude. Write name, time and altitude of the observed celestial object.

1. It's good practice to adjust the sextant micrometer drum always in the same direction. For example, put the star below the horizon and then bring it up by turning the drum in the same direction in all observations. If you go past, repeat the operation from the start. Do the same for the Index Error measurement. The sextant will give different readings, depending on the direction you adjust the drum. Using the same direction for both altitudes and index error measurements cancels this problem.
2. After adjusting the sextant's drum, read the watch first, because it's changing fast. Write the time. Then write the sextant altitude.

Before **and** after taking altitudes, measure the Index Error:

- Set the altitude to 0°00' and point to the horizon.
- Adjust the drum until both sides of the horizon are level.
- Read the Index Error and write it.

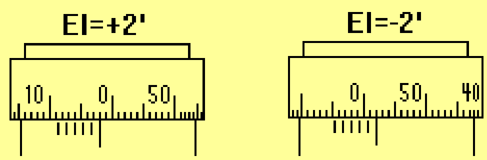
Back to the navigation table, run Navigator.

- Enter the index error.
- Enter Height of the eye (Dip). In version 3.0+, you can choose the Dip units (meters, feet or minutes) .
- Enter **watch error**, in seconds. See **keeping the time** for more information on time keeping methods.

Note on the **index error**: In versions prior to 2.5, the IE was typed with the plus signal when the index error was inside the drum scale. This number was then subtracted from sextant reading by the program.

Many users complained that this input convention was against the common practice in celestial navigation. They were used to work with the Index Correction (**IC**), with signal - when the IE was inside the arc scale.

After many messages, I agreed. Starting with version 2.5 and up, I changed this. So, if you are upgrading, make sure you use the correct input convention, as illustrated on the right.



Navigator 2.5 and up

Type IC = -2 **type IC = +2**

Old versions (navigator 2.0 and prior)

Type +2 type -2

Clear all previous LOPs:

- Select the tab "Astronomical Position".
- Press the toilet button, to clear all LOPs.
- Now select the "Line of Position" tab.
- Set the assumed position (Latitude and Longitude).

Now enter the measurements, one by one. For each celestial object, do:

- Select the celestial object from the listbox.
- Enter time of the observation.
  1. You can use local time or GMT time edit boxes. In this case, automatic conversion to GMT is done.
  2. If using local time, make sure the time zone and watch error edit boxes are correctly set.
- Enter altitude of the celestial body.
- Press the "Calculate" button.

The result will be something like this:

```
LOP for Sun
05/04/2001 13:43:54 GMT
Ass.Pos. Lat:23°40.0'S  Lon:40°30.0'W
Inst. Altitude: 56°24.5'
Altitude of lower limb
Altitude corrections ------------
Par: 0.0'  Refr:-0.6'  SD:16.0'
Dip:-3.1'  IE:-2.0'
Total Altitude Correction:10.3'
Corrected Inst Altitude: 56°34.8'
Object Positional data -----
LHA: 344°48.9'
GHA: 25°18.9'
Decl:  6°13.8'N
LOP Results-----------------
Calculated Altitude: 56°37.8'
Intercept: -3.0 NM (away)
Az.calc:   28°
```

The two last lines have the results (Delta and Azimuth).

If you feel the result is consistent with the expected , press the button "Save LOP". This will save this Line of Position for the calculation of the Astronomical Position (Fix), which will be done after you calculate all LOPs.

After calculating and saving all LOPs, go for the astronomical position calculation:

- Select the tab "Astronomical Position". The LOPs you have just saved will be in the spreadsheet.
- Press the "Calculate" button, to calculate the astronomical position. Your astronomical position will show. Please note that, in order to calculate the astronomical position, you have to have two or more LOPs. Having more lines is advisable, because errors in one observation will show more easily. A good number is 4 LOPs. Also, as we will see, sometimes we are going to discard some of them.

Refining your calculations

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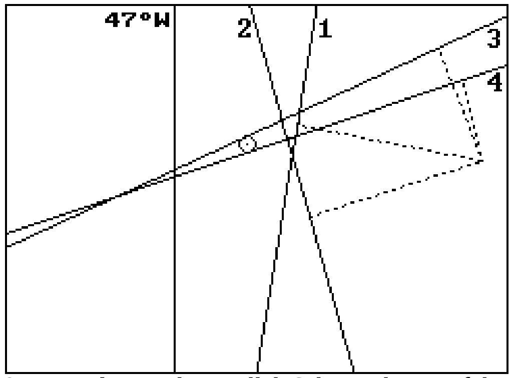
To achieve good results in celestial navigation, you need to be methodic. As you can see, there are many steps, and a mistake in one of them will only show in the end, if at all.

Enumerate the tasks you are doing - or are going to do - and read the measurements loud before taking note (navigators are said to speak to themselves). Make your notes in an organized table, one row for each celestial object. In the header of the table, write date, assumed position, time of twilight and index error. Have the sky preparation ready before going to the deck.

But even with all the care, some errors will eventually show. Wrong time or altitude (the so called 60 mile error). Bad star identification. Even wrong date. The important thing is to detect mistakes, and drop the LOPs with problem.

Having good dead reckoning navigation helps a lot. It's also a good idea to take a look in the chart showing the Lines of Position. If one of them seems out of the flock, you may deselect it and recalculate de position. This is why it's good to have more lines.

Another problem is to have two or more LOPs that are nearly parallel. They will probably cross very far from the correct position, even if they are close together. Navigator accounts for this situation by giving a small weight to crossings forming small angles. But it's better to deselect one of them and recalculate the position.



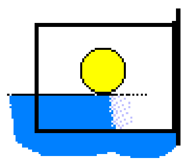
LOPs 3 and 4 nearly parallel. Select only one of them.

In the figure above, we can see that LOP 3 and 4 are nearly parallel. Deselecting one of them would improve the resulting calculated astronomical position.

Observing the Sun

During the day, you can observe the Sun and the Moon. If you can see both at the same time, and they are in suitable positions for observation, you can calculate a fix, using the two lines of position. The procedure is the same described above for stars and planets.

The only difference is that the Sun and Moon have appreciable diameters (about 32'). When measuring the altitude of Sun and Moon, align the lowest part of the body with the horizon. This is known as the lower limb. Navigator will correct for the semi-diameter automatically.



Sextant image

You can also use the upper limb. In this case, uncheck the "Use lower limb" checkbox.

Running fix

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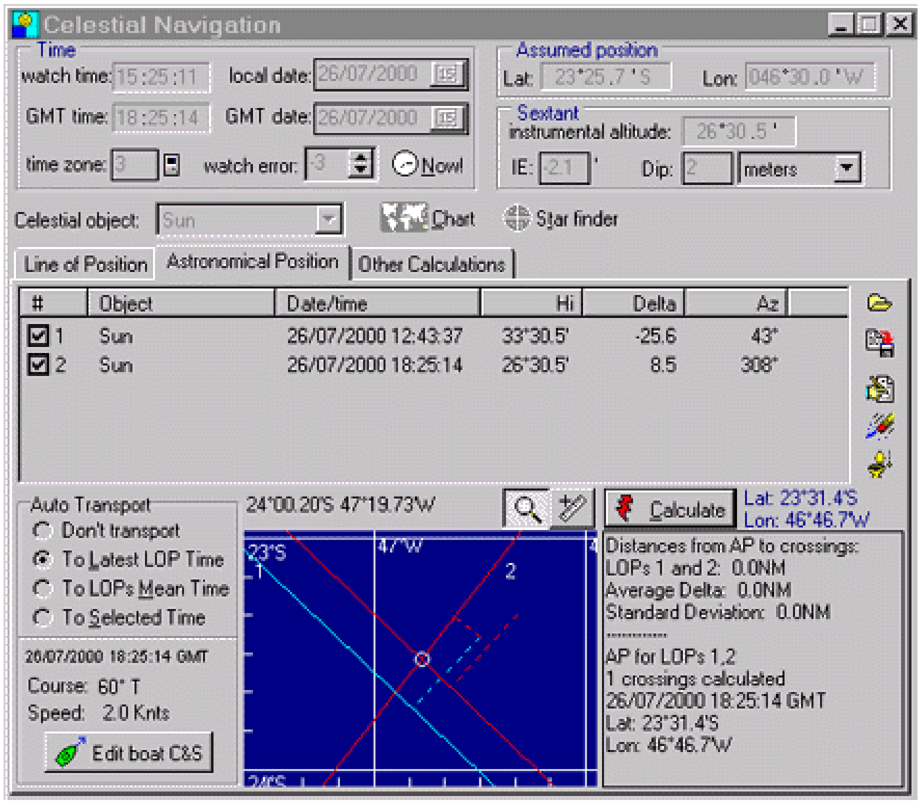
The altitude of the same celestial object in two different times may be used to find the position. For example, you can take two Lines of Position for the Sun, one in the morning and one in the afternoon. Because your boat is moving, you will have to transport the first line to the second line time. The position obtained with this method is called **running fix**.

Navigator (version 4.0 and up) can be set to transport LOPs automatically, when calculating the astronomical position. This is done by moving the assumed position. The LOPs chart shows the original LOP (blue) and the transported (red).

Take a look at the Auto Transport frame n the image to the left. This is where LOP transport is setup.

- Choose one of the following transport modes.
  - Don't transport
  - To latest LOP time
  - To LOPs mean time
  - To Selected Time (i.e. specified in the top time frame)

- Click 'Edit boat C&S' (course and speed) and update boat movement



data.

- Click 'Calculate' to calculate the astronomical position.

Simple meridian passage (noon sight)

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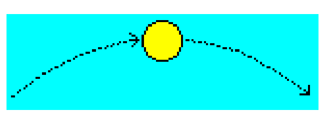
When the Sun crosses our meridian, its azimuth is either 0° or 180° (North or South). This means that a Line of Position (LOP) for the Sun, taken at this time, will have constant latitude. This event is called transit or meridian passage. For the Sun, it happens around local noon (+/- 20 minutes).

The navigator can take advantage of this event to check the latitude. The longitude can also be calculated, although with smaller precision.

This is what you must do:

- Start taking observations of the Sun (time and altitude) about 25 minutes before the expected transit time. In **Navigator**, select the Sun and use the command **Object Data** to estimate the transit time for the Sun in your assumed position. Take a couple altitude observations (p.e. 5 minutes apart) until 15 minutes before transit.

- At transit time, observe the highest altitude the Sun reaches. This is known as culmination altitude. It´s easy to measure, since the Sun will appear to hang with constant altitude while passing your meridian. After that, it will start to go down.



- Write the culmination (maximum) altitude.
- Keep checking the altitude until the Sun, now going down, is at the same altitude it was in one of the observations made before transit. The time of transit is the average of two times with equal altitudes (before and after transit).

  For example, if you measured 61°32' at 11:45:30 and 61°32' at 12:10:10, the time of transit is (11:45:30+12:10:10)/2 or 11:57:50. The altitude value is the maximum altitude you observed (near transit time).

- Enter the transit time (the average you calculated) and the culmination altitude in **Navigator**. Select the tab "**Other calculations**" and click the **"Simple Sun Meridian Passage"** button. Program will give your position.

It's important to understand that the Latitude result is related to the maximum altitude the Sun reaches, and the Longitude to the exact time of the passage. So, the latitude can be safely determined even if you don´t have a reliable watch.

Better meridian passage calculation

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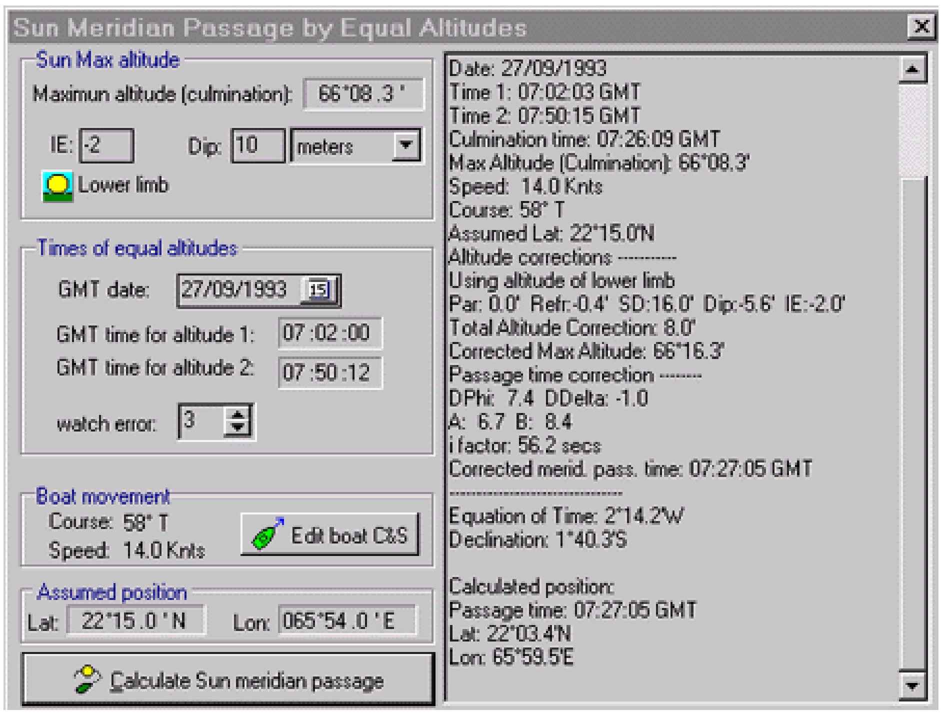
While the method just described is OK, is does not account for two factors: Sun declination change and boat position change. These two factors can affect the longitude result.

The Sun declination is always changing. It changes faster on equinoxes (spring and fall) and slower in solstices (summer and winter). So, the Sun 30 minutes after the passage is not in the same place (in the celestial sphere) as 30 minutes before the passage.

The boat movement during this period can also be of significance, particularly if the boat is fast and is moving along the meridian.

These two changes affect the actual meridian passage time. In this case, the average time between two equal altitude observations (before and after transit) is not the meridian passage time, but rather the culmination time. A correction must be applied to find the right passage time (and the Longitude).

To perform this calculation on the Navigator, select the tab "**Other calculations**" and click the "Sun Meridian Passage by Equal Altitudes" button. The form below will show.



Enter maximum altitude (w/o corrections), IE, Dip, GMT date, GMT time of altitude 1 (before transit, w/o watch correction), GMT time of altitude 2 (after transit), watch error, boat speed, boat course and assumed position. The GMT times 1 and 2 are the ones of equal altitude observations (the actual value of the altitude is not used in the calculation, but remember to write it down, because you will have to use the sextant to measure the maximum altitude between the two observations).

The correction **i** is the difference, in seconds, between the culmination time and the transit time. It can be as much as a minute, or 15' in the longitude.

Please note that there are a couple **conditions** to use this method:

1. Sun altitude must be at least 65°.
2. The Sun's azimuth must be at least +/-20° on equal altitude observations.
3. The equal altitude observations must be up to 40 minutes - before and after - transit time.

This method is particularly useful near the Equator.

> **Tip:** If there are clouds in the sky, it's recommended that you take several observations before transit. If you take only one, the Sun may become covered in the critical time after transit. By having many observations, you increase the chance of having one usable observation pair.

Source: Navegação Astronômica e derrotas

Artificial Horizon

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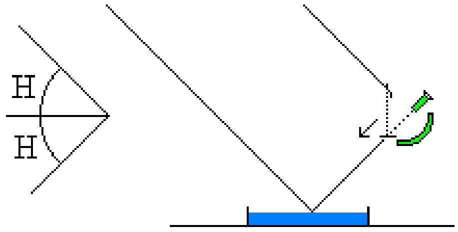
If you live in a city far from the sea, you can't take altitudes of celestial bodies with a marine sextant, because you can't see the sea horizon. One way to work around this problem is to use an **artificial horizon**. The artificial horizon can easily be made with a plate filled with liquid. Water will do, but oil is better. The surface of a pool can also be used, if there is no wind or waves (the water surface must be completely flat).



To take the altitude with the artificial horizon, point the sextant towards the artificial horizon and make reflected image of the celestial body coincide with the direct image. The angle you read is twice the altitude of the body, as illustrated in the figure below.

Also read the index error.

Navigator automatically corrects for the use of artificial horizons:

- The program divides instrumental altitude by two. Enter sextant reading directly.
- The Dip and semi-diameter corrections are set to zero.
- The index error is also divided by two.

Printing Nautical Almanac Pages

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Navigator (registered version 2.5 or latter) has a Nautical Almanac page generator/printer. These pages are not exactly the same as real almanac pages, but they contain most of the information needed to do celestial calculations in the traditional way, without the computer.

Navigator generates the so-called "daily pages" (the ones with 3-day celestial data for planets, stars, Sun, Aries and Moon). The yellow ("increments") pages are not generated because they don't change from year to year. You can use the yellow pages of an old almanac or do the interpolations with a pocket calculator.

I choose to make the Navigator daily pages as similar as possible to actual almanac pages. But there are differences:

- Did not include the latitude dependent tables (Twilights, Sunrise, Moonrise, Sunset, Moonset).
- Did not include the Aries meridian passage time. This number is used to calculate the meridian passage of stars, and is seldom used.
- Did not include the Sun's Equation of Time and meridian passage table. You may use an old almanac for the Sun's meridian passage calculations, as these tables are almost unchanged from year to year. Just use the table of the same day.
- Did not include the Moon's meridian passage and age table.
- Did not include the planets' SHA and meridian passage table.
- Added three stars not included in most Nautical Almanacs

I plan to include some of these numbers in future versions. Feedback from users about what features are most important is welcome.

If you compare the Navigator's almanac pages with nautical almanac pages, you will note small differences in the numbers. These are caused by different celestial calculation methods and should not be bigger than 0.5'. This error is small when compared with other imprecisions that affect celestial navigation, and will not impact your position significantly.

Printing the almanac pages

To print almanac daily pages, do:

1. Go to the celestial navigation window.
2. Select the "Other calculations" tab.
3. Press the "almanac pages" button. The "Almanac Pages" window will show.
4. Set the initial date for the 3-day page.
5. Select "Aries and planets" (left side page).

6. Press "Build page" and "Print".
7. Select "Sun, Moon and Stars" (right side page).
8. Press "Build page" and "Print".
9. Click in the "Arrow" button to advance 3 days and repeat operations from step 5). Proceed until you have printed all the pages for the desired period.

In order to print your almanac pages, you have to use a non-proportional font (a font with fixed pitch). The default font is Courier New, size 7. Pages printed with this font will use a single sheet of paper (size A4). I know this is a small font, but using a larger one will result in two paper sheets for each page. You may experiment with other non-proportional fonts. True type fonts are better, because they can be resized to any small size.

Check the online web service, open to the public. Click to **visit this service**.

Chapter 2 - Star Finder

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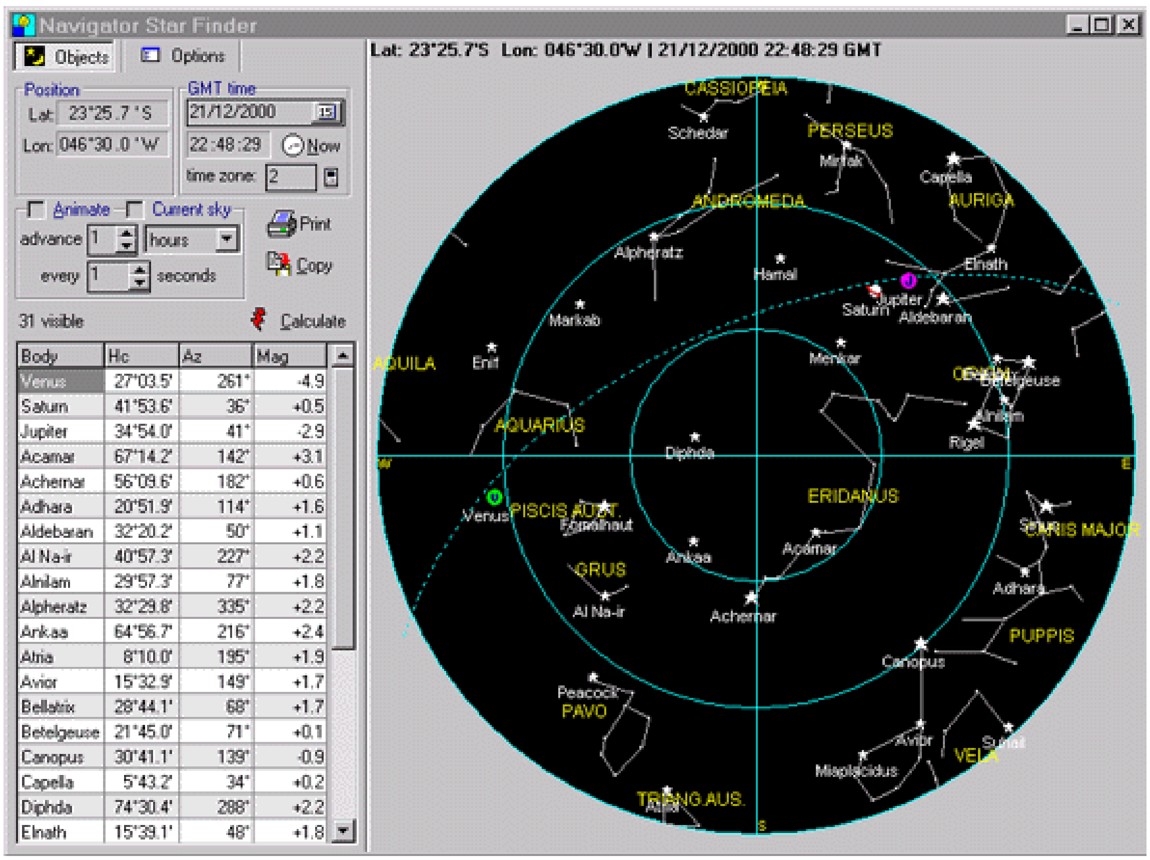
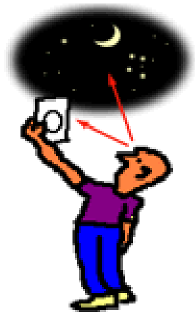


Navigator Star Finder (version 3.0+) was completely redesigned. To accommodate the new set of features, this chart of the visible sky was moved to its own window (in previous versions, it was part of the celestial navigation window).

The new features include:

- Constellation lines and names make it easy to identify constellations and celestial objects.
- Ecliptic plot shows the path of the Sun, Moon and planets.
- Celestial objects grid can be sorted by columns (ascending and descending order) clicking the column header.
- The spreadsheet now includes object magnitudes (note: many celestial objects have changing magnitudes. These values are fixed, to be used only as rough estimate).
- Mouse cursor shows altitude and declination when moving. When pointing an object, its name, altitude, azimuth, declination and right ascension are shown. Values cursor is transparent, so you don't loose the big picture.
- Prints the object list and chart. The printed chart uses the printer higher resolution.

- Time zone is now imported from the operating system, accounting for Day Light Savings time.
- Sky background color indicates the light conditions (day=blue, night=black and twilight=navy).
- Windows® Clipboard support allows to cut-and-paste the chart to other applications.



- Overhead view option, so you can look up to the sky and the chart simultaneously. In this representation, E and W are flipped and the chart is to be viewed upside down
  (see figure to the left)

- Options tab allows easy and interactive chart setup (see figure to the left).
- Boat course plot, to easy printed chart orientation.
- Star finder chart and table now print in the same sheet of paper, much more convenient.

Using the Star Finder is easy:

1. Set your position (Lat/Lon)
2. Set the GMT date and time. If you opened the star finder by clicking the button in the celestial navigation window, these values are automatically set.
3. Set the boat course (optional)
4. Click the **Calculate** button

You can also animate the sky, specifying time increments and calculation frequency. This can produce very interesting animations, like how the sky changes from hour to hour, day to day and year to year.

And it can also be set to show the current sky.

Chapter 3 - Chart Navigation

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The **Navigator** chart module is relatively new (started in version 2.5), but has received important additions in version 4.0. It's now much more useful with the addition of raster chart capabilities.

Instead of supporting the existing electronic chart formats, I choose to provide a set of tools to allow the user to import existing paper chart images into the program. This 'do-it yourself' approach gives the user maximum flexibility.

All **Navigator** files are in text format and their structures are easy to understand, to allow integration with other applications and Internet file sharing. The table below enumerates the **Navigator** data file types.

File extension	Description

.CHT	Navigator vector chart file
.NAV	Navigator desktop file
.CID	Navigator chart image description (raster image)

Vector and raster charts

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The **Navigator** chart engine can show two kinds of charts: vector charts and raster charts.

Vector charts - In this type of chart, islands, continents, routes and tracks are represented by polygons and lines, defined by a collection of points (Lat/Lon pairs). This kind of chart can be easily zoomed in and out, and is very fast to render. Navigator uses its own vector chart file format. No other chart file format is supported at this time. These files can be produced, from scanned charts, using the ChartMaker program.

Raster charts - These charts are images (normally scans of paper charts). Navigator can use raster images in formats **JPG**, **GIF** or **BMP**. These are popular file formats in the Internet, and many charts can be found for download over the Net.

All raster chart image files must first be imported - using ChartMaker program - before they can be used in the **Navigator**. This step is necessary to describe the chart image scale (i.e. how pixels in the image map to the real world).

Both vector and raster charts can be produced or imported using the ChartMaker program, which is described in the next chapter.

Using raster chart images

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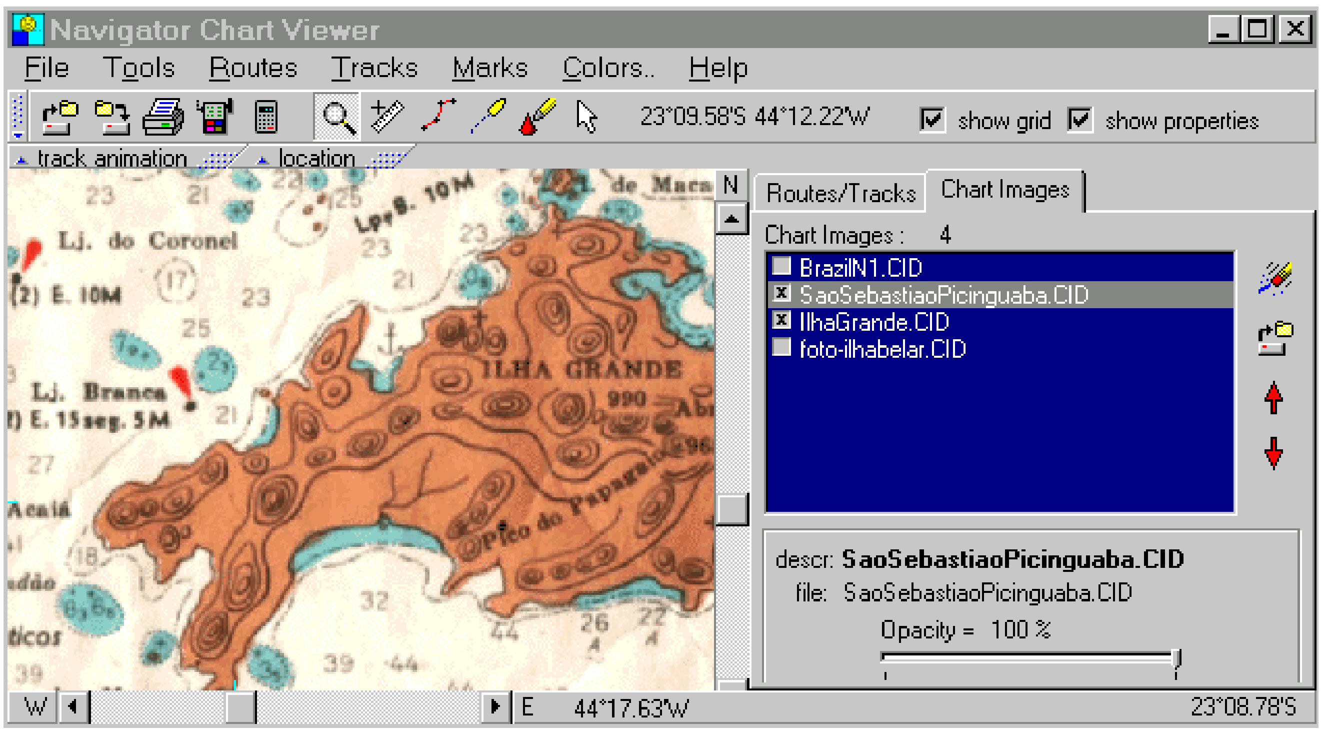

In the image above you can see two raster chart images visible in a desktop, on a zoom animation. Before opening it in the **Navigator**, a raster chart image it must be imported. This is done only once for each image, with the ChartMaker program. The step creates a .CID file that is associated with the chart image (GIF or JPG). This file contains:

- Name of the associated image file (GIF, JPG or BMP)
- File description
- Reference points (which define how the image pixels map to the real world)
- Image MD5 digital signature (to prevent accidental changes in the chart image)
- Chart limits (outside rectangle)

Once the CID file is created, it can be added to a desktop. Click the chart image open button and select the CID file. Many chart images can be added to a given desktop. Images can be either visible or not. To play with chart visibility, use the small checkbox in the chart images listbox.

Tip: Since images are large in size, making many visible at the same time would consume a lot of memory. Making only the charts you need **visible** reduces the amount of memory used by the program. A memory of at least 32MB is recommended to use raster charts.

The image resampling process also consumes a lot of CPU power. To reduce the bumpy behavior while zooming or scrolling, these calculations are implemented in different threads of program execution . That's why it takes some time for the raster charts to show after you zoom or scroll.

You can also play with raster image **opacities**, making them partially transparent. This allows you to see how two charts overlap each other or compare them with the vector chart underneath.

Tip: Partially opaque (i.e. transparent) chart images consume CPU power - a 100% opaque chart will display a lot faster.

The chart images rendering order can also be changed, using the up and down arrow buttons in the right. The rendering order is:

1- Background (sea color)
2- Vector chart polygons
3- Chart images (top-down order in the listbox)
4- Routes, tracks and marks

Tip: To transfer a CID file to another computer (or to share it over the Internet) , you also need to transfer the associated image file (GIF or JPG). Since the CID file contains the image file digital signature, there is no risk of accidentally changing the image while copying.

Printing Chart Images

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Navigator Desktops containing raster chart images can be printed. You can use this to integrate different charts together in a single and compact printout. Quality is even better than the computer screen, because printers have a much higher pixel resolution than monitors (monitors typically 75 DPI x printers 300 or 600 DPI).

This quality comes at a **cost**. Ressampled chart images may turn out big, requiring a lot of CPU cycles and memory to calculate. So be patient and make sure your computer has at least 64MB of memory. If you have a laser printer, limit the print resolution to 600 DPI. Don´t use 1200 DPI, because this would result in really big ressampled image and would probably hang your computer.

I´m working to make sure that the printing process is smooth. You may find problems in extreme situations (printing large chart images with high resolution printers and little memory available).

Partially opaque (transparent) images are not supported by printers. When printing, all chart images will be rendered opaque.

Chart tools

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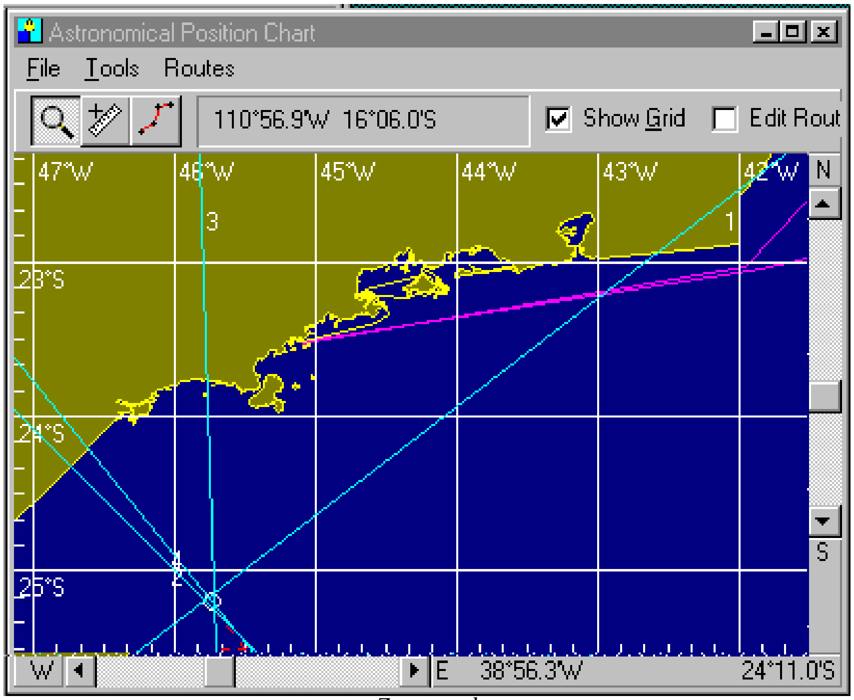
The **Navigator** chart viewer has the following tools:

Zoom - Lets you zoom in and out the chart, from the whole world to a very small scale. To zoom in, press the left mouse button in the point you want to focus (screen center). To zoom out, use the right mouse button or click the left mouse button with Shift key pressed.

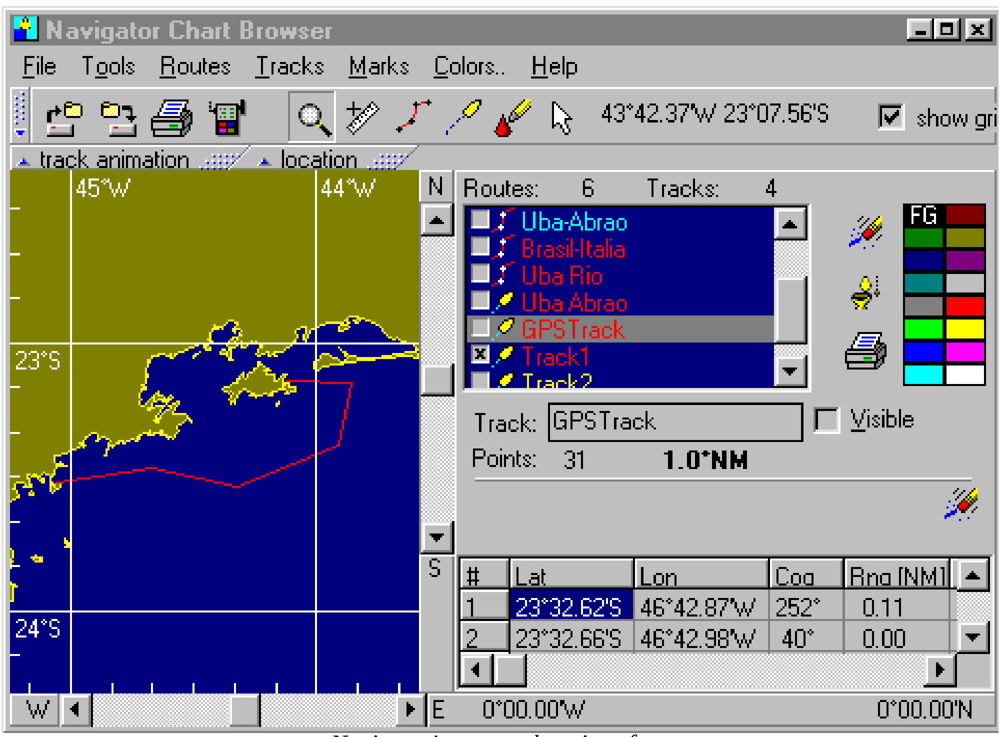
Measure - Click a position and drag the mouse. The caption will show two numbers: COG and Range.



Zoom tool

COG is Course Over Ground. It's the true direction of the line. Range is the distance between the end points, in nautical miles.

Both COG and Range are calculated using Lines of Great Circle (LGC). This means that they are accurate, even for large distances.



Navigator's vector chart interface

Route - This tool is used to draw routes. A route is a set of points in the surface of the earth, with optional associated text. Routes can have any number of points or waypoints. You can draw as many routes as you wish. Routes can be stored in Navigator Desktop files (.NAV files). You can make some routes invisible and concentrate on your current route. You can also edit routes, change their colors and names.

At anytime you can check the COG and Range between two points of a route, and the total length of a route. To edit a route, click the checkbox "Edit routes/tracks". The route editor will show. You can change all attributes of a route (Color, Name, and Visible). You can also edit coordinates of points, by double-clicking the point in the spreadsheet. To add a point to an existing route (or track), click the route tool. In the menu, select *Routes Add Point* to route. Choose the route. Add one or more points. Right click to save points and end addition.

To create a new route, click the route tool and click the route points. Right click end route. When prompted, enter route name.

Tracks - This tool is used to draw tracks. Tracks are like routes, except that each track point has an associated date/time value. They are used to log the positions on a trip. Like routes, they can have any number of points. Tracks can be stored in Navigator Desktop files (.NAV files). You can make tracks invisible to concentrate on your current track. You can also edit tracks, change their colors and names.

To edit a track, click the checkbox "Edit routes/tracks". The track editor will show. You can change all attributes of a route (Color, Name, and Visible). You can edit point data, by double-clicking the point in the spreadsheet.

To create a new track, select the track tool and click the first route point (left button). If you want, add more points with left clicks. When done adding points, right clicks the chart. Enter track name.

To add a point to an existing track, click the route tool. In the menu, select Tracks Add Point to route. Choose the track. Add one or more points. Right click to save points and end addition.

Marks- You can also add marks to the desktop. Select the mark tool and click one point, specify optional text for the mark and choose a mark icon.

Pointer- Use the pointer tool to point chart objects (islands, tracks, marks etc). If a name is associated with the object, a text will appear near the cursor.

Navigator Desktop files

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After loading a vector chart and/or raster charts; changing routes or tracks, you can save all to a desktop file. A **Navigator** desktop file contains the state of the chart viewer, including:

- One Vector charts.
- Raster charts (i.e. chart images)
- Routes
- Tracks
- Marks

Desktop files have the extension .NAV, and are in text format.

GPS Interface

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Navigator has GPS interface. This interface accepts NMEA (National Marine Electronics Association) standard GPS messages. Two kinds of NMEA messages are accepted:

RMC - Transit Specific Navigation information message- This is the recommended (default) accepted message, because it has date and course information. RMC messages give Latitude, Longitude, date, time, course and speed.

GLL - Geographic Position Latitude/Longitude message - Select this one if your GPS does not support RMC messages. GLL messages have only Latitude, Longitude and time (no date).

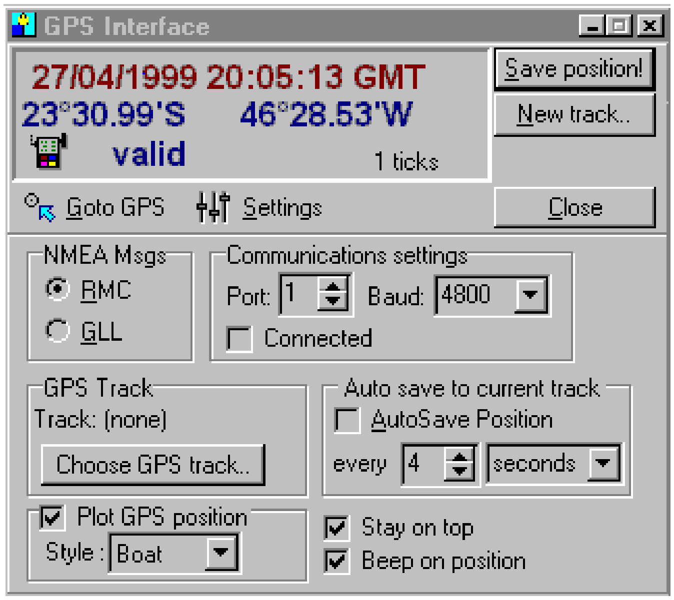
> **Note**: The NMEA interface, available in most GPS devices, uses a RS422 hardware interface. This is not the same as the RS232c serial interface, available in PCs. While the 422 interface uses +12/-12V electric signals, the RS232 uses 0/5V. But since the PC uses the level of about 3V to distinguish between 0s and 1s, the connection works fine in most cases. However, they are different things, and you may experience problems connecting them.

You will need a connection cable, which is an optional part for some GPS models. Check your GPS documentation for more details on activating the NMEA interface and selecting the messages. Some GPS devices disable the dataport, to save battery. You probably will have to change the default configuration to enable the GPS data output.

To open the GPS interface dialog click the GPS Interface button. A window will show, with current GPS position. Clicking the *Settings* button will show the GPS settings page, as shown below. Clicking again hides the settings.

- Set the baud rate to the same value as your GPS device. Most GPSs have a default baud rate of 4800.
- Choose computer port number.
- Click the "connected" checkbox to open the communications port and start receiving GPS data.

The upper panel will show the current position, date/time and position status (as reported by GPS device).



The GPS interface can be set to save a position periodically (AutoSave feature). Positions are saved to the current GPS track. A given desktop can have only one GPS Track. Use the "Choose GPS Track" button to choose the GPS track. If starting a new travel, use the "New track" button.

You can also save positions manually, by clicking the "Save position!" button. Just make sure the current position status is "valid".

> **Tip**: If you use RMC messages, Navigator will plot a small boat in the current position, pointing to the actual course. If you use GLL, which has no course information, a square will be plotted.

Troubleshooting the GPS connection

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PC/GPS connections are sometimes tricky. A problem of either PC or GPS settings will unable the communication.

First, make sure that the GPS device is transmitting data. Stop the Navigator and open the Windows terminal (or Hyperterminal in Windows 95/98). Set terminal communications settings to 4800 baud, 8 data bits, parity None, 1 stop bit. If the GPS device is set correctly, you will see text messages coming from the GPS, like these:

```
$GPRMC,001556,A,2332.648,S,04642.969,W,000.9,045.8,230997,018.5,W*6E
or
$GPGLL,2337.479,S,04718.352,W,235808,V*3
```

The first is a RMC message and the second a GLL. If you don't see any message, the GPS is probably not sending data. You may have to activate the GPS dataport and/or the transmission of each message type (Some GPS devices disable the data port every time they are turned off). After you start receiving one of these messages (choose RMC if available), return to the Navigator and make sure the correct data port, baud rate and NMEA message type are set. You may set the Navigator's GPS interface to beep on each incoming message.

Leg Calculator

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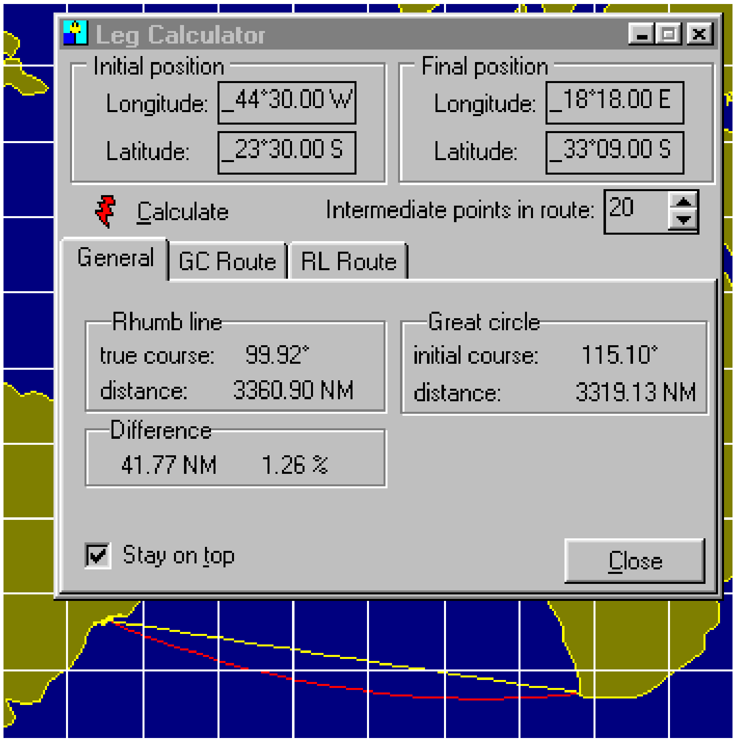
When planning a route between two points far away (over 1000 NM), many issues must be carefully considered: sea currents, prevailing winds, ship routes, shallow and dangerous areas, foul weather, etc. While these points are very important, there are also geometric considerations: the Earth is a sphere and routes are not straight lines but arcs in the spherical surface. Two kinds of routes are of special interest: the **lines of great circle** and the **rhumb lines**.

A **Line of great circle** (LGC) is the shortest path between two Earth points. This kind of route is contained in a plane defined by three points: the two route end points and the center of the Earth. When plotted in a Mercator chart, a LCG is represented by a curve, and a straight line in Gnomonic charts. While LGCs are shortest, they have a few problems:

- True course changes constantly from point to point.
- Depending on the end points, a LGC can take you to high latitudes, which is sometimes undesirable.

Rhumb lines (RL) are routes with constant true course. They are represented by straight lines in Mercator charts and curves in Gnomonic charts (the opposite of LGCs). RLs are easy to navigate because the course is constant. They are, however, a little longer (the difference is larger in higher latitudes).



Navigator **Leg Calculator** will calculate both LGC and RL routes between the two end points. To open the Leg Calculator, press the calculator button in the toolbar or choose 'Routes, Leg Calculator' in the menu.

Besides distance and course, Navigator shows the difference between the two options and builds routes with specified number of segments.

These routes can be inserted in the current desktop. Routes are added to the desktop with names "Rhumb Line" and "Great Circle". You may change these names in the route editor.

In the picture to the left, the yellow line is the RL route and the red one is the LCG (both created with 22 points). The difference between the two is 41.8 NM (1.26%). The LGC route has a crosstrack difference of 241 NM to the RL route (that is, it goes up to 4° south of the RL).

When building the routes, LGC route points are set by the program at constant longitude increments. RL route points are set at constant distance increments.

Chapter 4- ChartMaker program

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The **ChartMaker** program was designed to work with chart images in formats GIF, JPG and BMP, and prepare them for use in the **Navigator** chart viewer.

This program has two main functions:

1. Importing a raster chart images, producing CID files.
2. Making vector charts (i.e. digitalizing points and polygons), producing CHT files.

How it works

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A computer image is formed by a large number colored dots - also known as pixels - disposed in a rectangular mesh. If the image is from a nautical chart or satellite photo, an algorithm can be designed to find the real world coordinates of any of these pixels and vice-versa. This is exactly how ChartMaker works.

The first step to make a vector chart or to import a raster chart image is to establish the scale model between the image and the real world. To do this, you have to click 3 **reference points** and enter their world coordinates (Lat/Lon pair). This is enough to define a scale between the real world and the image pixels.

Technically, when you click the three reference points and enter the Earth coordinates, you are actually defining four vectors: two in screen coordinates (S12 and S13) and two in Earth coordinates (E12 and E13). Since both geometries are similar, for any point P, we can write:

$$SP = S1 + k * S12 + r * S13 \qquad (1)$$
$$EP = E1 + k * E12 + r * E13 \qquad (2)$$

where:
SP = Screen coordinates of point P
EP = Earth coordinates of point P
S1 = Screen coordinates of reference point 1
E1 = Earth coordinates of reference point 1
r and k constants

From relation (1), we can calculate constants *k* and r. With these constants, we can calculate the earth coordinates of P from relation (2). This is how the program calculates the earth coordinates of any screen point (and screen coordinates of a Lat/Lon pair).

Mercator Latitude scale correction

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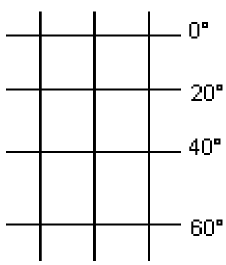
The method above works for linear latitude and longitude scale charts. But most navigation charts (and particularly the detail charts) are Mercator projections. Mercator projections have a great advantage: distances and courses between points can be measured directly from the chart. Angles are true, no correction is needed.

As any coast navigator knows, distances in these "regular" charts must be measured in the latitude scale, one minute of latitude being one nautical mile. To allow this, the Mercator projection latitude scale is not linear.

If you look at the picture below, you will see that, as latitudes get higher, distance between parallels in Mercator charts expands. The size, measured in screen pixels, of a given latitude minute is proportional to 1/cos(Lat). For instance, when Lat=0, cos(0)=1.0. For Lat=60°, cos(60)=0.5, and so a minute of latitude at this point twice as large as at Lat=0. Of course this "latitude grow" is variable, and integral calculations are needed to calculate the size factor between two latitude intervals.



Navigator's screen chart representation is **not** a Mercator chart. The latitude scale is linear and the factor between latitude and longitude axis tick sizes is equal to Mercator projections in the center of the chart window. This is, however, of no consequence, since you are not going to "measure" anything on the screen. You will use programs calculators and measurement tools, which use the mathematically perfect Lines of Great Circle (LGC) for distance and course calculations.

Still, **Navigator** knows how to deal with Mercator chart images. When using a Mercator chart image on the Navigator, remember to **check the Mercator latitude scale checkbox**. The program will correct for the Mercator scale automatically.

Which chart images can be used ?

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- Mercator chart images are OK, even if the image is rotated (like chart 1 on the left). It's difficult to perfectly align a large chart when scanning. **ChartMaker** will rotate the chart in order to align its grid with the vertical direction (chart 2). This is necessary to speed up chart resampling, for displaying.

- Gnomonic and other curved grid projections **cannot be used**.

- Some images (particularly satellite images) are skewed. Their constant latitude and constant longitude lines are not orthogonal (like chart 3 on the left). These images **cannot be used**. After entering the three reference points, Chartmaker will inform you if this kind of problem is present.

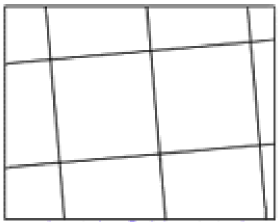

chart 1 - Grid rotated

chart 2 - Grid adjusted

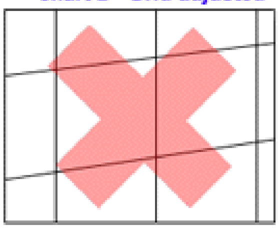

chart 3 - usuitable skewed grid

Tips for scanning charts

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- Scan using resolutions between 75 and 150 dpi. Avoid large files (over 1MB GIFs or JPGs). Images will have to be ressampled by the Navigator at run time while zooming. Large images will consume a lot of CPU cycles, resulting in poor and bumpy performance.
- When scanning large paper charts, you may detach the page scanner cover (if the scanner allows) to avoid folding the chart. Put some weight over the scanner cover, so that the paper is flat and perfectly in contact with scanner bed.
- If the chart doesn't fit in the scanner bed, scan it in parts, overlapping between them. Then make a CID file for each image. Navigator can display different charts together, and will even allow partially opaque rendering, merging the overlaps.
- Larger scanners (A3) are preferred, when available. A4 scanners are small for large paper charts.
- Hand scanners are not recommended, because they can distort the image scale. Use only page scanners.
- Images should be saved in GIF or JPG format (JPG is usually better).

Choosing the 3 reference points

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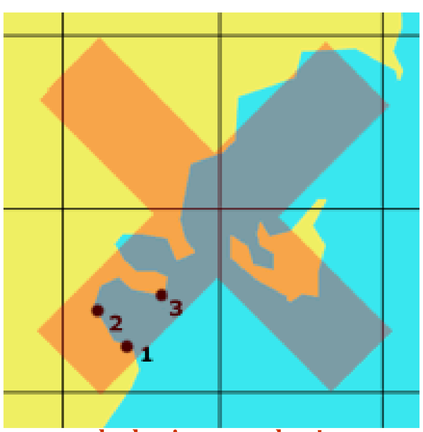
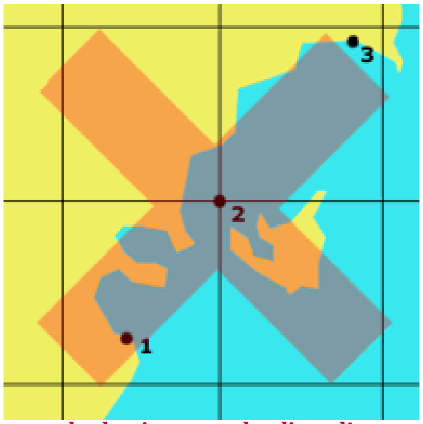
The 3 reference points indicate how the pixels in the chart image map to the actual world. Care must be taken in choosing these points, in order to achieve a precise scale. Below are some guidelines for choosing the reference points:



bad points- too close!

Choose reference points that are **as far from each other as possible**. This will result in a more precise scale. If possible, choose points near the corners of the image. In the image on the left, points are too close and the scale will be poor.



bad points- nearly aligned!

Reference points **must not be aligned**. In the image on the left, points are nearly aligned and the scale will be poor.

good reference points

In the image on the left, points are well positioned (i.e. far from each other and not aligned). Choose points that are close to the corners of the image, if possible.

If the chart has a grid, the grid line crossings are logical candidates for reference points (like point 2). But other points can be used and they don't need to define a right angle between them.

Importing a raster chart image

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1. Open the **chartmaker** program and click **Import chart image** and load the image to be imported.
2. Check the **Mercator scale** checkbox, if chart is a Mercator projection (most are).
3. Take a good look in chart and choose the 3 **reference points**, as described above. Click each reference point with great care. Inform the precise latitude and longitude for the point.
4. Chartmaker will then calculate the scale and produce a summary, rotating the image as needed (rotation is considered necessary if the angle between a meridian and the vertical is larger than 0.001 rad).
5. If the image was rotated by ChartMaker, you must save it. I use to save the image with a different name, keeping the original scan intact, but you may save with the same name, ovewriting the original.
6. If you made any mistake or if the image is unsuitable for use, the summary will inform you of this. You may try again, if you think the image is suitable and you made a mistake.
7. After the summary, you can click extra points in the chart. This is optional, but highly desirable, to further check if any error was done in the reference points.
8. If everything is OK, save the **CID** file (Chart Image Definition). This text file contains the information for the Navigator program to use the image: the reference points data, image file name and description.
9. The CID file also contains the image digital signature (of type MD5). This is to make sure that the associated image is unchanged. So, if you do any changes in the image - even changing a single pixel color, the CID file will become invalid. This is a **security feature** to avoid accidental image change.

Making vector charts

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While raster charts are very complete, with the all relevant navigation information, vector charts cosume less memory, are a lot faster to draw and are "zoomable". This is why is interesting to have a vector chart to be loaded underneath the local raster charts.

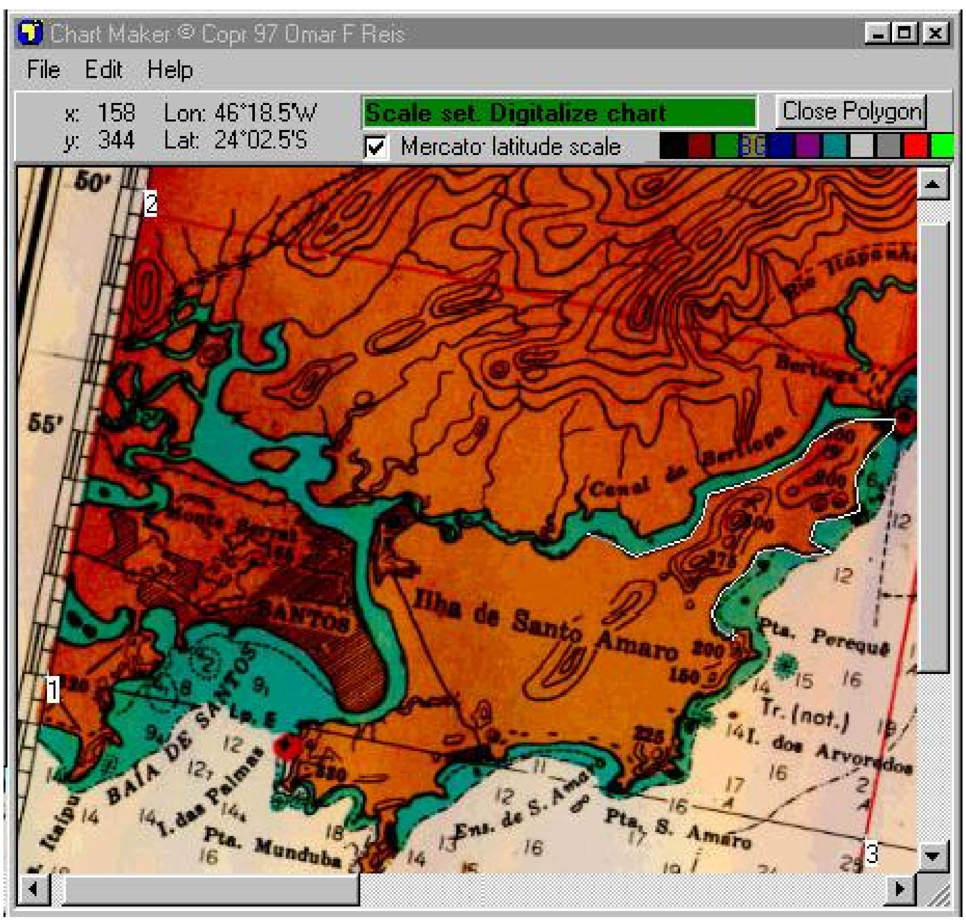
Navigator uses a custom chart file format, with the CHT extension. These are plain text ASCII files and can be edited with the Windows Notepad or Wordpad. Because providing detailed vector charts of all regions of the Earth is a demanding task, I choose to give users a tool to roll their own charts. Producing a vector chart means using a raster chart image to digitalize the points in the shoreline.

Chartmaker accepts three image formats: Windows BMP, GIF and JPG. If you are scanning paper charts, JPG is probably the best format, because files are smaller. It's a compressed format.

The CHT file

Once you have the image of the chart, load it in Chartmaker. Now you have to define the scale for this chart. Click and enter the Earth Coordinates for three distinct **reference points** of the image, as described above.

1. Choose three points that are relatively distant to each other (at least 1/3 of the screen). Select points that form a right angle. Click the points and enter their Earth coordinates.
2. After the third point, the caption will show the coordinates of the cursor, as you move the mouse. Check the coordinates of other points, to certify that your scale is accurate.
3. Select "Edit, Draw Axis" in the menu. The program will draw vertical and horizontal axis in 30' intervals. Check if they are the same as the image's axis. Draw again to erase the axis.
4. Now draw the shoreline, clicking the points with the mouse. Draw different polygons to represent the islands and continents.
5. After clicking all points of a given polygon, press the "close polygon" button. The last point will be connected to the first. All polygons must be closed.
6. Give a name for the polygon.
7. After drawing all the polygons, save the **CHT** file.
8. Open it in Navigator chart viewer, to see the result. Zoom in and out, to check the details.



In the figure to the left, the 3 reference points are marked 1, 2 and 3. The coordinates are:

```
1) 24°00.0S 46°25.0W
2) 23°50.0S 46°25.0W
3) 24°00.0S 46°06.6W
```

If you open the supplied **myworld.cht** file in Navigator, you will see a simplified chart of the whole world. I made it more detailed in one part (44°00'W 23°30'S), the region I usually navigate. You can do this for your region, by directly editing the CHT file with a text editor and adding the polygons of your region. This is a little tricky. You might prefer to roll a chart of your region only.

You may also merge CHT files, using an ASCII text editor (like the Notepad or Wordpad). Take a look in the CHT file header for more technical details on the CHT file format.

xxx

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The X-tant project

Build your own sextant

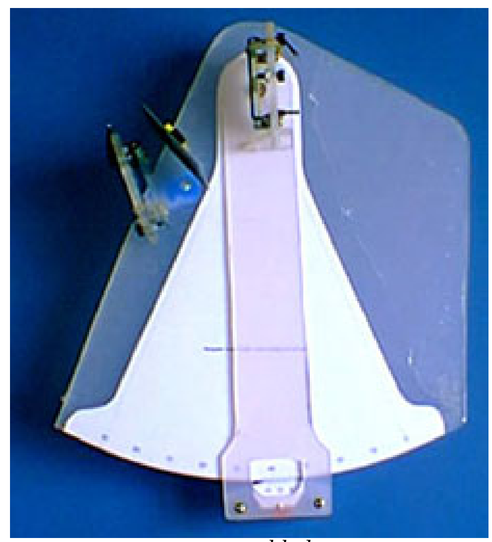
Note: Since I published this text, I've done another, much easier sextant using a CD and its box. Click the banner to the righ to visit it.

But the octant described in this text is better ;-)

From times to times I get tired of writing abstract computer programs. This time I decided to do a more concrete project: a **sextant** (actually, an octant). I'm not a very experienced craftsman and don't have a equipped shop. The design is simple and can be reproduced with hand tools. I used a small jigsaw and a belt sander. I have made no blue prints.

In tests, when compared to a Davis plastic sextant, this octant did agree within 6' (see test results in the bottom of this page).

My octant parts ...

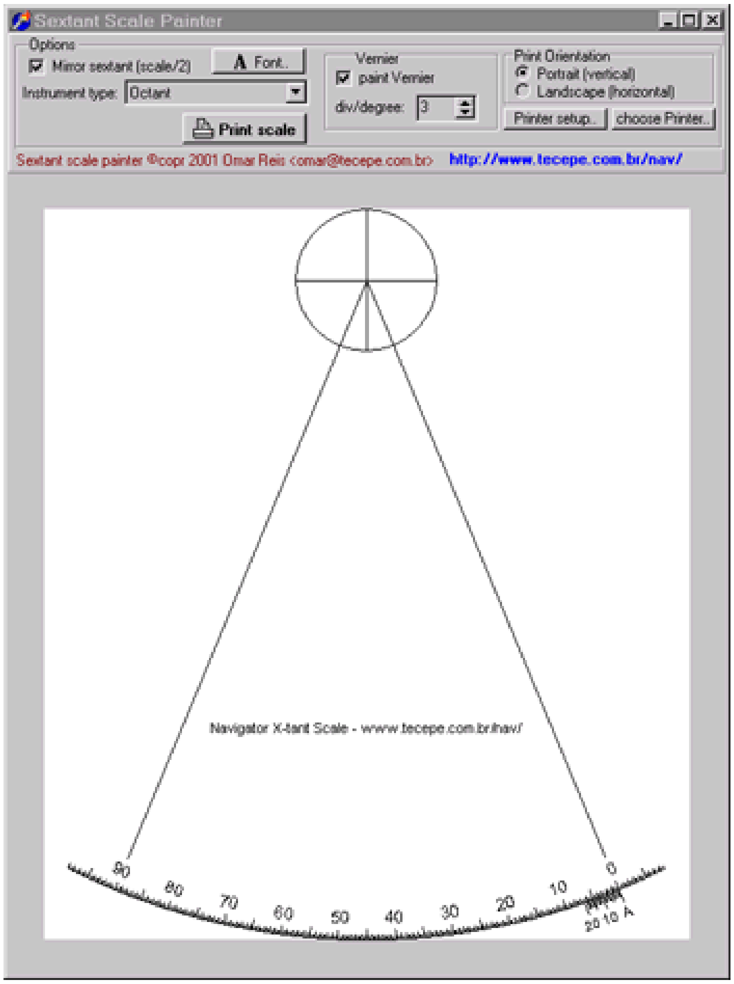


.. assembled

Printing the Scale

The scale is probably the most difficult sextant component to do using traditional techniques. It must be very precise and allow reading degrees and minutes, with accuracy at least within 5' of arc.

Fortunately, most of us have a precise printing equipment right on our desktop: a inkjet or laser printer. These machines can print 300 dots per inch (1200 for laser), with enough precision to print a good sextant scale.



Laser or inkjet ?

Laser printouts are more resistant to water than inkjet ones. And have better resolution. Use a laser printer, if available.

But a inkjet printer will also do the work. If using a inkjet scale, protect it from water spray, either by adding a thin layer of transparent plastic or by taking extreme care with the instrument...

Sextant scale printer program

In order to achieve the best results, I wrote a small scale printing program. This will print the sextant scale using vector rendering, for best resolution. The scale will be the larger possible in the current printer page size.

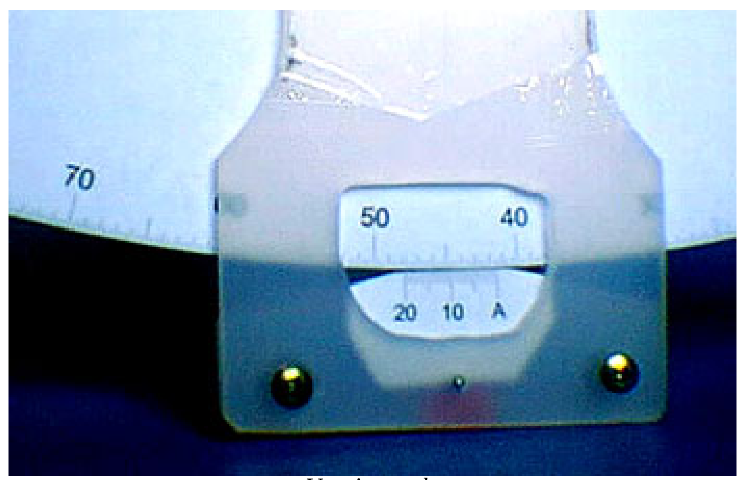
To the left, you see a screenshot of my **XtantScalePrinter** program. I used the default options in my project, but you may experiment with other designs (sextant types, ticks per degree etc.).

XtantScalePrinter - download **here**

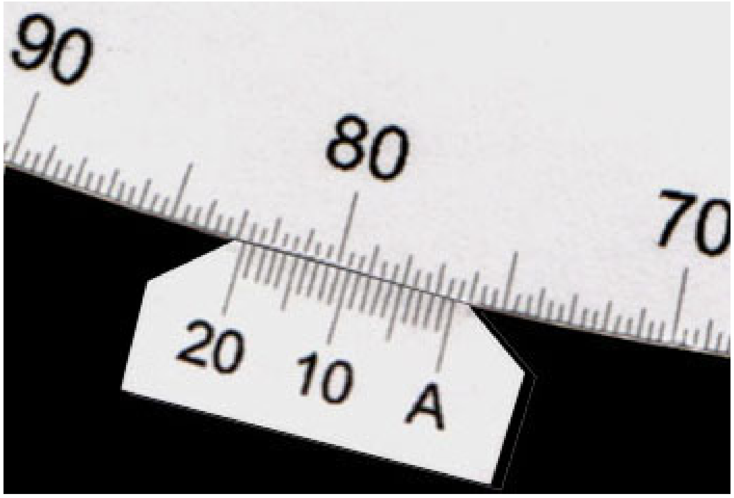
For Windows, 192.874 bytes - This program can be freely used for personal, noncommercial purposes, provided that the credit (name and URL) is not removed from the printed scales.

The Vernier scale

Since I didn't have the sophisticated machining equipment required, I discarded the idea of a drum sextant and went on to build a vernier scale sextant. Vernier sextants appeared before the modern drum sextants. In the vernier scale sextant, each degree in the scale is divided in 3 ticks (20' wide).



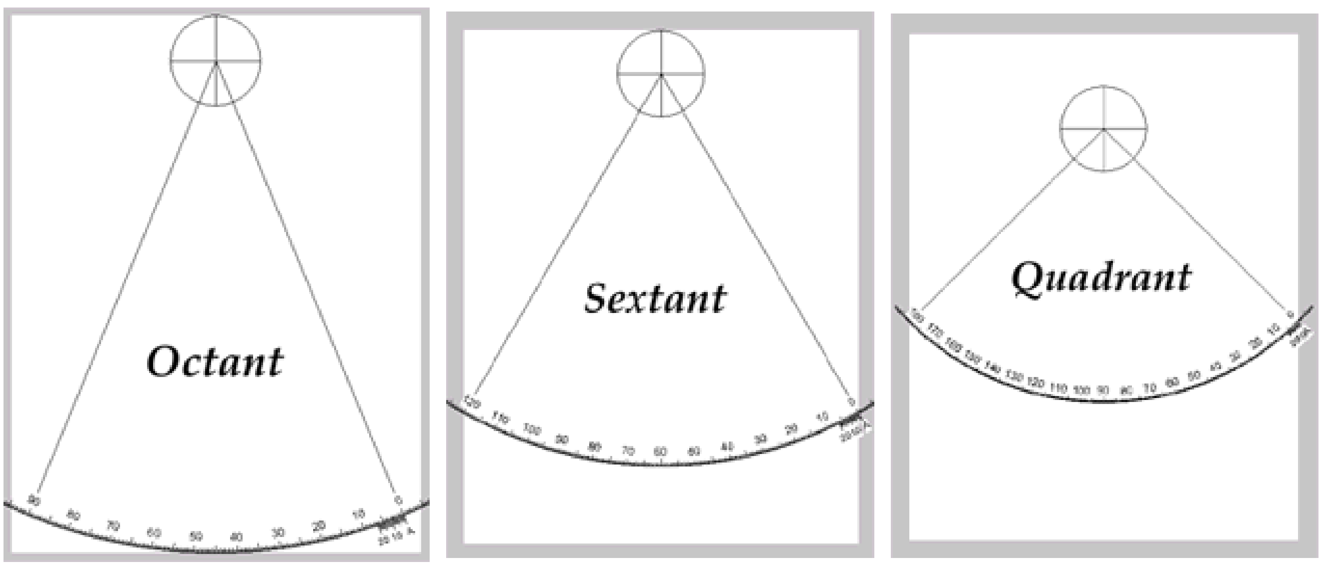
Vernier scale



The vernier scale precision can be as good as a drum scale. The only difference is that the vernier scale requires a much more delicate handling of the sextant arm while trimming.

Reading the vernier scale is easy, once you get used to it. In the scale to the left, the index reads 76° with minutes between 20' and 40' (tick **A**). In the vernier, we can see that the 6th vernier tick coincides with the index tick, so the reading is 76°26'.

Below are the three basic X-tant types. The octant can measure up to 90°, the sextant up to 120° and the quadrant up to 180° (see below). I choose to build an O*ctant*, since this design fits better in a A4 printer page, giving the largest possible degree size in the scale, for best detail. And the 90° scale is enough for most observations.



X-tant types

I used A4 ink jet sticker paper to print the scale (the ones used for printing labels). Choose a paper with no cuts. After printing the scale, check how good is your printer, using a compass to see if the index is a perfect circle segment.

Scale Transfer - An alternative way to print the scale was suggested by Mr. Schmit, by email:
"When you print documents with laser printers or photocopiers it is done by fusing the toner on the paper. You can transfer the print on any solid heat resistant material by refusing the toner with a very hot 'cloth iron'. Place the laser printed document on the cleaned material (printed side facing the surface) then apply the iron on the paper back just long enough to melt the toner. I used that to make gratings and reticules on glass or metal sheets and it's working fine if your print is strong enough... but the print must be reversed! "

While this reversed print is not directly supported by the scale printer program, most printer drivers (e.g.: HP) offer this as an option. Open the "Printer Setup" dialog, click "Properties" and check the "reverse horizontally" checkbox.

Another way was suggested by Mr. Kunnar:

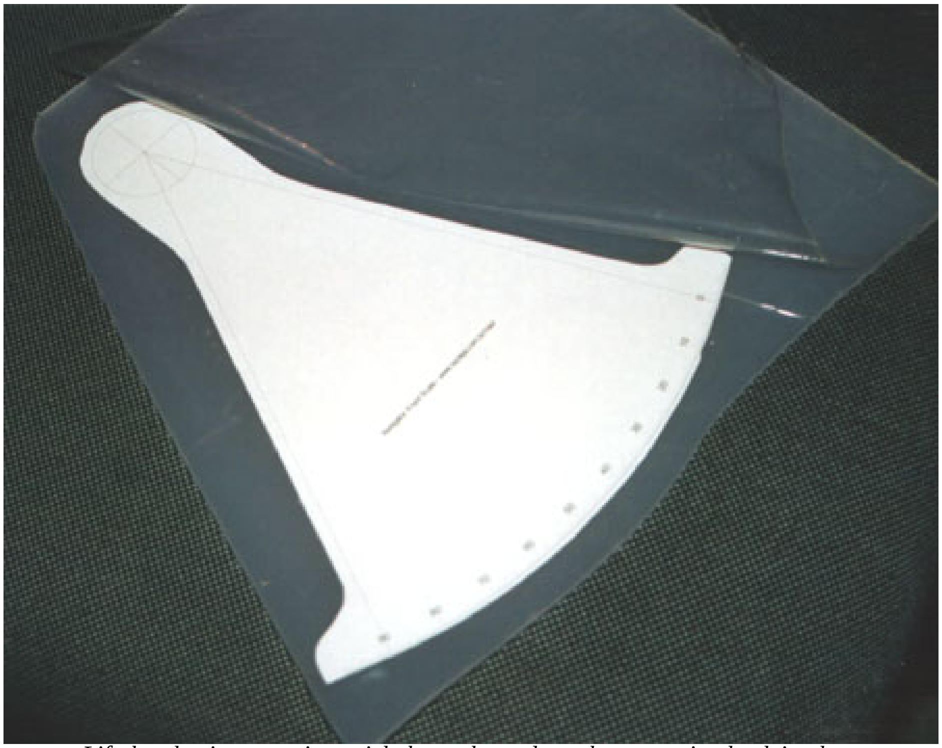
" I used inkjet iron transfer paper. It is a kind of plastic that can be transfered to clothes using a hot iron. Since the ink ends up trapped between the sextant frame and the plastic layer, this scale is water proof".

Instrument frame

I used a 3 mm tick acrylic board for the instrument frame. This material is easy to machine and is relatively rigid. Acrylic boards are usually sold in large sizes, so you might want to search for someone who works with this material, in order to get the small piece you need with minimum expense.

The size of the sextant will depend on the printed scale size (that´s why there is no blue print). So, you will only "design" the instrument after you have stick the scale on the acrylic board.

The acrylic board comes with plastic layers in both sides, for protection. It's a good idea to keep this protection as long as possible, because the acrylic will be easily scratched. I carefully lifted the plastic protection (see below), stuck the scale and put the plastic back in place, so the sextant scale was also protected while machining the frame.



Lift the plastic protection, stick the scale, and put the protection back in place

After printing, cut around the scale, leaving like 3 mm around the outside line.

Sticking the printed scale in the board is a critical operation. It must be perfectly stuck, free of air bubbles or ripples. Otherwise the scale will not be correct.

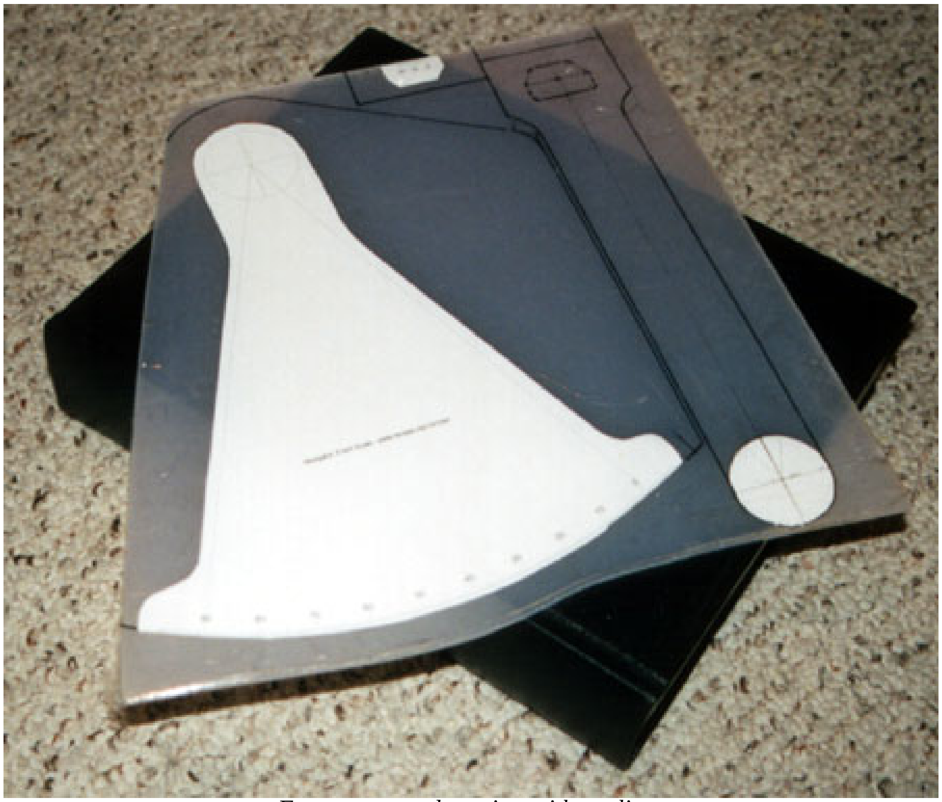
Remove from the sticker paper backing completely. Hold it with the two hands and gently place in the acrylic board, the arm axis circle first. Then use one hand to spread the scale, while holding the other side. Keep the paper slightly tensioned, but not so much as to distort it. If you make a mistake, you probably will have to print another scale and start again.

After this, you can use a marker pen to draw the parts (frame, arm and vernier).

The arm window (where the scale is read) must be sized and positioned so that you can see both the scale and the vernier touch point (that will define the arm radius). My octant arm is about 40 mm wide.

When designing the arm, measure the scale radius and add 10mm on either side (towards and away from the arm axis). My arm window is 30 mm wide.

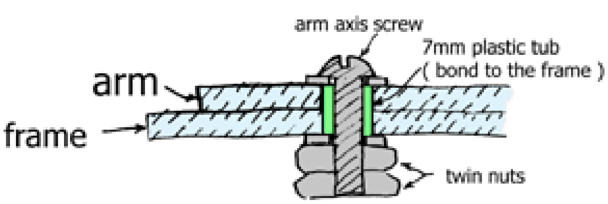
The image to the left shows the 3 frame parts, marked and ready to be cut.

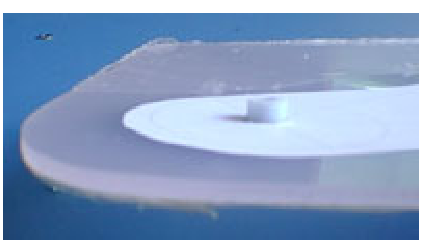


Frame, arm and vernier, with cut lines

I cut the parts with an electric jigsaw, with thin teeth blade. Take care when cutting along the scale ticks. Never cut across the scale line. If you are careful, you can cut as close as 0.5 mm from the scale. Then you will have little trouble sanding out the rest, until you precisely reach the fine scale line. Use fine sanding paper for finishing the scale arc.

Also carefully cut and sand the vernier contact point, testing frequently against the scale arc. The vernier and scale contact must be as close as possible.





To drill the arm axis hole, first mark it with a hard point. Drill a 2mm lead hole and then a 7 mm hole. Use sharp drills. Do the same in the frame and make sure the hole center is precisely positioned.

I inserted a 7 mm hard plastic tube in the axis, so there is no contact between the arm and screw as the arm is moved (only between the tube and arm). Bond the tube to the frame.

The axis screw goes in the middle, with twin nuts. Make sure there is no slack in the arm axis setup

After cutting, drilling and sanding, you can assemble the arm and frame for the fist time. Then you can position and bond the vernier in the arm, using a couple small drops of loctite (Cyanoacrylate glue). Use small self tap screws to secure the vernier.

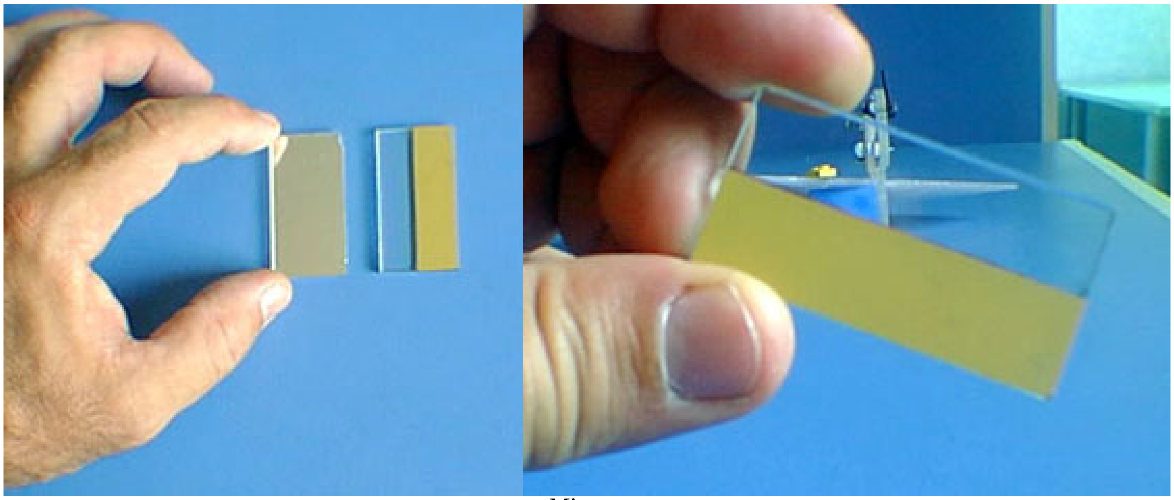
If you did these steps right, the vernier should be in smooth, close contact with the index, as you slide the arm along the arc.

Add a plastic device in the back of the arm to press it against the frame (the green part on the left image). It is important to have some friction between the arm and frame, so the instrument will hold the reading if left alone (i.e. the arm will not move by itself). This is also important for fine trimming.

Mirrors

I used 2 equally sized glass mirrors (46 mm x 24 mm, 3 mm tick). Any glass shop will cut these for you. As you know, one of the mirrors must be half silvered. So you must remove half of the mirror silver backing. I used a paper cutter blade for this job (Olfa cutter).

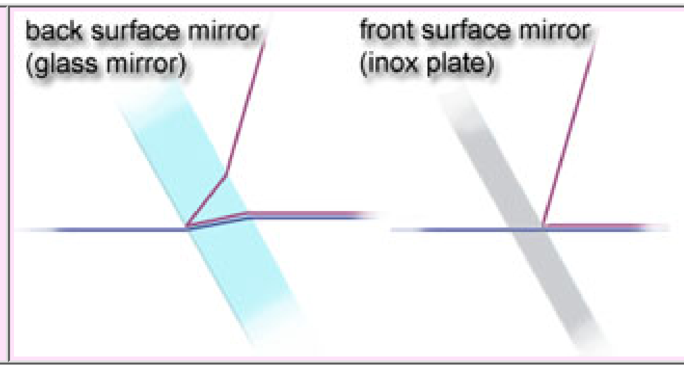
First make a sharp longitudinal cut along the middle of the mirror. Then scratch half of the epoxy protective layer from the back of the mirror, with the blade inclined. The epoxy backing is a hard material, but will come out with patience. Don't use any abrasive material or the blade point, to avoid scratching the glass. Once the epoxy is gone, the silver is easy to remove, rubbing hard with a wet cloth. In the end, the glass must be clear and scratch free (fig. below).



Mirrors

Note: You may be tempted at this point to use a thinner mirror and eliminate the transparent part altogether. Don´t do that. This would introduce a refraction error. The direct (horizon) light ray must pass thru the glass, as the light ray from the star does.

This can only be done if you use a front mirrored surface, such as a polished inox plate.



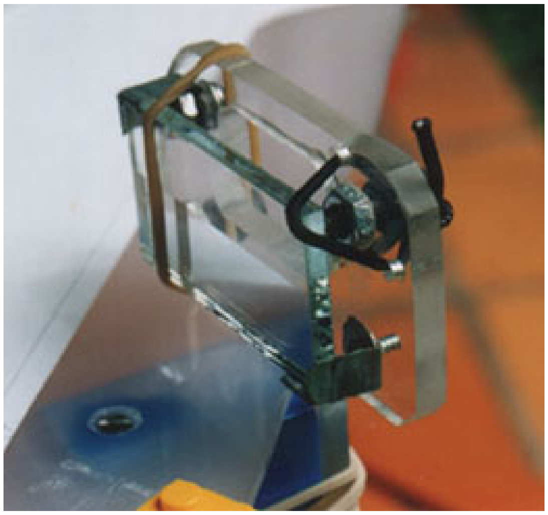
Mirror holders

I used a thicker acrylic for the mirror holders (4mm), as these parts are sometimes subjected to abuse. They will also have to be fixed with self tap screws so a thicker material is better.

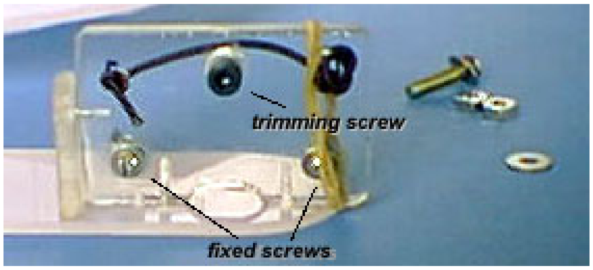
Both mirrors must be supported by three contact points (from geometry, we know that 3 points are required to define a plane). I used 3 supporting screws to position each mirror. Some of the screws are adjustable, for mirror trimming, and some are fixed. For the adjustable screws, I used Allen screws, which have a large head, easy to turn by hand. The fixed points are regular inox nut screws.

Make a point in all screw tips, to reduce the contact area between mirror and screw to a point. I also added thin metal plates to prevent the mirrors from moving sideways while trimming.

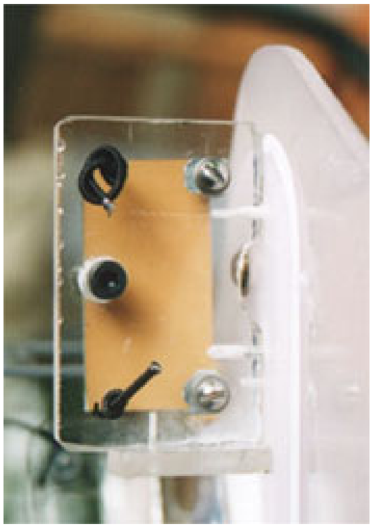
To ensure a perfect contact between the 3 screws and mirror, I used rubber bands (see right). These press the mirrors against the screws. Commercial sextants use metal springs for this function, but I could not find any suitable part in my junk collection.



Arm Mirror setup

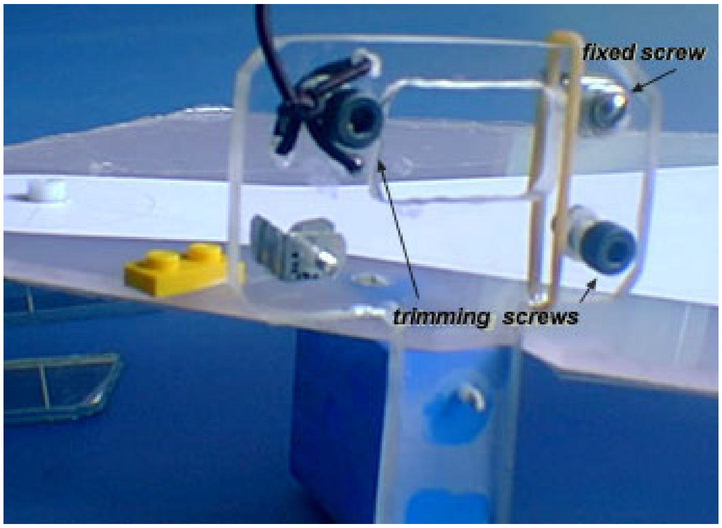


backview



The **arm mirror holder** is basically a rectangle, with a side supporting plate. The arm mirror has one adjustable screw (top screw in the figure above). Make a 1mm deep housing for the adjustable screw nut and bond it to the acrylic, so it wont move when you trim the screw.

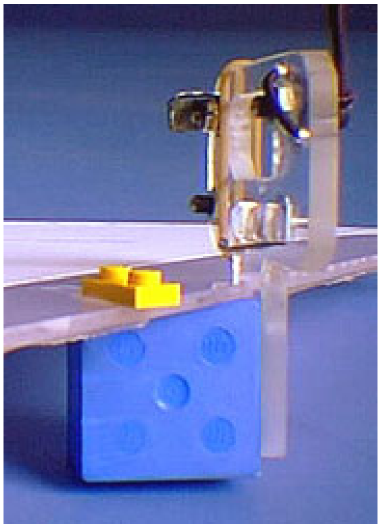
*The **frame mirror holder** is a T shaped part, with 2 adjustment screws (below). Cut a window, so that the sight thru the glass part of the frame mirror is clear.*



After completing the two mirror holder setups (i.e. after drilling, cutting, sanding and securing the mirror screws), you can bond them to the frame and arm. Start with the arm mirror.

The arm mirror assembly must be positioned so that the center of the mirrored surface (the back surface of the mirror) is over the arm axis center. This way the center of the mirrored surface (i.e. the back of the mirror) remains fixed while the arm is moved.

Make sure you have space to introduce and remove the arm axis screw, or you wont be able to assemble and disassemble the arm. After bonding with Loctite, use small flat head self tap screws to secure the assembly to the arm. Make a housing for the screw head, to avoid interfering in the arm movement.



After securing the arm mirror assembly, set the arm to 0°00' reading and place the frame mirror assembly parallel to the arm mirror. I used a Lego Dupplo block (the large blue piece) to support the frame mirror assembly. This way the right angle between the frame mirror and instruments plane is garanteed.

I like to use Lego parts (no, I'm not Lego sponsored) because they are widely available (at least in my house floor), have good dimensional precision and there are all sorts of blocks and devices.

Make sure both mirror holders are firm, by bonding and securing with screws. Having reached this point, you already have a sextant to take twilight sights. But you still need shades do take Sun sights.

Shades

As shades for Sun and Moon sights, I used 35 mm dark negative photography film (there is one in the end of every film roll). The negatives were mounted in slide frames. I used double negatives for the Sun frame and single for the Moon.

Both slide frames are removable and are attached to the instrument frame using Lego blocks (the yellow one in the pictures above). I must say I'm not happy with this fixation solution. A more skilled (less lazy) craftsman would probably do a better job, with some pivoting design.

The thing to watch here is the shade position. The filter surface must be orthogonal to the line connecting both mirror centers. This is to avoid introducing a refraction error. Try to position the slide center in the line connecting the two mirror centers.

Don't make the same mistake I did, letting the shade support interfere with the arm at large angles. The arm must go at least up to 90° (for the octant).

Sun shade

No eyepiece ?

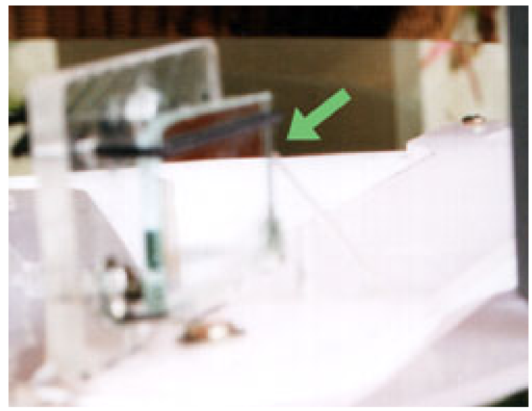
I was looking for a good 2x or 3x small telescope that I could use as an eyepiece for my sextant. I played with small toy telescopes, but results were poor. In the end, I decided to use no eyepiece. This actually gives a lot of freedom handling the sextant.

When taking a sight, remember to hold the instrument so that your eye is on a plane parallel to the instrument's and containing the fixed mirror silver-glass division. This is easy to find: turn the instrument up until you face the fixed mirror. In this position, you should see half of your eye in the silvered part of the mirror. Move it sideways until you see it. Then turn the instrument back down to observation position.

Trimming the mirrors

Trimming this octant is no different then any other sextant.

First trim the arm mirror adjustment screw. The arm mirror must be perpendicular to the arm/frame plane. This may be checked by looking at the index scale reflected in the arm mirror. The reflected index must be perfectly aligned with the index part you see directly (green arrow on the right).



Then trim the frame mirror. This is a little trickier, because two screws have to be trimmed simultaneously. Set the arm to 0°00' and point the instrument to a far object (like a star or boat far away). Then trim the two screws until the object remains a single image while you swing and rock about the instrument axis.

- - - - - - - - - - - - - - -

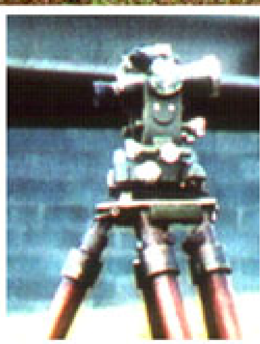
Sun sight

As future improvements, I would change to a better shade positioning system, add a nice handle and a case (I'm currently using a cardboard box). The case is probably the most important of the three, for a sextant - like a violin - is not be left hanging around, if it is to last long.

There are many materials, design ideas and garage junk devices that can used to build a Sextant. If you build such an instrument - using these ideas or not - I would like to hear about it. I would also be happy to publish other design solutions here.

A sextant is a fun thing to build, and getting a precise reading from your own instrument is one thing that will make you feel good.

- - - - - - - - -



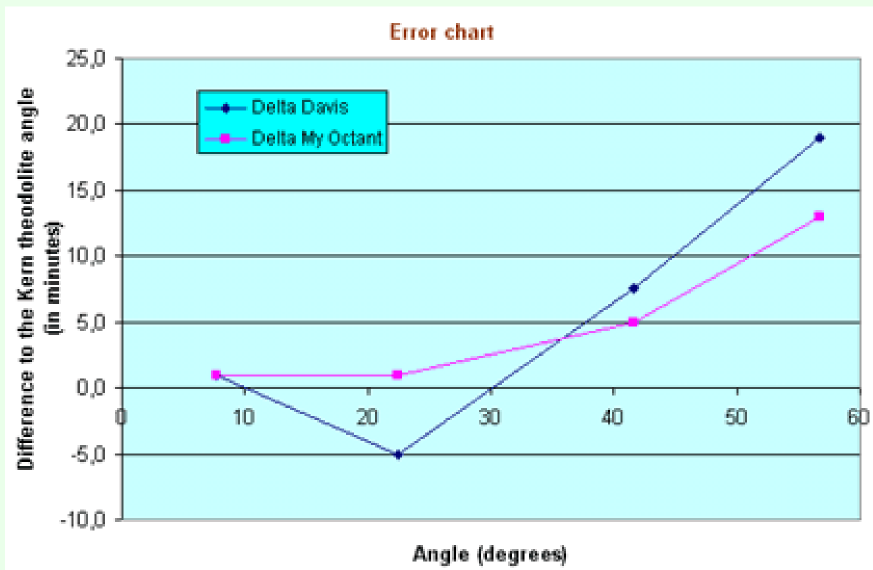
Sextant Field Test

I did some tests comparing the same vertical angles, measured by 3 different instruments:

1. A Kern theodolite
2. A Davis MK15 plastic sextant
3. My Octant

The theodolite (a survey instrument) is presumably more precise than the sextants and was used as a benchmark. Sextant angles were corrected for index error. I measured 4 vertical objects, obtaining the following results:

Object #	Kern theodolite	Davis sextant		My Octant	
1	7°41'	7°42'	+1'	7°42'	+1'
2	22°24'	22°19.5'	-5'	22°25'	+1'
3	41°37'	41°44.5'	+7'	41°42'	+5'
4	56°42'	57°01	+19'	56°55'	+13'



Bibliography

>> **"The American Practical Navigator "** by Nathaniel Bowditch
ISBN 0781220211 - 1200 pages

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History:

1. (jun/02) - Added text about inkjet printed scale problem with water spray.
2. (oct/02) - Added a arm axis screw diagram

3. (nov/02) - Added sextant test results and note about laser print transfer.
4. (fev/04) - Added note about mirror refraction

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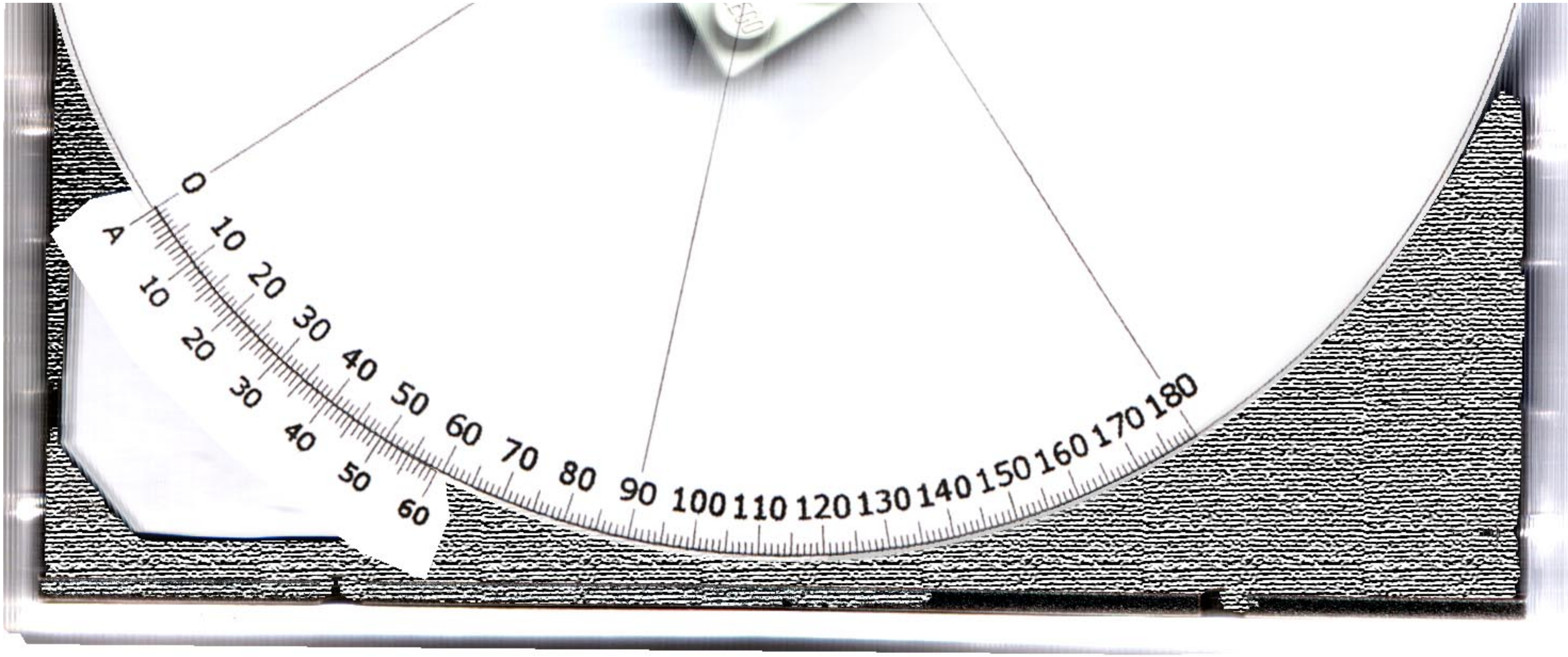
Navigator CD-Sextant - www.tecepe.com.br/nav/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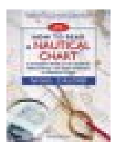

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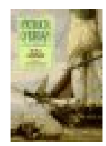

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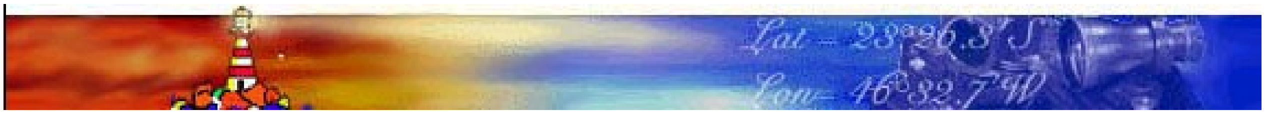

Navigator - Electronic version

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NAVIGATOR
Omar Reis

Navigator is a remarkable program, and has received high praise from many expert navigators. It embodies many features rarely found in one program, and certainly not at such a low price. Its many **celestial navigation features** are:

- Perpetual Almanac for all bodies (to year 2031)
- Star Finder
- Meridian passage calculation
- Lines of position calculation
- Fix calculation
- Print star finder and star charts
- Print daily pages of the almanac

The **star finder** is a polar chart of the visible sky at a given time and position. You can point at a star and see its name, altitude and azimuth. Or you can point on the speadsheet and see the corresponding star on the chart.

Lines of position are actually plotted on a small inset chart (centered at your estimated position) with all the data affecting its computation shown. **Fixes** are shown as a result of the LOPs.

Daily nautical almanac pages can be printed out. All that is needed is the initial date of a 3 day period. These pages are very similar to the official Nautical Almanac in arrangement and data, and show: star position tables (SHA and dec), sun and moon hour tables complete with increments and semi-diameter, planets hour tables with increments, aries hour table. Not included are: The latitude functions such as twilights and sun and moon rise and set, sun equation of time and meridian passage, and moon meridianpassage. While not intended to substitute for the official Nautical Almanac, it nevertheless is quite enough to do celestial navigation using the traditional methods.

Charting Features

- Scan your own charts
- Import GIF and JPEG images as raster charts
- NMEA GPS interface
- Create routes and tracks
- Plot position and save track in real time

It should be understood though, that this is primarily a celestial navigation program, and is not meant to replace other more expensive and more complete charting software. It will not read commercially available raster or vector charts. It will, however, read charts you scan yourself, and save as a GIF or JPEG image. In fact you will have unlimited zoom in or out capability with excellent clarity. This feature of making your own charts from paper charts, cruising guides, or even roadmaps is becoming very popular with navigators using other programs (such as Fugawi).

The program comes with a beautifully illustrated and comprehensive printed User1s Manual. System requirements are PC (486 or pentium) running Windows 95/98/ME/NT/2000/XP. SW 1 lb.

Navigator Software BUY
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Navigator - Celestial Navigation Software
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Navigator's performance.

*Navigator Light - particularly the **visible stars** command - does a great deal of floating point calculations. The use of a computer with numeric coprocessor is recommended. This particular command, that takes less than 0.5 sec on a Pentium 133, takes 12 seconds in a 486 SX 25.*

Navigator's calculation methods.

For the technically inclined.

Celestial navigation fundamentals | *On Line Almanac*

e-mail orion

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Navigator shareware version (1.0) known issues

A few problems have been found in version 1.0 of Navigator, which currently is available for download as the "shareware" version. Unfortunately I no longer support this version to correct the bugs. I will release a new limited feature version for free download in the future. In the mean time use this version as-is.

The known issues are:

1- Problem in the Local Time, GMT Time and Date editboxes. These are set to update each other as you type. Sometimes the 'stack overflow error' message appears, and the program terminates.

2- There is a systematic error of as much as 0.5' in the GHA of the Moon. This is related to dynamical time correction, which is wrong in this version. Note that this error is relatively small, as it will result in a 0.5 NM error in the position (not much for celestial navigation).

OFR nov/03

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Navigator Light for DOS

Important note (05/18/99): A bug was found in version **1.2** date input procedure that mislead the user to enter date in the wrong format (day and month switched). This resulted in absurd results.

The error is corrected in the new version 1.3, which is available for download.

The program version appears when you close the program. Check it out. If your version is not 1.3 or latter, updating is **strongly** advised.

Many people asked me about the DOS version. The reason: it is small enough to run on the little palmtop computers from HP, the HP95lx, HP100lx and HP200lx. These computers are very small and run on ordinary AA alcaline batteries. I made some changes in the graphics interface, so the program now draws the simplified chart in the palmtop screen, which has a different graphics interface.

I know this documentation is incomplete. The original program documenation - in portuguese - has 45 pages. Some of it is already translated in the web site (http://www.tecepe.com.br/nav/).

This document explains some aspects of operating Navigator Light for DOS. The program has all the same calculation features found in the Windows version, and even some that are not. Users familiar with the Windows version should have no problem.

Uploading NAV.EXE to the palmtop

Palmtops don't have floppy disk drives, so you have to use its serial port to upload the program from a desktop computer. In order to do this, you will need a special serial cable (HP part 82222A). To upload, use the Windows Terminal, or any communications program that support Xmodem or Kermit transfer protocols. You can also use the infrared port, if you have the IR adapter in your desktop computer.

Once the cable is connected, run the terminal in the PC and press the COMM key in the palmtop. Set both programs to 19200 bps, 8 data bits, 1 stop bit, parity none. Try typing something, to see if the other computer is receiving ok. Select either Kermit or Xmodem transfer protocols in both sides. Do the binary transfer of the file NAV.EXE. This transfer takes about 2 minutes.

Note: Once uploaded, you have to keep palmtop batteries charged or you loose the virtual disk data - and the program. AA Duracells will last 2 months, with minimal usage. Palmtops have a backup battery that keeps the memory while changing the main batteries. Keep spare batteries of both types. Check battery charge often.

Note: Navigator Light for DOS uses about 180k of memory. If the program gives a low memory error on start, try to allocate less memory to the virtual disk, leaving more memory for programs. Reserve at least 230k for programs. Read the palmtop manual for more details.

Running the program

This program runs in palmtops and PCS with MS DOS.

Running in a PC

type **NAV PC** (use the PC parameter)

Make sure you have CGA.BGI and EGAVGA.BGI files in the same directory.

Running in palmtops

You don't need any parameter. Just run **NAV.**

To start the program in the palmtop, use the FILER. Point the file NAV.EXE and press F4 (Run).

Operating the program

Once running, you can activate the **menu**, by pressing the space bar or the '/' key.

Menu commands can be activated by the capital letter, or by moving the cursor and pressing Enter.

Inputting data for Lines of Position calculation (LOPs)

1) First, select a celestial body, pressing 'B' 'S' (Body Select). Choose the celestial body.

2) To enter your measurements, press 'I' (Input)

- Press 'I' (Instruments) to enter Dip, IE, watch error and Time Zone
- Press 'D' (Date) to enter date of measurement (GMT date)
- Press 'P' (Position) to enter assumed position. Enter position in decimal notation, as in the following examples:

For 23°45.6'W, type 23.456 (Use negative for East longitudes)

For 54°32.1'S, type 54.321 (Use negative for North latitudes)

- Press 'A' (Altitude) to enter time of measurement and instrumental altitude. Enter altitude in decimal notation, as in the following example:

For 34°67.8' , type 34.678

3) Calculate the LOP, by pressing 'C' 'L' (Calc Lop). If Lop looks ok, press 'S' to save it for the Fix calculation.

Calculating an Astronomical Position (Fix)

After saving two or more LOPs, press 'C' 'F' (Calc Fix). Program will calculate the Fix. Press 'M' to see the map with your LOPs and astronomical position.

Download Navigator Light for DOS

This program is released as shareware. If you like it and plan to use it regularlly, please register your copy.

Registration is only US$35.

Click here to download version 1.3 for DOS.

(navdos.zip - Zip compressed - 92047 bytes)

Comments and bug reports

Please contact me via e-mail <omar@tecepe.com.br> or visit the website (http://www.tecepe.com.br/nav).

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Celestial Navigation Fundamentals

Note: This is the first chapter of the manual of Navigator Light, a DOS program I developed in 1993 (yes, my Navigator is older than Netscape's). The original Portuguese full text is available in this site.

This text is available in English, French and Portuguese

Angles, angles, angles...

Angles are the most common type of number used by the celestial navigator. The position of the celestial bodies and points on the surface of the earth may be described by angles. The sextant is an instrument that measures angles. Angles are usually measured in degrees, minutes and seconds. The complete circumference has 360 degrees (360°). One degree is equivalent to 60 minutes. The seconds of arc are not used in the celestial navigation, since the angle measurement instrument - the sextant - is not precise enough to measure them. The smallest unit of angle used by navigators is the tenth of minute. Recently, the popularization of GPS devices added the 1/100 of minute.

The nautical mile (=1852 m) is a unit conveniently selected to simplify the conversions between angles and distances. One nautical mile corresponds to an arc of one minute on the surface of earth. Angles and distances on the surface of earth are, therefore, equivalent. One exception is the minute of longitude, equivalent to one mile only near the Earth Equator. Another important equivalence is between time and degrees of longitude. Since the earth goes one complete turn (360°) in 24 hours, each hour corresponds to 15° of longitude. Or 900 Nautical miles (NM).

The Earth and the Celestial Sphere.

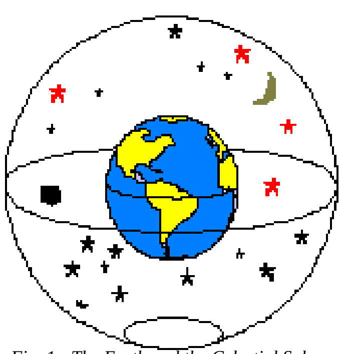


Fig. 1 - The Earth and the Celestial Sphere

Imagine that the Earth is the center of the universe and that around the Earth there is a larger sphere, centered in the same point, in which the stars are fixed, as if they were painted in its internal surface. This other ball we call the **Celestial Sphere.**

To specify a position on the surface of Earth we use a system of coordinates that consists of two angles: latitude and longitude. **Latitude** is the angle measured from the Equator in direction North-South. **Longitude** is the angle in the Pole between the Meridian of Greenwich and that of the considered position (fig. 2).

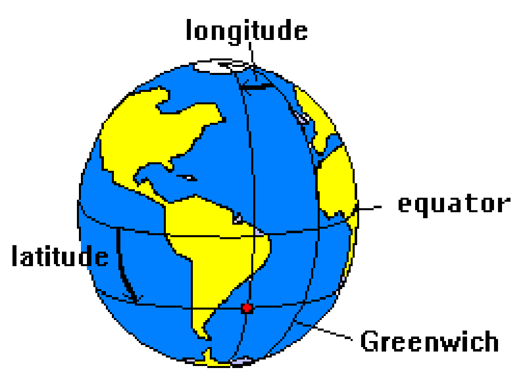


fig. 2 - Earth coordinate system

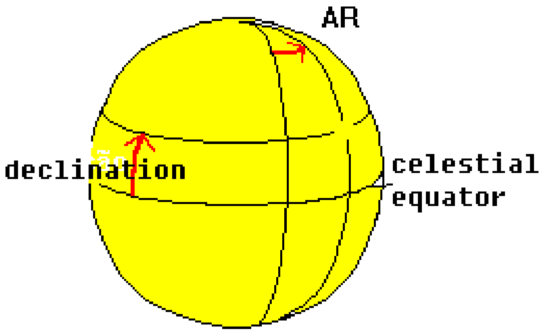


fig. 3- Celestial Coordinate System

A similar system is used for the Celestial Sphere. The angle analogous to the latitude in the celestial sphere we call **declination**. The declination is measured in the plane North-South, from the Celestial Equator. The analog to the longitude is named **Right Ascension** or **RA**. Like the longitude, the Right Ascension is measured from an arbitrary Meridian: the Vernal Equinox Point (a.k.a. first point of Aries).

Apparent movement of the stars

The stars have nearly fixed positions in the Celestial Sphere. The Sun, Moon and planets move around during the year, but their movement is slow when compared to the apparent movement due to the rotation of the Earth. So let's consider for now that the celestial objects (stars, planets, Sun and Moon) are fixed in the Celestial Sphere.

Using the Earth-at-the-center-of-the-universe model, imagine that the Earth is stopped and the celestial sphere is turning around it, completing a turn every 24 hours. You should not be confused by this idea: it's exactly what you observe if you seat and watch the night sky long enough.

The Earth's and Celestial Sphere's axes of rotation are in the same line. Both equators are, therefore, in the same plane (see fig. 1).

The stars, fixed to the celestial sphere, turn around the earth. The celestial sphere poles, being in the axis of rotation, remain fixed in the sky. So, a star located near a celestial pole will appear to be stationary in the sky. That's the case of **Polaris**, a star that is near the North Celestial Pole (its declination is 89°05' N). It's always in the north direction, a wonderful fact known by every navigator. Unfortunately there's no corresponding bright star near the South Celestial Pole.

Finding the Earth position by observing the stars

Now consider a line connecting the center of a star and the center of the Earth. The point where this line crosses the surface of the Earth we call **Geographical Position** of this star (or **GP**). An observer positioned in the GP of a star will see it directly in the vertical, above the head.

Since stars move with the celestial sphere, their GPs also move on the surface of the Earth. And they are fast. The Sun's GP, for example, travels a mile every four seconds. The GPs of other stars, closer to the celestial poles, move more slowly. The GP of Polaris moves very slowly, since it's very close to the North Pole.

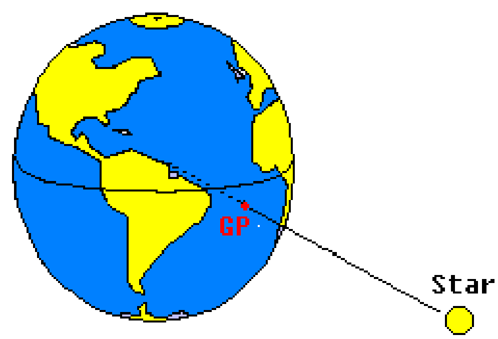
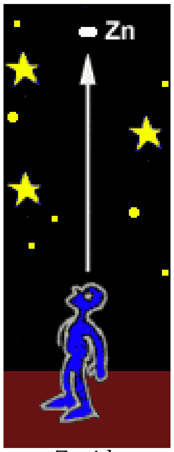


Fig. 4- Geographical Position of a Star

Because both Earth and Celestial equators are in the same plane, the latitude of the GP is equal to the declination of the star. The longitude of the GP is known as **Greenwich Hour Angle -** or **GHA -** in a reference to the correspondence between hours and longitude.

We can determine, using a Nautical Almanac, the GP of a star (it's GHA and declination) in any moment of time. But we must know the exact time of the observation. As we have seen, 4 seconds may correspond to one mile in the GP of a star. This shows the importance of having a watch with the correct time for the celestial navigation. The Beagle - ship of Charles Darwin's travel in 1830 - carried 22 chronometers on board when she went around the globe in a geographic survey.



Zenith

Another important point is the **Zenith**. The Zenith is the point in the celestial sphere located in the vertical, over the head of the navigator. The line that connects the Zenith and the center of the Earth crosses the surface in the position of the navigator, the one we want to find. So, we have the following correspondence between points:

Surface of Earth	Celestial Sphere
Geographical Position of a star	Center of the star
Position of the navigator	Zenith

In the figure 5, the GP of the star is represented by X and the Zenith by Z. The distance XZ, from the GP of the star to the point Z of the navigator is called **Zenith Distance**. This distance, as we have seen, can be expressed in miles or degrees, since it's an arc on the surface of the Earth.

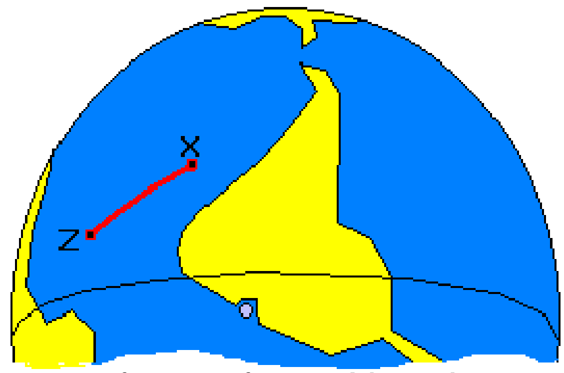


fig. 5 - GP of a star and the Zenith

The angle that XZ makes with the True North (i.e. the "bearing" of the star) is called **Azimuth** (**Az**) (fig. 6).

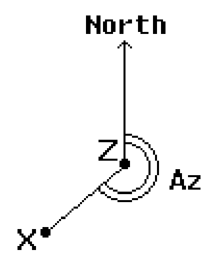


fig. 6 - Azimuth of a star

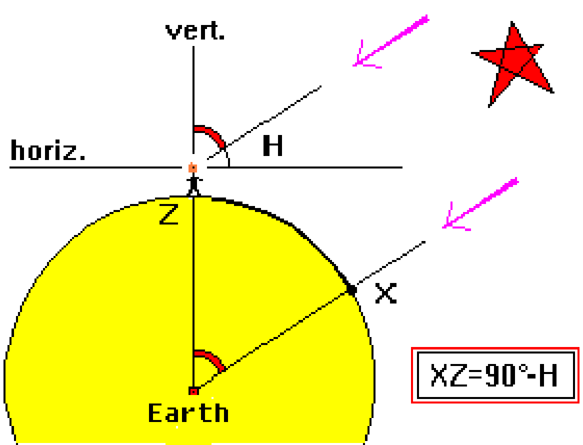


fig.7 - Altitude and Zenith distance of a star

The stars are at a great distance from the earth and so the light rays coming from them that reach the Earth are parallel.

Therefore, as illustrated in the figure 7, we may say that the distance XZ (as an angle) is equal to the angle that the navigator observes between the star and the vertical. This is important. **The distance XZ, measured as an angle, is equal to the angle that the navigator observes between the star and the vertical.**

However, it's difficult to determine the Zenith distance with precision, since it's difficult to find the vertical direction in a rocking boat. It's a lot easier to measure the angle between the star and the horizon. This important angle for the celestial navigator is called **altitude (H)** of the star. The altitude of a star is taken with the sextant held in the vertical plane, measuring the angle between the horizon and the star. In the fig. 7, we can see that the zenith distance equals 90° less the altitude of the star.

We have seen how to determine the zenith distance of a star using the sextant. The Zenith Distance and the GP of a star, however, are not enough to determine our position. With this data we can only say that our position is in a big circle, with the center in the GP of the star and radius equal to the Zenith Distance. This is known as the **Circle of Position**. Figure 8 shows a Circle of Position. Point X is the GP of the star.

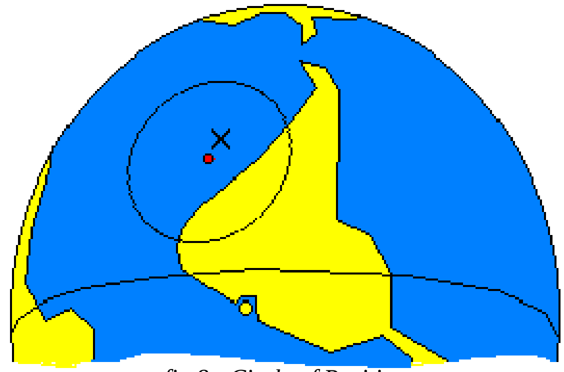


fig.8 - Circle of Position

Any observer located on this circle will see the star at the same altitude, but with different Azimuths. In the example of the figure, suppose the navigator observes the star with an altitude of 65°. As we have seen, the Zenith Distance is 90°-H, or 25°. To determine this distance in miles, we multiply by 60, since one degree is equal to 60 nautical miles (NM). So, the Zenith Distance in the example - the radius of our circle - is 1500 NM.

If we just could determinate the exact direction where the GP of the star is - it's Azimuth - that would establish where in the circle we are. How about using a compass? Unfortunately, the compass is not precise enough for celestial navigation. One error of just 3°, common when reading a compass, corresponds to 78 miles of error in our example! Not an acceptable error.

The way to find our position is to draw two or more circles - for two or more celestial bodies - and see where they intercept each other. But drawing these big circles would require really big charts! We work around this problem by making a guess at our **position**. No matter how lost we are, we can always make a guess. Using this **assumed position** we can calculate **expected altitude** for the star at a given time (using the Nautical Almanac).

This **Calculated Altitude** can then be compared with the **Observed Altitude** (the actual altitude, measured with the sextant). The difference is the error of our assumed position (also known as **Delta**) in the direction of the star. The Delta can be towards the star or away from it.

>> Click here for the next page

>> Homepage

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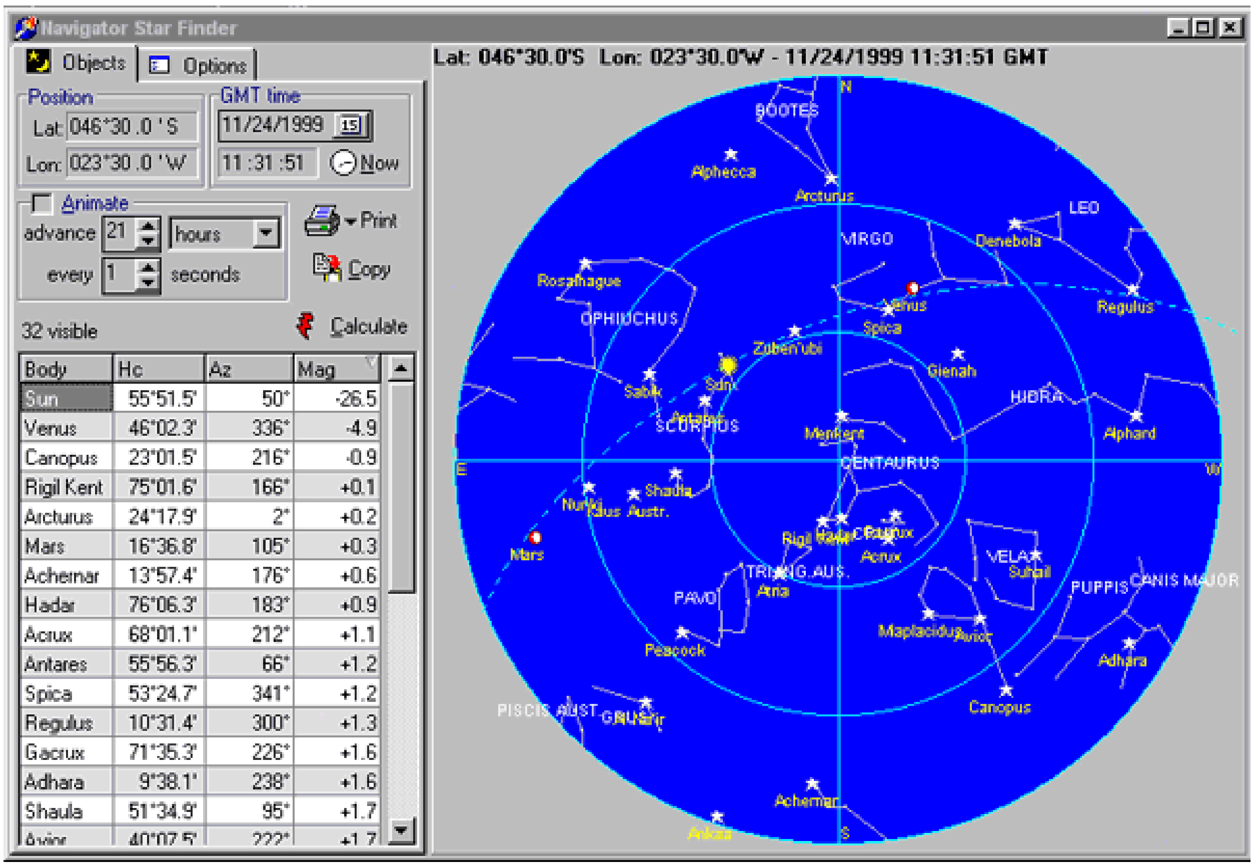
Navigator screen shots

In this section, you will see how **Navigator** features look like:

Star Finder

The figure below shows the Navigator's star finder window. This is a polar chart of the visible sky in a given time and position. You can point a star and see it's data (Name, Altitude and Azimuth). Or you can point on the spreadsheet and see the corresponding objects on the chart.

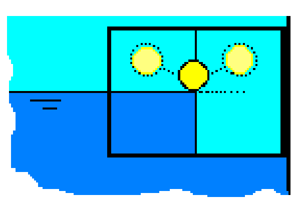


The center of the chart is the Zenith and the external circle is the horizon. The two blue concentric circles are the 30° and 60° altitude. The best stars to observe are between these two circles (altitudes between 30° and 60°) .

Line of Position

Calculating a Line of Position is easy. Input:

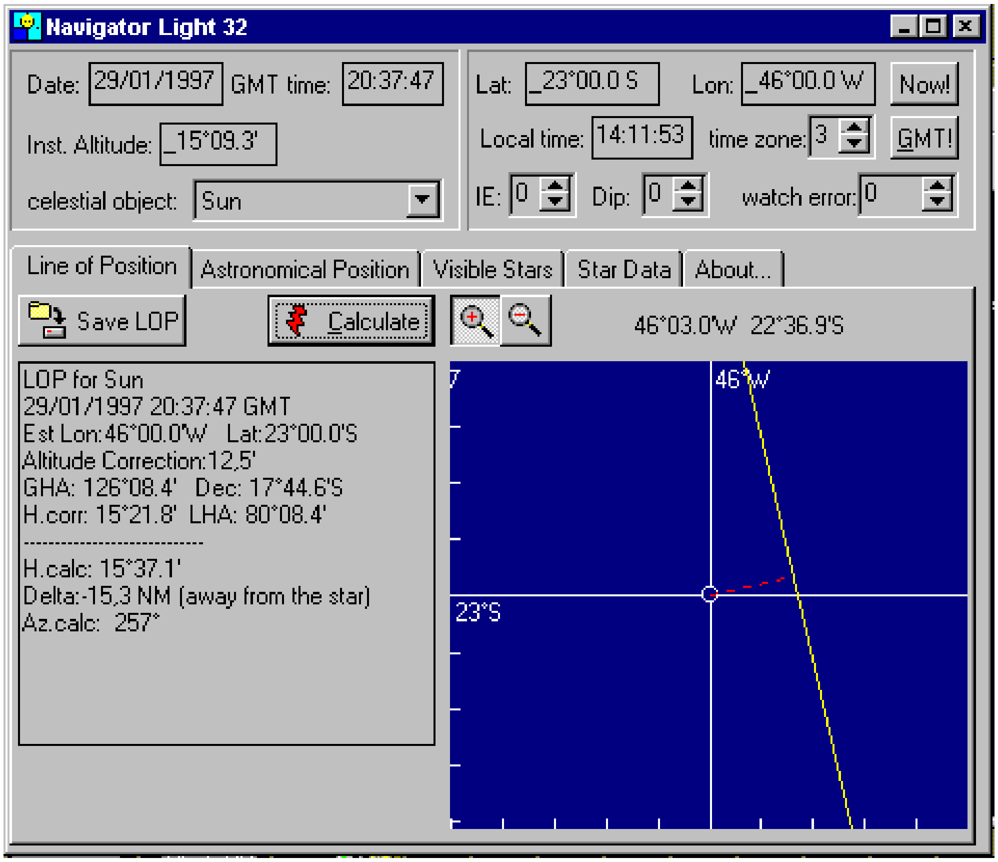
- Date and GMT time of the observation. You can also input the local time and click **GMT!**. The program will calculate the GMT time, adding the time zone and watch error. Click **Now!** to fill with the current date and time.
- Select the star observed.
- Instrumental altitude of the star. For the Sun and Moon, use the altitude of the lower limb, as shown.



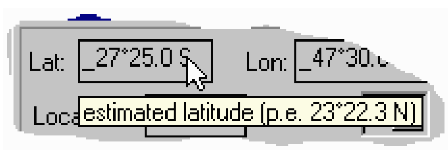
- *Estimated position (Latitude and Longitude).*

- *Index Error in minutes and Height of the eye in meters or feet.*

*Press **Calculate**. The LOP will show in the chart, as illustrated.*



All input fields and buttons have hints that explain what they are and what units should be used. Place the cursor over the field to see the hint.



Astronomical position

After you calculate two or more Lines of Position, you can calculate your astronomical position. The figure bellow shows an astronomical position calculated with 2 LOPs. Note the blue chart, showing the LOPs diagram. The astronomical position is indicated by the white circle. Use the cursor to zoom in and out. Auto transport LOP feature makes calculating a running fix an easy task.

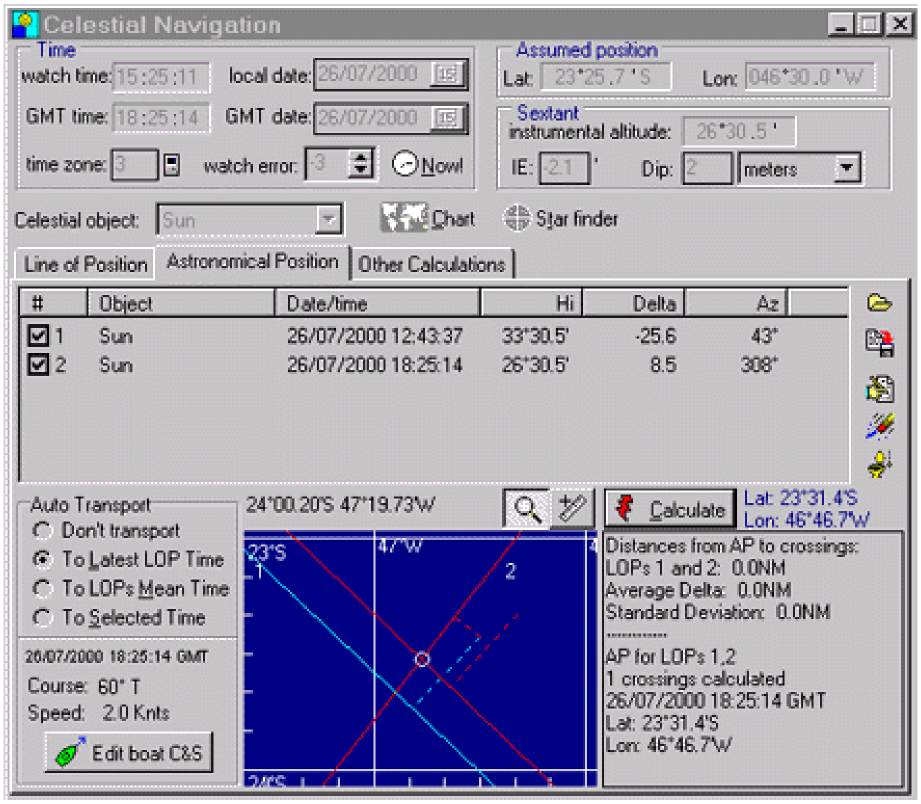


Chart Navigation

Navigator Chart Viewer can work with vector and raster charts. Vector charts can be produced with ChartMaker program (also included in the registered version). There are a couple charts available in our **chart library**. It can also import popular raster image formats, like GIF, JPG and BMP. None of the other proprietary chart formats is supported at this time.

In the Navigator chart viewer you can:

- View multiple charts, integrated in a whole world vector chart background.
- Draw routes and calculte leg distances and courses
- Connect a GPS and save your track on-line
- Draw marks, with text.
- Calculate rhumb lines and lines of great circle and generate routes.

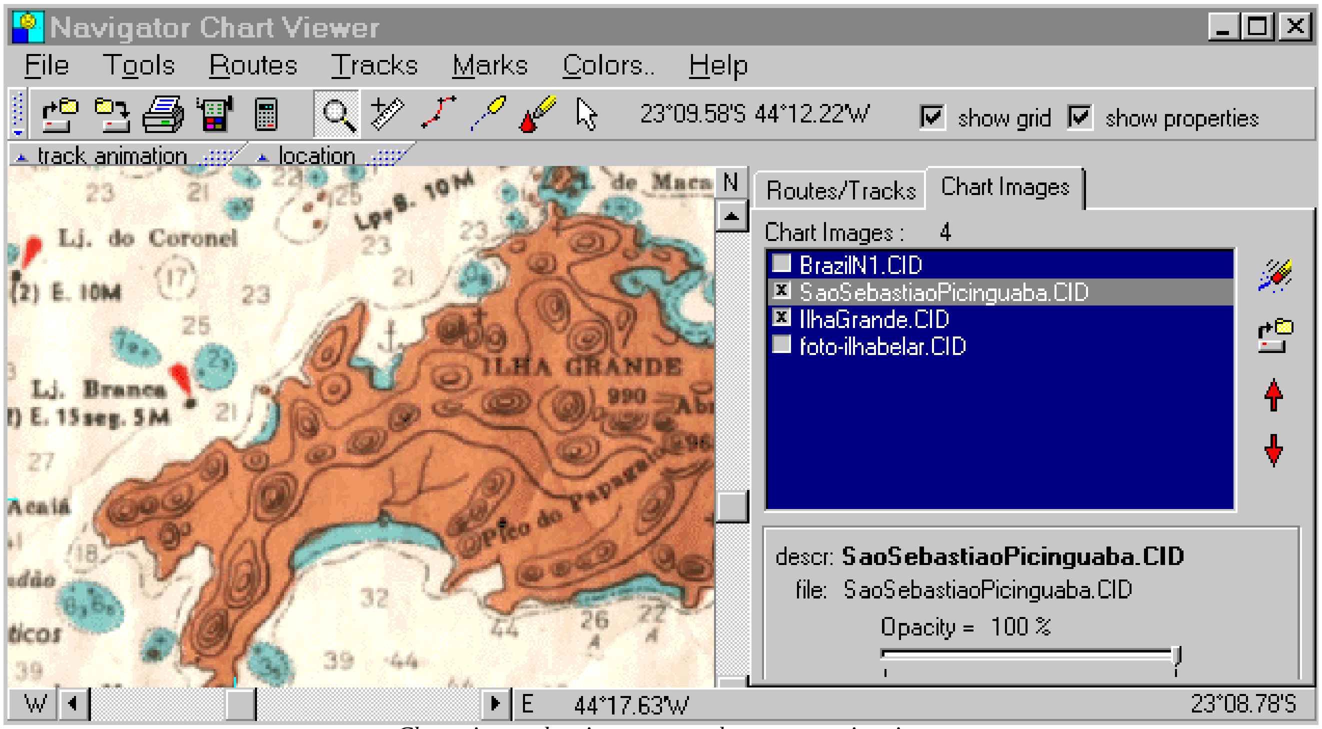


Chart viewer showing a raster chart zoom animation

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Astronomical observations

Date:		twilight time:		assumed lat:		assumed lon:		
index error:		watch error:		time zone:		Obs:		
celestial object		**sky preparation**		**observations**		**results**		
LOP	**Name**	**Altitude**	**Az**	**Time**	**Hi**	**Delta**	**Dir**	**Az**
1								
2								
3								
4								
5								
6								
Astronomical position for ____ LOPs				Lat:		Lon:		

Date:		twilight time:		assumed lat:		assumed lon:		
index error:		watch error:		time zone:		Obs:		
celestial object		**sky preparation**		**observations**		**results**		
LOP	**Name**	**Altitude**	**Az**	**Time**	**Hi**	**Delta**	**Dir**	**Az**
1								
2								
3								
4								
5								
6								
Astronomical position for ____ LOPs				Lat:		Lon:		

Date:		twilight time:		assumed lat:		assumed lon:		
index error:		watch error:		time zone:		Obs:		
celestial object		**sky preparation**		**observations**		**results**		
LOP	**Name**	**Altitude**	**Az**	**Time**	**Hi**	**Delta**	**Dir**	**Az**
1								
2								
3								
4								
5								
6								
Astronomical position for ____ LOPs				Lat:		Lon:		

Navigator Light Software - www.tecepe.com.br/nav

Keeping the time

keeping the time is crucial to have good results from celestial navigation. This is because the Earth is in constant rotation, moving 15° each hour. So, each 4 seconds error in the time will result in a position error of up to one nautical mile.

Longitude is the coordinate affected by time errors. In fact, if you don't have the correct time, you can't calculate your longitude by celestial navigation.

The traditional way to calculate the time using celestial navigation is by performing a **Lunar Calculation**. This uses the Moon fast celestial sphere movement as a clock. More details **click here**.

In the old days of mechanical clocks, keeping the time was a real nightmare. Chronometer paces were affected by boat movement and temperature. They were kept near the boat keel (where boats rocks less). Larger ships usually carried many chronometers, to improve reliability. The Beagle (the ship Charles Darwin went around the globe, in a geographical survey) carried 22 chronometers on board.

They were wound once a day, always in the same time by the same person and with the same number of turns. The expensive precise chronometers would remain on a safe place and the time would be copied to a smaller, cheaper watches for day to day use. All this care to make sure these devices behaved in a predictable way.

Today quartz watches are much more reliable and predictable. They are not affected by boat movement and little affected by temperature. Any good quality quartz watch can be used for celestial navigation. But we still have to use some old techniques:

- Having two or more watches is necessary, for reliability. At least one of them should be kept in a safe place, protected from the sun and water.
- Know your watches (and the watches of other crew members). A watch behavior should be observed well before taking it to the sea as a navigator watch. You must know how much time the battery will last and how the watch error increases over time, compared to the official Universal Time (UTC).
- Calculate the watch error change rate every two weeks, starting at least 3 months before the actual navigation use. Most electronic watches have a stable error change rate. I use a TIMEX that adds 4.5 seconds every month.
- Keep a page in the navigation log book for each watch, were information about battery changes, time adjustments and watch error change pace are kept. This page can also be used calculate the current watch error.
- Have spare batteries on board.
- Forget the computer built in clock. These are very bad clocks and behave erratically. Use a good quartz watch instead.

Getting the time from the Internet

As I said, the computer clock is less reliable then a quartz watch. But you can use your computer to obtain the accurate time, as long as it is connected to the Internet. There are several reliable time sources in the Internet. These are accessible using SNMP, Time and Daytime protocols compatible clients.

A good time keeping program is **Dimension 4**. It can be installed as a service and will automatically keep the computer clock adjusted while connected to the Internet. It is freeware. Reference time sources include the US Naval Observatory and several universities and research centers. Check Dimension 4 **web site**.

An interesting URL is **http://nist.time.gov**. This is a Java applet with the official US Government time. Click the UTC link to get the GMT time. It's said to be within 0.6 sec, depending on your internet connection. And requires no client software installation.

Other time sources

Correct UTC time can be obtained in a number of sources.

- There are short wave band radio stations that broadcast the time continuously. The Hydrographic Office publishes a list of these stations worldwide (H.O. 117).
- TV and radio networks usually have good time keeping, to coordinate their network activities.
- Large vessels always have the correct time.
- GPS receivers are also a good time source, as they receive time data from very precise atomic clocks on the GPS satellites.

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Navigator celestial calculation methods

Most of algorithms used in Navigator software come from two sources: the book "Astronomical Algorithms" by Jean Meeus and the Almanac for Computers (US Naval Observatory - 92).

1) Calculation of celestial body positions: Right Ascension (RA) and declination (Decl)

1.1) Sun - Positions calculated using the VSOP 87* theory, with accuracy within 0.2'.

1.2) Stars - Starting from Nautical Almanac positions on 1/1/1993 00:00:00 UT, positions calculated by adding the effects of precession, nutation and aberration. The effects of the proper movement of stars were not calculated since they are small (considering the precision needed for celestial navigation). Star positions are precise when compared to planets and the Moon. The accuracy is within 0.2'. Positions valid at least until 2100.

1.3) Planets - Planets have by far the most complicated calculation method of all celestial bodies. Calculated the rectangular heliocentric coordinates of the planet and the Earth, using numerical series (VSOP 87 theory*). Then added the apparent effect of the time of propagation of the light and calculated the geocentric coordinates, adding the effects of nutation and aberration. Accuracy within 0.6'.

(* Variations Séculaires des Orbites Planétaires 87 - French planetary theory by Bretagnon and Francou of the Bureau des Longitudes of Paris).

1.4) Moon - The coordinates of the Moon were calculated by formulas, which gives an accuracy within 0.2' (In versions prior to Oct./2001, this accuracy was within 0.7')

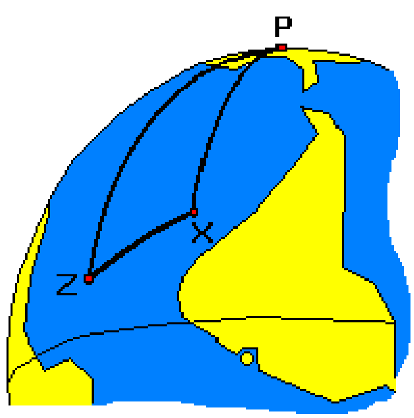
1.5) GHA of celestial bodies is calculated using the formula GHA=15* (GAST-RA) , were :

GAST (Greenwich Apparent Sidereal Time) calculated with approximated formula.
Precision within 0.2 sec.

1.6) Universal Time (UT) to Dynamical Time (TD) difference calculated by a combination of tables (from 1620 to 1992), actual values (from 1992 to 2001), short term predictions (from 2001 to 2016) and prediction formula (after 2016 and before 1620).

2) Solution of the position triangle PXZ

Position triangle PXZ is an spherical triangle and the solution requires the use of spherical trigonometry formulas (law of sines and law of cosines). read more>>



3) Calculated Altitude and Azimuth:

Calculated altitude Hc:
sin (Hc)=sin j * sin d + cos j * cos d * cos (LHA)

Calculated Azimuth Az:
tan (Az) = sin (LHA) / (cos (LHA) * sin j - tan d * cos j)

were:

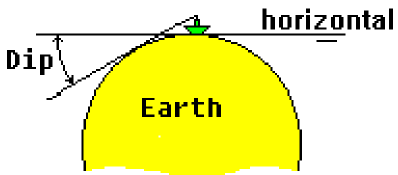
j : Latitude of observer
d : Declination of star
LHA : Local Hour Angle (LHA = GHA - Observer's Longitude)
Also used the following relationships:
j =90°-PZ
d =90°-PX
XZ=90°-Hc

4) Corrections to the Instrumental Altitude

Hc = Hi + TC
TC = IC + Dip - R + SD + Par
were:

TC: Total Instrumental altitude correction
Hc : Corrected altitude
Hi : instrumental altitude
IC : Instrumental correction (Index Error)

Dip: Correction relative to the height of the eye is calculated with the formula:



Dip = -0.97 * Sqrt(h/0.3048))

Dip in minutes.
h is the height of the eye, in meters

Some users correctly noted that the factor in the formula deduced using trigonometry differs significantly from -0.97. I can only speculate that this is related to refraction correction, but I'm not sure. This formula is described in the Almanac for Computers (USNO) and I use it because does agree well with the Nautical Almanac table, which is my preferred benchmark.

R: Atmospheric refraction (calculated with approximate formulas, depending on the body altitude)

SD: Semidiameter (Calculated for the Moon and Sun and 0 for planets and stars)

Par: Parallax in altitude (Calculated for the Moon, 0 for all others)

5) Solution of the Astronomical Position (AP)

For each LOP (Line of Position):

$$LatQ = LatE + d^* \text{ Cos } Az$$
$$LonQ = LonE - d^* \text{ Sen } Az / \text{Cos } LatE$$
$$a = Az + 90°$$

were:
d : Delta (error of the estimated position, in the direction of the Azimuth
E : Estimated position
Q : Intersection point between line of Azimuth and LOP.
a : Angle between the LOP and the true North
Az : Azimuth of the star.

The equation of the LOP *i* in the plane can be expressed by:
$Lat = a_i * Lon + b_i$

$a_i = -\cos(LatQ) / \tan Az_i$
$b_i = LatQ + Lon Q * \cos(LatQ) / \tan Az_i$
Factor Cos(LatQ) makes the conversion between horizontal Nautical Miles and minutes of longitude.

Make the intersection of each two lines *i* and *j*

$LatX = (b_i . a_j - b_j . a_i) / (a_j - a_i)$
$LonX = (LatX - b_i) / a_i$

were X is the point of intersection.

The astronomical position is found using the average of all the LOPs intersections, as follows:

$L= Sum (L_{ij} . \cos a_{ij}) / Sum(\cos a_{ij})$

for every i different from j, were L is the Latitude or Longitude. The use of the factor (cos a) gives smaller importance to intersections of LOPs forming small angles between them.

Bibliography

>> **"Astronomical Algorithms"** by Jean Meeus
ISBN 0943396611 - Willman-Bell

buy from **Amazon**

Complete positional calculation methods for stars, planets, Sun and Moon. Accurate descriptions, with many examples. Excellent book for any astronomy programmer.

>> **"Astronomical Formulae for Calculators"** by Jean Meeus
ISBN 0943396220 - Willman-Bell

buy from **Amazon**

Simple positional astronomy formulas, easy to program on pocket calculators or personal computers.

>> **Almanac for Computers** - 1992 publication by the US Naval Observatory, with simple formulas for the Sun. Also good source for sextant corrections.

>> **HP 65 Math Pack 1 documentation** - Geodesic formulas
1974 - Hewlett-Packard - Early programmable calculator software manual with many useful formulas.

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Chapitre 1: Les bases du Point Astro.

Note: Ceci est le premier chapitre du manuel de Navigator light, un programme DOS développé en 1993. (Hé oui ! Mon "Navigator" est plus vieux que Netscape!). Le texte intégral en Portugais est disponible sur ce site.

This text is available in english, french and portuguese

Traduction française©: William Talgorn (williamtalgorn@hotmail.com)

"E pur si muove" Galileu Galilei

Angles, angles, angles...

L'angle, comme nous le verrons dans ce chapitre, est l'unité la plus utilisée par le navigateur Astro. La position des corps célestes et des coordonnées à la surface de la terre peut être représenté par des angles. Le sextant est un instrument qui mesure les angles. Alors rappelons quelques généralités sur les angles.

Les angles sont généralement mesurés en Degrés, minutes et secondes. La circonférence d'un cercle fait 360 Degrés. Un degré est équivalent à 60 minutes. Les secondes d'arc ne sont pas utilisées pour le point Astro, car le sextant n'est pas assez précis pour les mesurer. L'unité d'angles la plus petite utilisée par le navigateur est le dixième de minute.

Le Mille Nautique (=1852 m) est l unité qui a été choisie pour simplifier les conversions entre angles et distances. Un mille nautique corresponds à un arc d'une minute, sur la surface de la terre. Ainsi, les angles et les distances, a la surface de la terre, sont égaux. Une exception a cette règle: Une minute de longitude est égale a 1 mille nautique, mais seulement près de l'équateur.

Une autre équivalence importante se retrouve entre le temps et les degrés de longitude. Puisque la terre fait un tour complet (360°) en 24 heures, chaque heure correspond à 15° de longitude. C'est à dire 900 Milles Nautiques (MN), Compris ?

La Terre et la Sphère Céleste

Imaginez que la terre est au centre de l'univers - (y'en a qui ne croient plus a ça aujourd'hui, mais bon...) - et qu'autour de la terre se trouve une plus grande sphère, le centre au même point, dans laquelle la position des astres est fixe, comme si ils étaient peints sur la surface intérieure de cette sphère. Cette autre sphère nous l'appelons la **Sphère Céleste.**

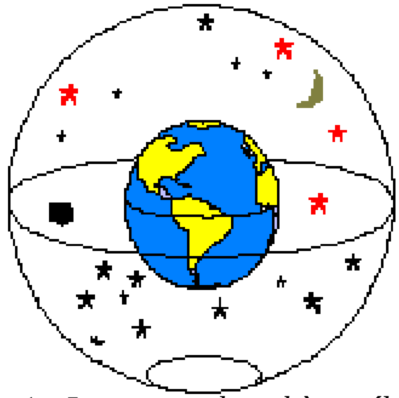

Fig. 1 - La terre et la sphère céleste.

Pour définir une position à la surface de la terre nous utilisons un système de coordonnées qui représente deux angles: La latitude et la longitude. La Latitude est l'angle mesuré à partir de l'équateur, sur le plan Nord-Sud. La **Longitude** est l'angle entre le Méridien de Greenwich et une position donnée. (Fig. 2.

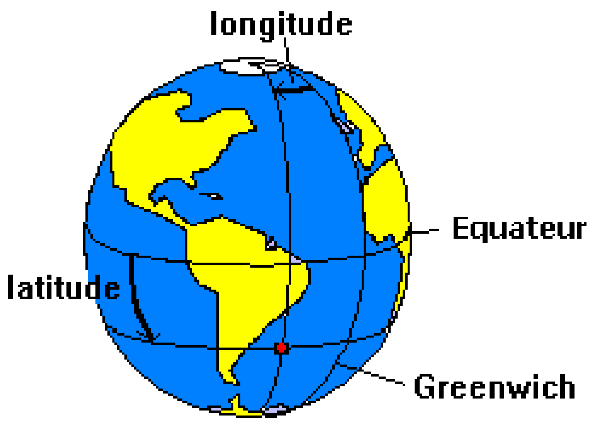

fig.2 - Système de coordonnées Terrestre.

C'est la même chose pour la sphère céleste. La mesure équivalente à la latitude sur la terre, s'appelle **déclinaison** sur la sphère céleste. La déclinaison se mesure aussi sur le plan Nord-Sud à partir de l'équateur. La mesure équivalente à la longitude sur la terre s'appelle l'**Ascension Droite**, ou **AD.** Comme la longitude, l'ascension droite est mesurée à partir d'un méridien arbitraire: Le point Vernal d'Equinoxe (alias Point origine du Bélier)

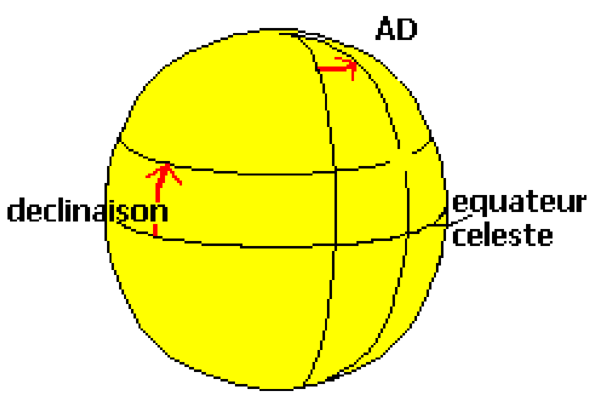

fig.3 - Système de coordonnées céleste

Le Mouvement Apparent Des Etoiles

Les astres ont une position presque fixe dans la sphère céleste. Le soleil, la lune et les planètes bougent pendant l'année, mais leurs mouvements sont lents comparés au mouvement apparent dû à la rotation de la terre. Alors imaginons pour l'instant que ces objets célestes (Les étoiles, les planètes et la lune) sont immobiles dans la sphère céleste.

En reprenant l'idée que la terre est au centre de l'univers, imaginons que la terre s'arrête, et que la sphère céleste tourne autour, faisant un tour complet en 24 heures. Que cette idée ne vous désoriente pas... c'est exactement ce que l'on observe quand on regarde le ciel étoilé !

Les axes de rotation de la terre et de la sphère céleste sont alignés. Les deux équateurs sont donc sur le même plan (fig. 1)

Les astres, "collées" à la sphère céleste, tournent aussi autour de la terre. Les pôles de la sphère céleste, étant sur l'axe de la rotation, reste immobile dans le ciel. Donc, un astre qui se trouve près d'un pôle céleste apparaîtra comme étant stationnaire dans le ciel. C'est le cas de l'étoile polaire, qui est une étoile se trouvant près du pôle nord céleste (sa déclinaison est de: 89°05' N). Elle indique toujours le nord, un fait bien connu des navigateurs. Malheureusement, une étoile aussi brillante n'existe pas près du pôle sud.

Trouver sa Position Grâce aux Etoiles

Maintenant imaginons une droite connectant le centre d'une étoile au centre de la terre. Le point où cette droite touche la surface de la terre est appelé la **Position Géographique** de cette étoile (**PG**). Un observateur se trouvant à la position géographique d'une étoile se trouvera directement à sa verticale, et la verra exactement au-dessus de sa tête.

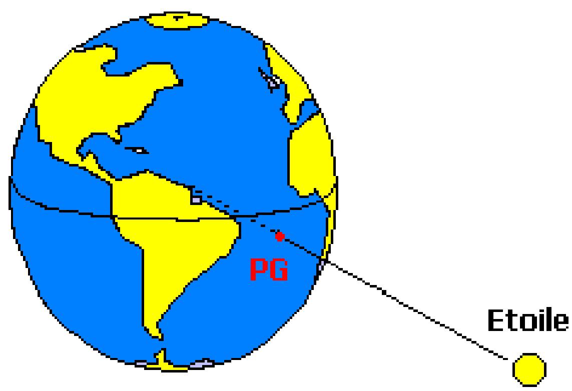

Fig.4 - Position géographique d'une étoile.

Puisque les astres suivent le mouvement de la sphère céleste, leurs PG bougent simultanément sur la surface de la terre. Le PG du soleil, par exemple, couvre une distance d'un mille nautique toutes les 4 secondes. Le PG d'autres astres, plus proches des pôles célestes, bougent plus lentement. Le PG de L'étoile Polaire se déplace très lentement, puisqu'il est très proche du pôle Nord.

Parce que les deux équateurs sont sur le même plan, la latitude du PG est égale à la déclinaison de l' astre. La longitude du PG est appelée **Angle Horaire du soleil a Greenwich** ou **AHvo**. En référence à la correspondance entre les heures et la longitude.

Nous pouvons déterminer, en utilisant les éphémérides nautiques, le PG (AHvo et déclinaison) d'un astre à n'importe quel moment dans le temps. Nous devons connaître l'heure exacte qui nous intéresse. Comme nous l'avons vu, 4 secondes peuvent correspondre à 1 mille pour le PG d'un astre. Ceci démontre l'importance d'avoir une montre très exacte pour le point Astro. Le "Beagle", (le bateau de Charles Darwin) transportait 22 montres a bord durant sa circumnavigation en 1830.

Un autre point important est le **Zénith**. Le Zénith est le point dans la sphère céleste, à la verticale, au-dessus du navigateur. La droite qui relie le Zénith et le centre de la terre transperce la surface de la terre au point exact où se trouve le navigateur, celui que nous cherchons à déterminer. Nous avons les correspondances suivantes entre ces points:

Surface de la terre	**Sphère Céleste**
Position Géographique de l'étoile	Centre de l'étoile
Position du navigateur	Zénith

Sur le schéma ci dessous, le PG de l' astre est représenté par X et le Zénith par Z.

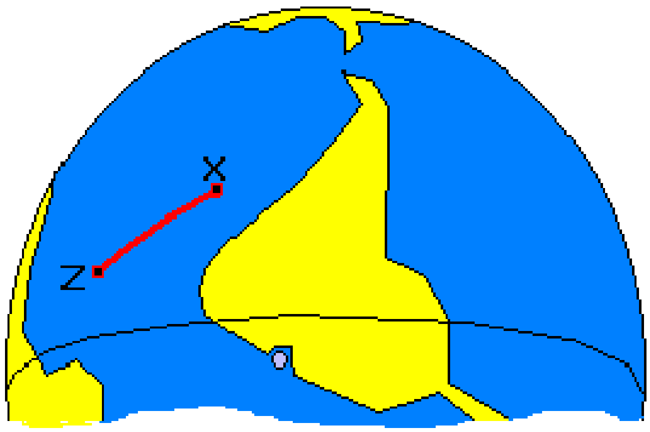

fig. 5 - PG d'une étoile et son Zénith

La distance XZ, du point X (PG de l' astre) et le point Z du navigateur est appelé la distance Zénithale. Cette distance, comme nous l'avons vu, peut s'exprimer en milles ou en degrés, puisque c'est un arc sur la surface de la terre.

L'angle que fait XZ avec le Nord vrai est appelé l'**Azimut** (Az) de l' astre (fig. 6). L'azimut est la direction horizontale vers laquelle se trouve le PG de l' astre.

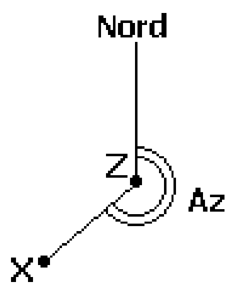

Fig. 6 - Azimut d'une étoile.

Les astres se trouvent à une grande distance de la terre, c'est pourquoi leurs rayons lumineux qui atteignent la terre sont pratiquement parallèles. Ainsi, comme l'illustre le shema 7, Nous pouvons dire que la distance XZ (c.a.d l'angle) est égale a l'angle observé par le navigateur entre l' astre et la verticale. Ceci est TRES IMPORTANT. **La distance XZ, mesurée en angle, est égale à l'angle que le navigateur observe entre l' astre et la verticale.**

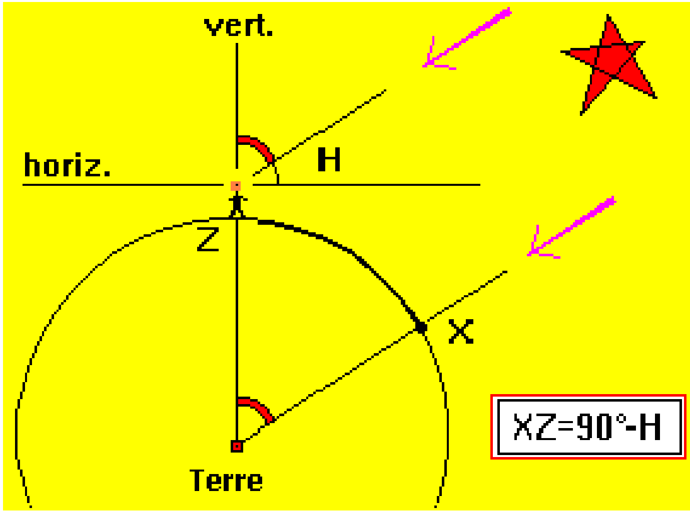

fig.7 - *Altitude et Distance Zénithale d'une étoile*

Il est difficile de déterminer la distance Zénithale avec précision, car il est difficile de trouver la direction verticale exacte sur le pont chahuté d'un bateau. Il est beaucoup plus facile de mesurer l'angle que fait l'astre avec l'horizon. Cet angle important pour le navigateur Astro. est appellé la **Hauteur (Ho)** de l'astre. La hauteur d'un astre est déterminée avec un sextant sur le plan vertical, en mesurant l'angle entre l'horizon et l'astre. Sur le shema 7, on peut voir que la distance Zénithale est égale a 90° moins la hauteur de l'étoile.

Nous avons vu comment déterminer la distance Zénithale d'un astre en utilisant le sextant. La distance Zénithale et le PG d'un astre, ne sont cependant pas suffisants pour déterminer notre position. Avec ces données nous pouvons seulement dire que notre position se trouve sur un grand cercle, dont le centre est le PG et dont le rayon est égal à la distance zénithale. Ce cercle est appelé le **Cercle de Position.** Le shema 8 montre un cercle de position. Le point X est le PG de l astre.

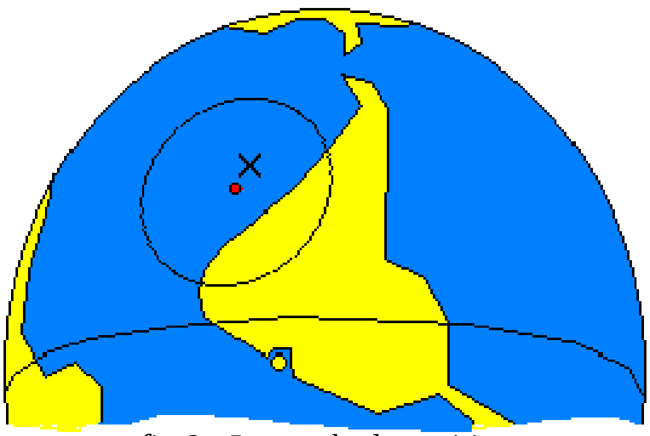

fig.8 - *Le cercle de position*

Tout observateur situé sur ce cercle verra l' astre à la même hauteur, mais avec un azimut différent. Regardons le shema 8 et supposons que le navigateur a relevé une hauteur de 65°. Comme nous l'avons vu, la distance Zénithale est égale a 90°-H, soit 25°. Pour convertir cette distance en milles, on multiplie par 60, puisqu'un degré est égal à 60 milles. Donc, la distance Zénithale de notre exemple c.a.d. le rayon de notre cercle, est égal a 1500 MN (Milles nautiques).

Si seulement nous pouvions déterminer la direction exacte du PG de l' astre et son azimut, cela nous permettrais de savoir où nous sommes sur ce cercle. Et si on utilisait le compas? Malheureusement, le compas n'est pas suffisamment précis pour un point Astro. Une erreur de seulement 3°, commune lorsqu'on lit un compas, correspond à une erreur de 78 milles dans notre exemple !

La façon de connaître notre position exacte est de dessiner 2 cercles ou plus, pour 2 objets célestes ou plus, et voir ou ils s'intersectent. Mais dessiner ces cercles demanderais des cartes géantes ! On évite ce problème en estimant notre **position**. Peu importe si l'on est complètement perdu, nous pouvons toujours l'estimer. A partir de cette **position estimée**, nous pouvons calculer une hauteur pour un astre observée à une heure donnée, en utilisant les Ephémérides Nautiques.

Cette **Hauteur Calculée** peut maintenant être comparée avec notre **Hauteur Observée** (celle mesurée avec le sextant). La différence entre les deux représente l'erreur entre notre position estimée et notre position réelle, que l'on appellera l'**Intercept**. L'intercept peut se tracer vers l' astre ou au contraire, à l'écart de l' astre.

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Capítulo 1 - fundamentos da navegação astronômica.

"E pur si muove" Galileu Galilei

Ângulos, ângulos, ângulos...

Ângulos, como veremos neste capítulo, são a matéria prima do astrônomo. As posições dos astros e dos objetos sobre a Terra são dadas por ângulos. O sextante é um instrumento que mede ângulos. Até as distâncias na superfície da Terra podem ser expressas na forma de ângulos. Por esta razão, cabe uma pequena discussão sobre o assunto.

Os ângulos são medidos em graus, minutos e segundos. A circunferência completa tem 360°. Um grau corresponde a 60 minutos. Os segundos de grau não são usados na navegação, uma vez que o sextante não tem precisão suficiente para medi-los. A menor unidade de ângulo para o navegador astronômico é o décimo de minuto.

A milha náutica (=1852 m) é uma medida que foi definida convenientemente de modo a simplificar as conversões entre ângulos e distâncias. Uma milha náutica corresponde a um arco de um minuto de grau sobre a superfície terrestre. A qualquer momento podemos converter ângulos de graus para milhas e vice-versa. Ângulos e distâncias são, portanto, equivalentes. Uma exceção são os minutos de longitude, que valem uma milha somente nas proximidades do Equador terrestre.

Uma outra equivalência importante da navegação é entre horas e graus de longitude. Como a Terra faz uma volta de 360° a cada 24 horas, cada hora corresponde a 15° de longitude.

A Terra e a Esfera Celeste

Vamos imaginar por um momento que a Terra esteja no centro do universo. Embora hoje saibamos que este modelo é pouco realista, ele foi adotado por muito séculos e pode nos ajudar a compreender a navegação astronômica. Imaginemos que em torno da Terra está uma outra esfera maior, centrada no mesmo ponto, onde os astros estão fixados, como se estivessem pintados na sua parede. Esta outra bola é chamada de **Esfera Celeste**.

fig. 1 - A Terra e a Esfera Celeste

Para especificar nossa posição na Terra, usamos um sistema de coordenadas que consiste de dois ângulos. A **latitude** é a distância em graus medida a partir do Equador terrestre na direção Norte-Sul. A **longitude** é o ângulo no polo entre os meridianos de Greenwich (na Inglaterra) e do ponto considerado (fig. 2).

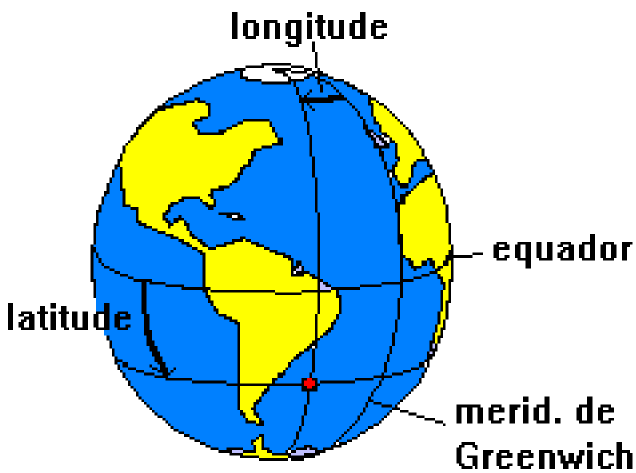

fig.2 - Sistema de coordenadas terrestres

De modo análogo, a posição de um astro na esfera celeste pode ser descrita por dois ângulos. À medida equivalente à latitude do astro na esfera celeste chamamos **declinação**. A declinação é medida na direção Norte-Sul a partir do equador celeste. A medida correspondente à longitude do astro na Esfera Celeste é denominada **Ascensão Reta**, ou AR. A figura 3 mostra o sistema de coordenadas celestes. Assim como a longitude é medida a partir de um meridiano arbitrário (Greenwich), a Ascensão Reta é medida a partir do chamado Ponto Vernal (também chamado de primeiro ponto de Áries).

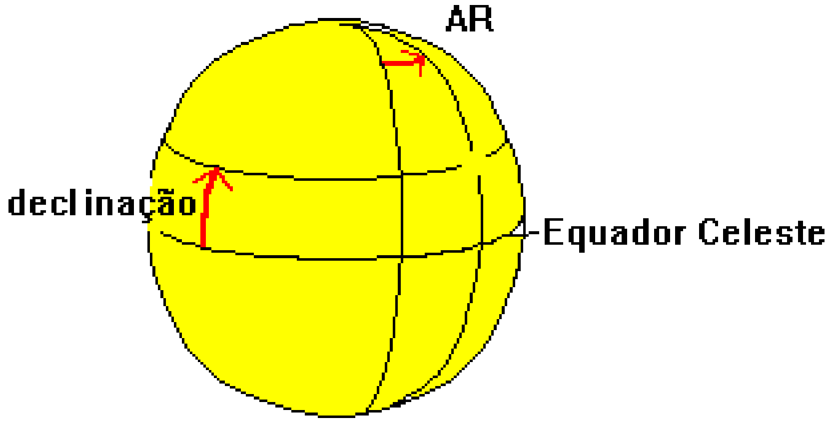

fig.3 - Sistema de coordenadas celestes

O movimento aparente dos astros

As estrelas tem suas posições quase fixas na Esfera Celeste. O Sol, a Lua e os planetas se movem ao longo do ano, mas este movimento é lento quando comparado ao movimento devido à rotação da Terra. Consideremos por hora que os astros tem posições fixas na Esfera Celeste.

Usando ainda o conceito da Terra como centro do universo, vamos imaginar que a Terra esteja parada e que a Esfera Celeste gire em torno dela, completando uma volta a cada 24 horas. O Eixo de rotação da Esfera Celeste passa pelos polos da Terra e da Esfera Celeste. Os equadores da Terra e da Esfera Celeste estão, assim, no mesmo plano (fig. 1).

Os astros, fixos na Esfera Celeste, também giram em torno da Terra. Os polos celestes, estando no eixo de rotação, ficam parados no céu. Assim, um astro situado próximo a um polo da Esfera Celeste parecerá estar estático quando visto da Terra. É o caso da estrela Polaris, que se situa nas proximidades do polo Norte Celeste (sua declinação é de 89°05'N). Ela está sempre na direção Norte. É fácil, portanto, determinar o Norte pela estrela Polaris. Infelizmente ela não pode ser vista aqui do hemisfério Sul e não existe nenhuma estrela tão convenientemente posicionada no Polo Sul Celeste.

Determinação da posição pelos astros

Suponha agora que em um determinado instante traçamos uma reta ligando o centro de um astro ao centro da Terra. O ponto onde esta reta "fura" a superfície da Terra é chamado de **Posição Geográfica do astro**, ou simplesmente PG (fig.4). Um observador colocado sobre a PG de um astro verá este astro diretamente na vertical, sobre a sua cabeça.

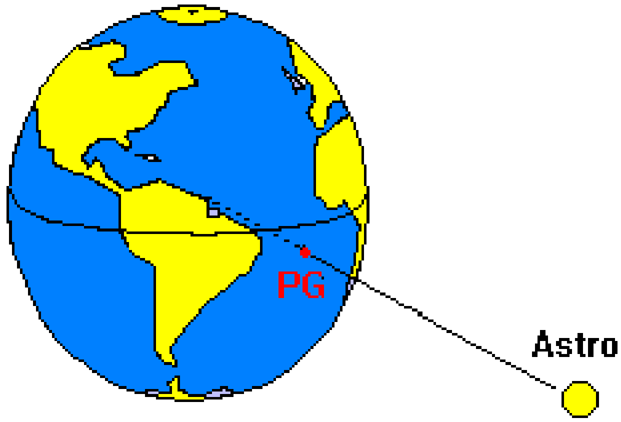

Fig.4 - Posição Geográfica do Astro

Uma vez que o astro gira junto com a Esfera Celeste, a sua PG se move na superfície da Terra. A PG do Sol, por exemplo, se move a uma velocidade de aproximadamente 900 nós - cerca de 1 milha náutica a cada 4 segundos. Outros astros mais próximos dos polos se movem mais lentamente. A PG de Polaris se move bem lentamente (cerca de 14 nós), uma vez que ela está próxima do Polo Norte.

Como os equadores terrestre e celeste estão no mesmo plano, a latitude da PG é igual à declinação do astro. A longitude da PG é chamada de **Ângulo Horário em Greenwich** ou AHG, numa alusão à correspondência entre horas e longitude.

Podemos determinar, com auxílio do Almanaque Náutico, a Posição Geográfica (AHG e declinação) de um astro em qualquer instante. Para isso é de fundamental importância que saibamos o momento exato que nos interessa. Como vimos, 4 segundos de erro podem significar até 1 milha de erro na PG do astro. Isto dá idéia da importância de se ter um relógio com a hora precisa para a navegação.

Um outro ponto importante é o **Zênite**. O Zênite é o ponto da esfera celeste situado na vertical, sobre a posição do navegador. A reta que une o Zênite ao centro da Terra fura a superfície terrestre na posição do navegador, a posição que pretendemos determinar. Temos então as seguintes correspondências entre pontos:

Superfície da Terra	Esfera Celeste
Posição Geográfica do Astro	Centro do Astro
Posição do navegador	Zênite

Na figura abaixo, a PG do astro é representada pela letra X e o Zênite pela letra Z.

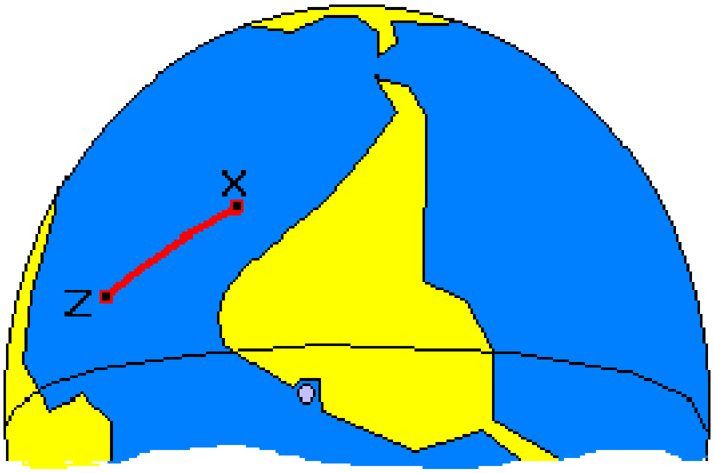

fig. 5 - PG do astro e Zênite

A distância XZ do ponto X (PG do astro) ao ponto Z do navegador é chamada de **distância Zenital**. Esta distância pode ser expressa em tanto em milhas como em graus, já que representa um arco sobre a superfície esférica da Terra.

O ângulo horizontal que XZ forma com o norte verdadeiro é chamado **Azimute (Az) do astro** (fig. 6). Azimute, assim, é a direção ou rumo em que se encontra a PG do astro.

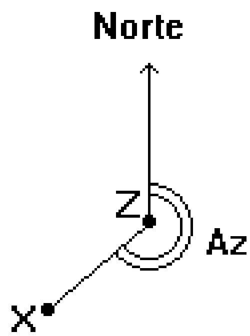

fig. 6 - Azimute do astro

Os astros estão a grande distância da Terra de modo que os raios de luz provenientes deles que incidem sobre a PG (ponto X) e sobre o navegador (ponto Z) são paralelos. Deste modo, conforme ilustrado na figura 7, podemos concluir que a distância zenital (XZ), medida em graus, é igual ao ângulo que o navegador observa entre o astro e a vertical. Vou repetir. **A distância zenital, medida em graus, é igual ao ângulo que o navegador observa entre o astro e a vertical.**

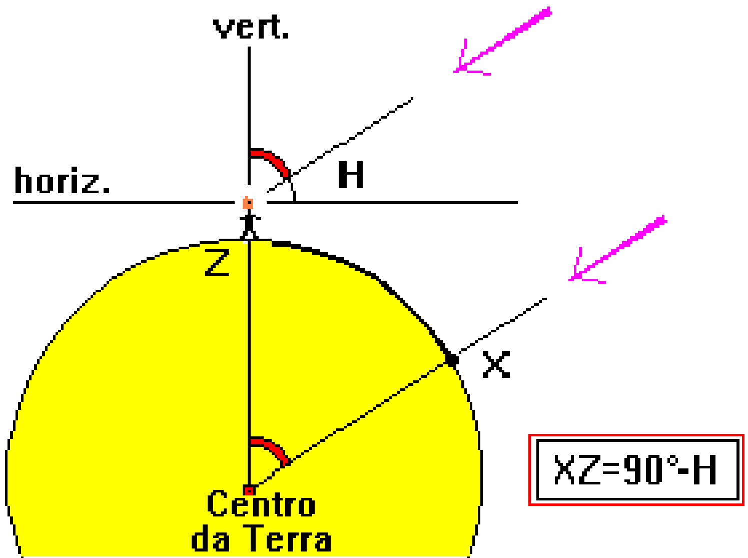

fig.7 - Altura e distância zenital de um astro

É difícil, porém, medir este ângulo dada a dificuldade de se determinar com precisão a direção vertical. É mais fácil medir o ângulo formado entre a horizontal e o astro. Este importante ângulo para a navegacão é denominado **altura (H)** do astro. A altura do astro é tomada com o sextante na vertical, medindo-se o ângulo entre o horizonte e o astro. Ainda pela figura 7, podemos ver que a distância zenital é igual a 90° menos a altura do astro.

Vimos como determinar a distância zenital de um astro usando o sextante. A distância zenital e a PG do astro, contudo, ainda não são suficientes para determinarmos nossa posição. Com esses valores, sabemos somente que nossa posição real está sobre o círculo cujo o centro é a PG do astro e o raio é a distância zenital. Este círculo é chamado **círculo de altura.** A figura 8 mostra um círculo de altura. O ponto X é a PG do astro.

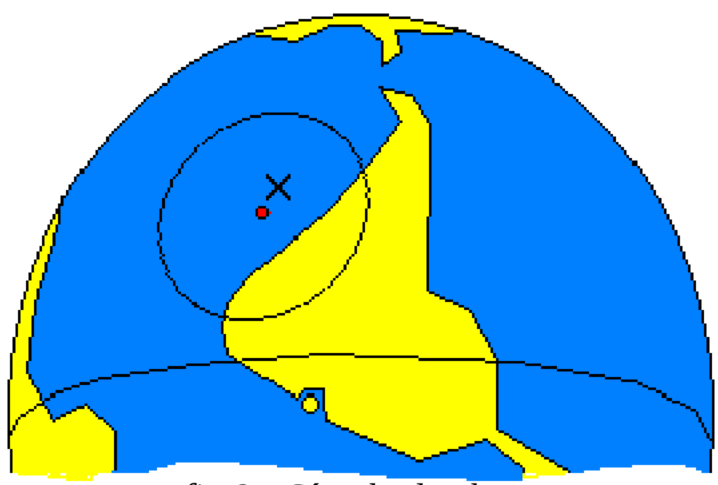

fig.8 - Círculo de altura

Qualquer observador posicionado sobre este círculo vê o astro com a mesma altura, só que em Azimutes diferentes. No exemplo da figura, suponhamos que um navegador posicionado sobre o círculo observe o astro a uma altura de 65°. Como já vimos, distância zenital é 90°-H, ou 25°. Para determinar a distância zenital em milhas, multiplicamos por 60, pois cada grau equivale a 60 milhas. Assim, a distância zenital do exemplo da figura, que é também o raio do círculo, é de 1500 milhas.

Se pudéssemos determinar com a bússola a direção exata em que se encontra a PG do astro - o Azimute - poderíamos dizer em que ponto do círculo de altura estamos. Esta determinação, contudo, não é possível com a precisão necessária à navegação. Ainda no exemplo da figura 8, um erro de apenas 3°, normal em leitura de bússolas, corresponde a um erro de 78 milhas na posição!

Tomemos então uma estimativa de nossa posição. Por mais perdidos que estejamos, sempre é possível estimar mais ou menos nossa posição. Poderemos, a partir da Posição Geográfica do astro (obtida no Almanaque Náutico) e da distância zenital (calculada com a altura do astro medida com o sextante), determinar o **erro de nossa estimativa na direção** do astro. Este erro pode tanto ser no sentido do astro como no sentido contrário ao astro. É chamado de **Delta**.

2a parte do Capítulo 1 |Índice do manual

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Celestial Navigation Fundamentals - Continued

This text is available in English, French and Portuguese

<< click here to go to previous page

Because a Geographical Position of a star is normally thousands of miles from our position, the circle of position is very large and the small piece that interests us - the one near our position - may be considered a straight line, orthogonal to the Azimuth of the star. This line is called the **Line of Position** or **LOP** (fig. 9).

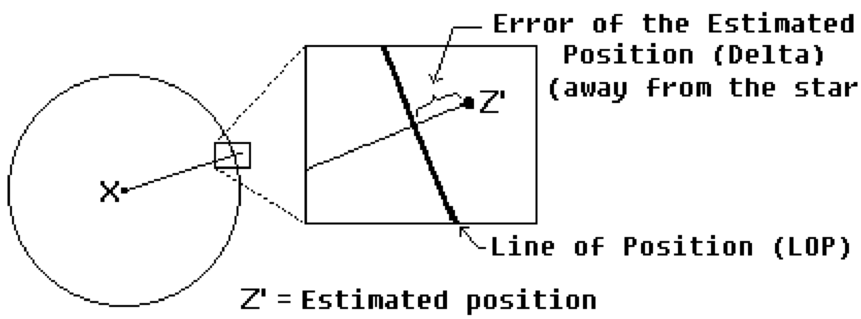

fig. 9 - Line of Position

We managed, from the measured altitude of a star at a certain time and our assumed position, to draw a line of position. We know that our actual position is somewhere along this line. To determine this point we can draw another line, for another star. The point were they intercept each other is our position - or our **Astronomical Position**.

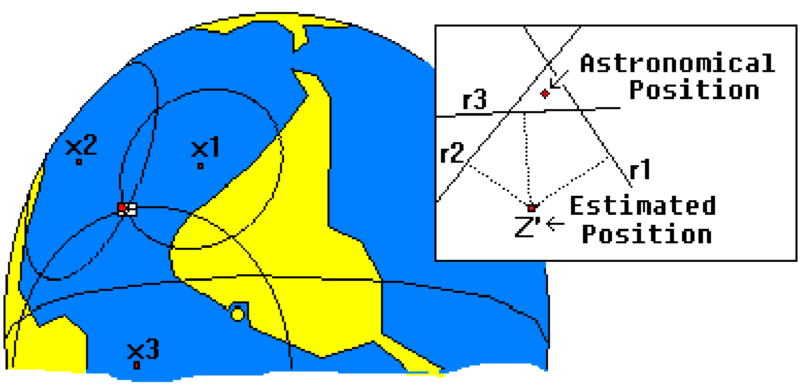

fig. 10 - Triangle formed by the intersection of three lines of Altitude

Normally, the navigator should repeat this procedure for yet another star, just to be sure. Since measurements are affected by minor imprecisions, the three lines will probably not intercept in a single point, resulting in a small triangle. Our position is probably in some point of this triangle (fig. 10). The smaller the triangle, the better. We usually assume that our Astronomical Position is in the center of the triangle.

In figure 10 above, we can see how three circles of position determine 3 Lines of Position r1, r2 and r3.

In traditional celestial navigation the determination of a Line of Position involves the computation of the GP of the star (GHA and declination) using the Nautical Almanac and the solution of the **Position Triangle** PXZ, formed by the terrestrial pole (P), the GP of the star (X) and the assumed position of the navigator (Z) (see fig.11).

This solution, using tables, yields the Calculated Altitude and the Azimuth of the star. The difference, in minutes of degree, between the calculated altitude and the altitude of the star measured with the sextant is the distance between the line of position and our assumed position - the error **Delta** of our estimate. This can be away or towards the star.

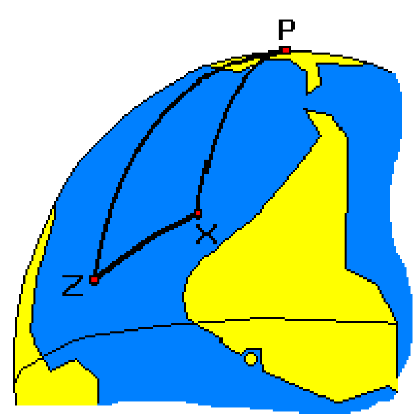

fig. 11 - Triangle of Position PXZ

Using *Navigator* software, the GP of a star and the triangle of Position are solved by the computer using formulas. All you will have to do is enter the sextant reading (date, time and altitude), name of the star and the assumed position (latitude and Longitude).

Determination of the Astronomical Position

It's not necessary to draw the lines of position when using *Navigator* software. But let's see how this is done using pencil and paper:

1. Plot your assumed position.
2. Using a parallel ruler, draw a line passing on the assumed position, in the direction of the Azimuth of the star.
3. Over this line, measure the error Delta of the estimate - in the direction of the star or contrary to it - according to the sign of the Delta.
4. Draw the line of position, orthogonal to the Azimuth, at this point.

Detailed Nautical Charts are usually only available for places near the shore. When in high seas, we normally don't have charts with the adequate scale to plot our position. Special plotting paper is used instead.

When navigating using Navigator software, the computer determines the altitude lines interceptions and calculates the astronomical position. A simplified map is drawn, showing the parallels, meridians, lines of altitude and the astronomical position.

The sextant

The sextant is an instrument that measures angles. Fig 12 shows a schematic sextant. The **eyepiece** is aligned to the **small mirror**, which is fixed in the frame of the instrument. This mirror is half transparent. By the transparent part, the navigator can see the horizon directly. The small mirror also partially reflects the image from the big mirror, where you see the star. The **big mirror** is mobile and turns with the **arm** of the sextant. Doing that, we change the angle between the two mirrors. The altitude of the star is measured in the **scale**. There is a drum to make the fine adjustments. Whole degrees are read in the scale and the minutes in the drum.

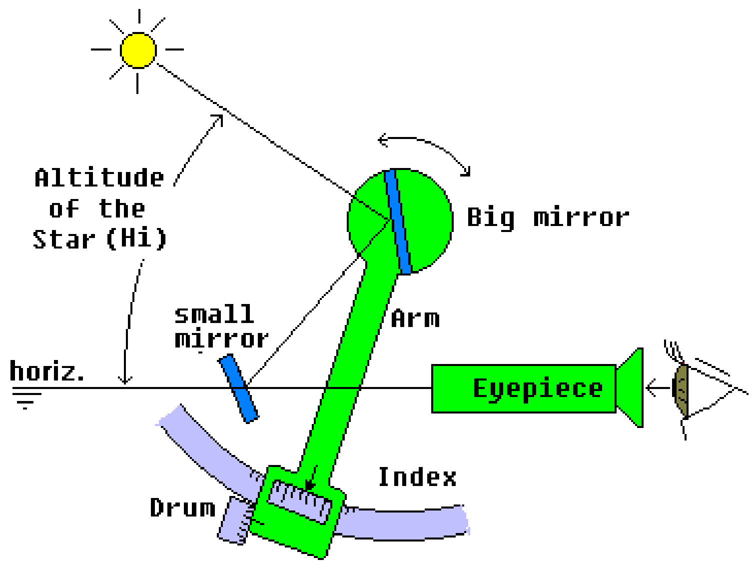

fig. 12 - The Sextant

sextant working model (requires Flash 5.0 plug-in)

The sextant has two sets of filters (or shades) to eliminate the excess of light, especially when observing the Sun. The use of two or more filters in front of the big mirror is necessary when observing the Sun. **Serious eye injuries will result from observing the Sun without filters, even for a brief period.**

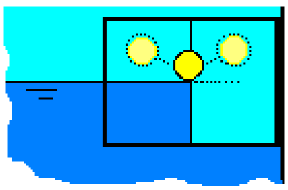

fig. 13 - Image of the Sun in the sextant

When looking through the eyepiece and adjusting the sextant, you will see something like figure 13, to the left. Sextant readings must be made with the sextant in the vertical position.

Inclining (rocking about the axis of the eyepiece) the adjusted instrument slightly, the image of the celestial body describes a small arc that touches the horizon in a point near the center of the mirror. In this situation, the angle is ready to be read in the instrument scale.

Altitude corrections

But before we can use this apparent reading in our calculations, some corrections must be made, in order to obtain the true observed altitude. These corrections are: 1) the height of the eye, 2) semi diameter of the body (only for Sun and Moon), 3) instrumental error, 4) atmospheric refraction and 5) parallax (only for the Moon).

Since most of these corrections depend only on the selected celestial object and altitude, they are performed automatically by ***Navigator*** software. The only information you will have to provide to the program are the ***height of the eye*** (a.k.a. Dip) and the ***instrumental error***. The application of these corrections to the instrumental altitude gives the *corrected altitude*, the one used in calculations.

An observer located in a high place will see a star with an altitude bigger than other at sea level, in the same location. This error is called height of the eye (Dip).

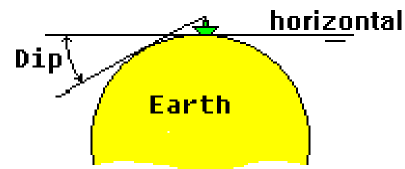

fig. 14 - Error due to the height of the eye (Dip)

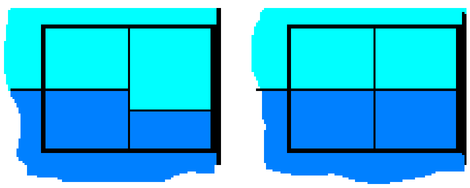
fig. 15 - eyepiece image of the sextant index error

The sextant index error (IE) is due to a small misalignment of the scale of the sextant (the "zero" of the instrument). To read the index error, adjust the scale to 0°00.0' and point towards the horizon. In fig. 15 left we can see this error. Turn the drum until the horizon forms a single line (fig. 15 right). Then you can read the index error.

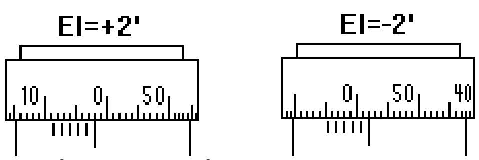

fig. 16 - Sign of the instrumental error

The index error can be positive or negative, as shown in fig. 16. The index correction has opposite signal (i.e. must be subtracted from altitude if positive and vice-versa)

Parallax error is illustrated in *fig.17*. Since the navigator is not in the Earth's center, but in its surface, the apparent object position is below the true geocentric position.

Parallax is only meaningful for the Moon. Other objects are so far, their parallax is very small.

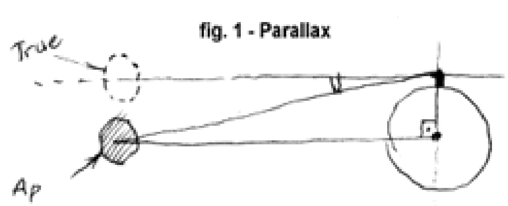

fig. 17 - Parallax in altitude error

Nautical Almanac data is tabulated for the centers of the celestial objects. For the Sun and Moon, however, it's easier to measure the altitude of the lower part of the body, as illustrated in fig. 18. This is known as the lower limb. Of course a correction must be applied in order to obtain the altitude of the center of the body. This correction is called semi diameter. Sometimes, the upper limb is also used.

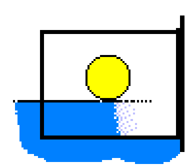
fig. 18 - Semi diameter correction

Now that you know how celestial navigation works, take a look in the [*Navigator* software manual].

---xxx---

Bibliography

>> **"Celestial Navigation for the Yachtsmen "** by Mary Blewitt
ISBN 0070059284 - 112 pages
Good and small book, with easy methods. A classic.

buy from **Amazon**

>> **"Ocean Yachtmaster"** by Pat Langley-Price, Philip Ouvry
ISBN 0713645539- 215 pages

buy from **Amazon**

Heavier book, with complete theory and practice of celestial navigation, with examples.

>> **"The American Practical Navigator "** by Nathaniel Bowditch
ISBN 0781220211 - 1200 pages

buy from **Amazon**

A must in every advanced navigator library. The first edition of this book was published in 1802. It has been said to be one of the few things a sailor absolutely needs before going to the sea, the other things being a "Bible and the mother's blessing".

Overtime, some of the original Bowditch's celestial navigation text was replaced by more modern subjects, like radar and radio communications. Unfortunately, the Lunar calculation section is one thing that was removed, apparently in 1914. If you have a copy of this text, I would like to read it <please!>.

You may want visit the site **Bowditch Online**, where the full current edition text is available (PDF format).

For those who don't know Bowditch, I recommend the book "**Carry on, Mr. Bowditch**" by Jean Lee Latham, a somewhat romanced biography of this great navigator.

buy from **Amazon**

Another interesting site is the **Bowditch Initiative**.

>> **"Memento Vagnon de la Navegacion Astronomique"** by François Meyrier

Good celestial navigation course in French, with step-by-step approach.

>> **"Navegação astronômica"** por Geraldo Luiz Miranda de Barros
Edições Marítimas - 250 páginas

Bom livro de navegação astronômica em Português.

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Raster chart and satellite images on the Net

> The best Internet raster chart source I know is the **NOAA Nos Mapfinder**. From this site you can download free charts for most of the US coast, in GIF format. Documentation says charts are not for use in navigation because they have low resolution, but they look fine to me.

(Please note that any GIF chart you download must be imported with ChartMaker program (included) before it can be displayed in the Navigator. Raster chart support is only available in Navigator 4.0+).

> Another interesting site is NASA's **MrSid Image Server** . In this site you can find high resolution satellite images from anywhere in the world. Click your region. Check the "Select Earth..." checkbox and click on the image again. Right click the image to save it in JPG format. Then you can import it and use in the Navigator chart viewer.

Navigator Vector Chart Library

This page contains vector charts (CHT files) for use with Navigator (registered edition). Most of the charts are work of users who have kindly agreed to share the files.

> **MYWORLD.CHT** - Low resolution chart of the world. Higher resolution in Brazil, from Santos to Rio de Janeiro.

64 polygons - 2479 points - File size 66317 bytes
chart by Omar Reis

Download **MYWORLD.ZIP** (Zip compressed - 23767 bytes)

> **DENMARK.CHT** - Denmark and sorrounding areas.

140 polygons - 9461 points - File size 246028 bytes
chart by Erik Nielsen

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> **USA.CHT** - Islands in NW United States, British Columbia, Gulf Coast (Louisiania, Florida, Texas) and Caribean (Bahamas, British Virgin Islands). The rest of continental US included with low detail.

1363 polygons - 70380 points - File size 1951491 bytes
updated jan/02
chart by Bill Newland

Download **USA.ZIP** (Zip compressed - 537,272 bytes)

Note: The continental US polygon has more than 32k points and had to be splitted in two because of Windows 9x GDI limitation.

> **DANMARK.CHT** - Another denmark chart , but this one with **much** more detail. Extensive use of site names.

1123 polygons - 29385 points - File size 793808 bytes
chart by Per Brun Jorgensen
posted nov/3/1999

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> **North Atlantic** - Chart and desktop. Atlantic Ocean chart from Equator to Artic Circle, including islands and detailled continent shoreline. Desktop even contains a few icebergs!

After download, unzip desktop (NorthAtlantic.nav) and chart (NA1.CHT) to the same directory.

245 polygons - 7508 points - File size 202688 bytes
chart by Ilmari Pirhonen
posted nov/3/1999

Download **NorthAtlantic.zip** (Zip compressed - 58,959 bytes)

> **New Zealand** - Small NZ chart. Includes North, South and Stewart Islands.

3 polygons - 595 points - File size 17361 bytes
chart by Will Redfern
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Download **NEWZEALAND.ZIP** (Zip compressed - 5.713 bytes)

> **North Atlantic 2** - This is similar to the North Atlantic file above, but with more detail in the BVI region.

708 polygons - 21460 points - File size 592538 bytes
chart by Phil Gerber - jan/2003

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> **Islands** - 3 vector charts: Falklands Islands (Malvinas), Easter Island and Sri Lanka.

Falklands - 101 plygons - 2605 points
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Sri Lanka - 35 polygons - 850 points
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Omar F. Reis

Angular Distances between two celestial objects and Lunar Calculation

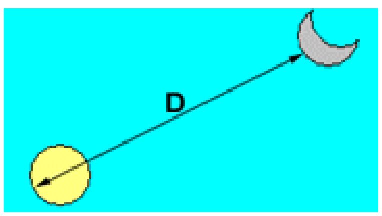
Every celestial navigator knows how to take a celestial object altitude, but few have ever measured the **angular distances** between two celestial objects. Yet these angular distances can be useful for two purposes: checking the sextant accuracy and determining the time.

Consider the movement of celestial objects in the celestial sphere. It is the movement observed when the Earth rotation is removed from the picture.

Stars are nearly fixed in the sky. Their so called "proper motion" is so slow, it can be ignored for celestial navigation. So, the angular distance between two stars is constant. One can take advantage of this fact to check the accuracy of the sextant.

The Sun goes a complete turn in the celestial sphere in exactly one year. Planets move more slowly, with irregular paths and periods.

The Moon does complete turn every 28 days. That's 12 degrees per day, or about 30' per hour. It is so fast, the distance between the Moon and other celestial object can be effectively used as a clock, to determine the time in a unknown Earth position, as we will see.



Measuring angular distances is different from measuring altitudes. Instead of the vertical plane, the sextant must be held inclined, so that its plane includes the two celestial objects. For the Sun and Moon, the near or far limbs are used rather than the lower or upper (see illustration).

Since the celestial positions of the objects (i.e. their Right Ascension and Declination) can be calculated using the Nautical Almanac, one can calculate the angular distance between them by solving the spherical triangle formed by the object centers and a celestial pole. This gives the true calculated distance.

Distance corrections

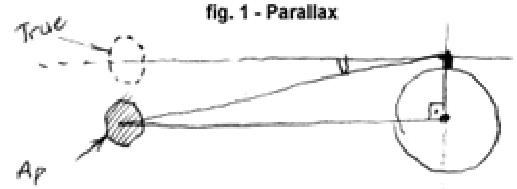
What we observe with the sextant is the apparent distance. A couple corrections must be applied to convert from the sextant apparent distance to true distance, before it can be compared with the calculated distance, obtained from the Almanac. These corrections are 1) the index error, 2) semi diameter of the object (SD), 3) atmospheric refraction and 4) parallax in altitude.

Only the Sun and Moon have appreciable semi diameters (SD). For all other objects, SD can be considered 0.

Parallax error is illustrated in *fig.1*. Since the navigator is not in the Earth's center, but in its surface, the apparent object position is below the true geocentric position.

Parallax is only meaningful for the Moon. Other objects are so far, their parallax is very small.

fig. 1 - Parallax



Refraction error is caused by light rays "bending" while crossing the air layers. It is a tricky correction, because it depends on atmospheric conditions. The best thing is to try to avoid too much refraction by selecting objects with altitudes greater then 20 degrees.

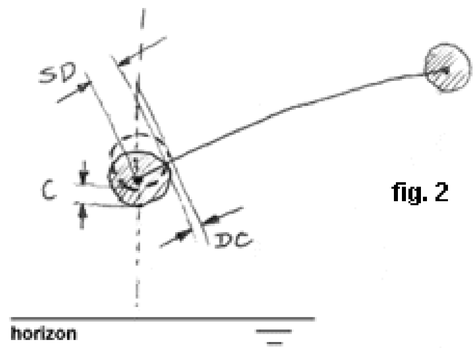


fig. 2

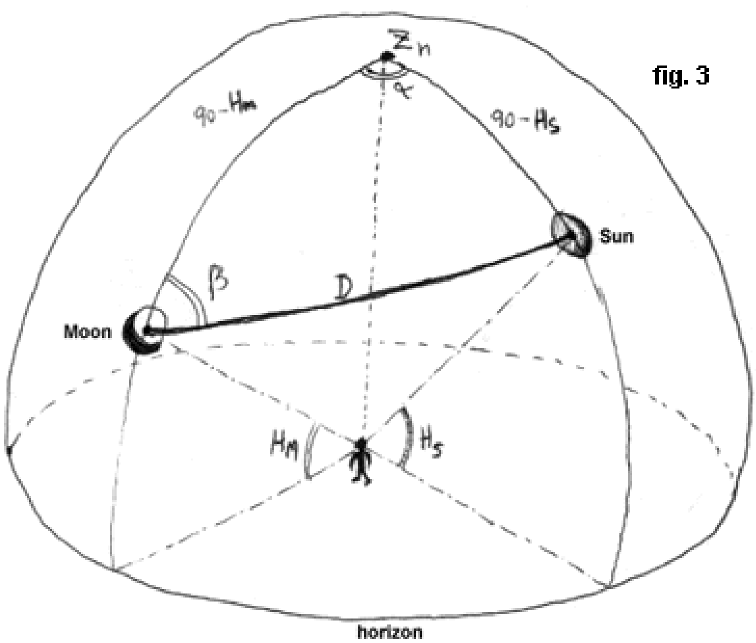


fig. 3

Both refraction and parallax displace the object in the vertical direction. In *fig.2* (a navigator's perspective) the combined effect of parallax and refraction is represented by **C** (The solid circle is the apparent object and the dotted circle is the true object).

DC is the correction C projected in the direction of the other celestial object. So, we have:

DC = C . cos ß

where **ß** is the angle between the vertical and the other celestial object (see fig.3). Note that, since both parallax and refraction corrections depend on the altitude, the objects altitudes must be either measured or calculated.

The total distance correction is:

Corr = SD + DC

These corrections must be calculated for each of the two celestial objects and subtracted from the sextant angular distance. The index error is corrected once.

After the corrections are applied, the corrected sextant angular distance can be compared with the Almanac calculated distance. The difference is the sextant error.

It's worth noting that this error is not the index error, which was already subtracted. It's a sextant construction error, and should be generally small. You might want to check your sextant periodically, or after it suffered some abuse, to check it's reliability.

The Lunar Calculation

Think about this situation:

- You fall on a deserted island, with unknown position. You have a sextant and a Nautical Almanac.
- You got no watch. Or the one you got is badly wrong.
- Also no radio or cell phone.
- You want to find your position, so you can send it in a message on a bottle, asking for help (or at least a pepperoni pizza).

You can always do a meridian passage observation and obtain the latitude. But the longitude cannot be computed unless you know the correct time. So, you must try to figure the time first. This can be done using the Moon.

Using the angular distance between the Moon and other celestial object to determinate the time is known as the **Lunar Calculation**. It was very important for navigators in times prior to affordable chronometers and radio communications. Unfortunately, this technique was only perfected about the same time affordable chronometers appeared.

Each Lunar calculation involves measuring three angles in about the same time: 1) the angular distance between the Moon and other celestial object and 2,3) the altitudes of both objects. The altitudes are used to calculate the parallax and refraction corrections.

Since the angular distance between the Moon and other object changes relatively fast, one can calculate the distance at three different times, distributed evenly around the estimated time, and then do a quadratic interpolation with the actual measured distance, to find the actual time.

It must be noted that the Moon movement in the celestial sphere is more or less along the Ecliptic. So the other celestial object chosen for this calculation must also be on the Ecliptic. Any planet or the Sun will do. As will a star close to the Ecliptic, such as Regulus, Spica or Antares. You also should avoid to choose a close object, for the distance line may be oblique to the Moon trajectory.

You will find out that it is tricky to measure the angular distance with the sextant inclined. Try to rock the instrument, as to find the inclination that gives the lowest possible sextant reading.

The Lunar calculation is not very precise, because the Moon is not **that** fast. Even a small 1.0' combined error (in the angular distance reading and calculation method) will result in nearly 2 minutes error (and 30NM in the position). Not very good by today's standards. It is considered obsolete and is seldom used, except as a historical curiosity.

Speaking of historical curiosity, I recommend a visit to the site Nathaniel Bowditch Initiative, about the life of the navigator who perfected this technique around 1790.

>> Object distances and the Lunar calculation will be available in the next Navigator version, due to the year end.

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Thinking Man Software

Dimension 4

Welcome to Thinking Man Software.

When Thinking Man Software started out, we only made software for our friends and co-workers. Most of that software is still in use today. But why stop there, when the Internet beckons?

Dimension 4 was the first program that we *unleashed* on the Internet, in 1996. It's been downloaded over 3 million times from various sites around the world. It's recently been updated (now at v5.0) with many new features and the latest operating system support.

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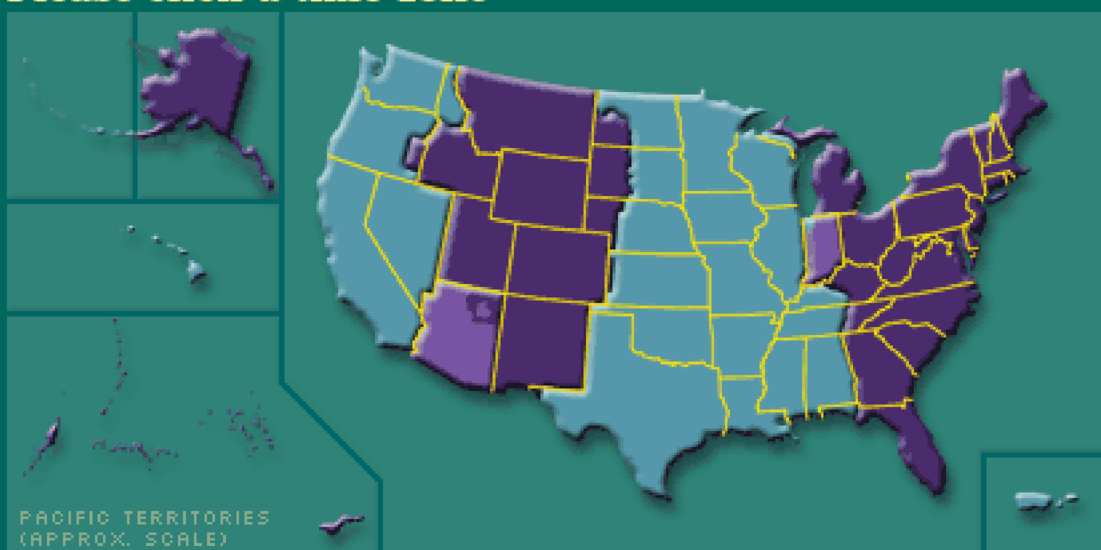

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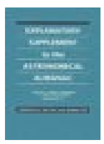

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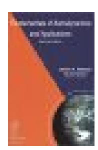

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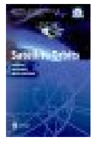

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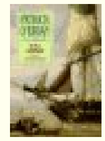

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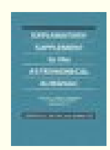

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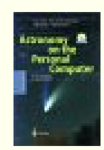

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Les Bases du Point Astro. - suite

This text is available in english, french and portuguese

Page précédente

Parce que la Position Géographique d'un astre est normalement à des milliers de kilomètres de notre position, le cercle de position est extrêmement grand et cette toute petite partie qui nous intéresse - celle près de notre position - peut alors être considérée comme une droite, orthogonale à l'Azimut de l'astre. Cette droite est appelée **La droite de Hauteur**. (Schéma 9).

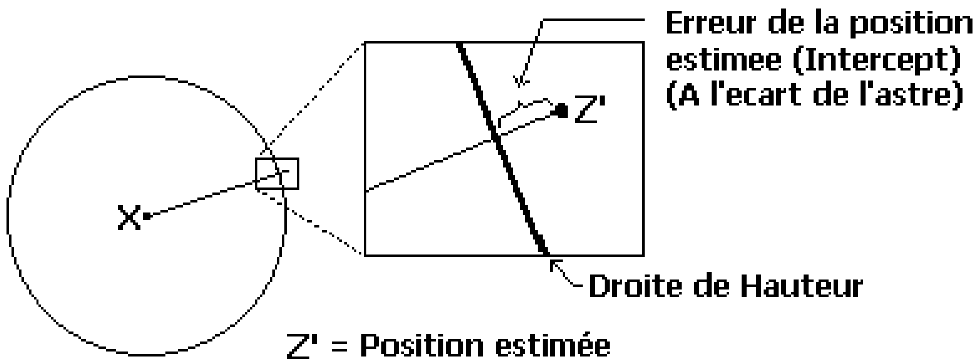

fig. 9 - La droite de Hauteur

Nous avons réussi, à partir de la Hauteur observée d'un astre à un moment donné et de notre position estimée, à dessiner une droite de hauteur. Nous savons que notre position réelle se trouve quelque part sur cette droite. Pour déterminer notre position exacte, nous pouvons dessiner une autre droite, celle d'un autre astre. Le point où ces deux droites s'intersectent sera notre position exacte - notre **Point Astro.**

Normalement, le navigateur devrait répéter cette opération pour un troisième astre, juste pour être sur. Puisque ces mesures sont affectées par quelques imprécisions mineures, les 3 droites ne se recouperont probablement pas en un point unique, nous aurons un petit triangle. Notre position est probablement quelque part à l'intérieur de ce triangle. (Shéma 10). Plus le triangle est petit, mieux c'est. On estime généralement que notre position est au centre de ce triangle.

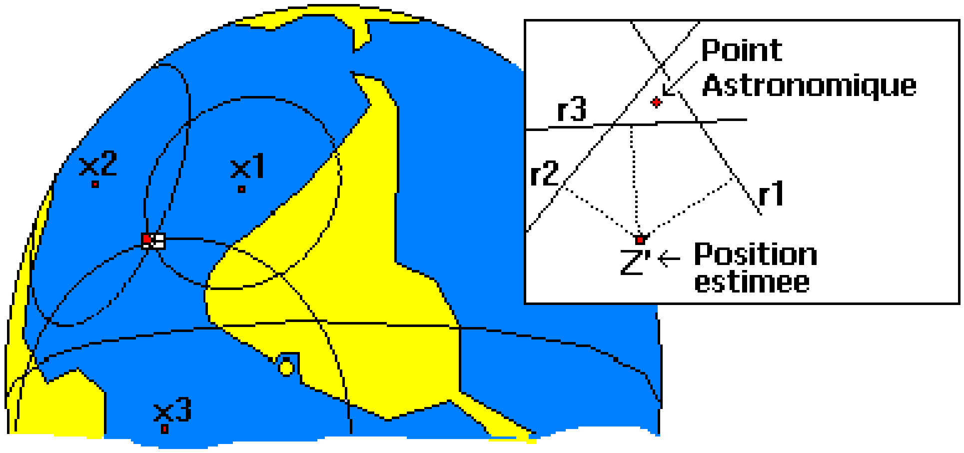

Fig. 10 - Triangle formé par l'intersection de 3 droites de Hauteur.

Sur le shema 10 nous pouvons voir comment 3 cercles de positions déterminent 3 droites de Hauteur r1, r2 et r3.

Le calcul classique du point astro exige pour déterminer une droite de hauteur, de calculer le PG d'un astre (AHvo et déclinaison) en utilisant les Ephémérides Nautiques ainsi que la résolution du **Triangle de Position** PXZ, formé par le pole terrestre (P), le PG de l' astre (X) et la position estimée du navigateur (Z) (voir shema 11). Cette solution, qui demande l'utilisation de tables, donne la Hauteur calculée et l'Azimut de l' astre. La différence, en minutes de degrés, entre la hauteur calculée et la hauteur de l' astre, mesurée avec le sextant, est la distance entre notre point astro et notre position estimée, c.a.d notre intercept.

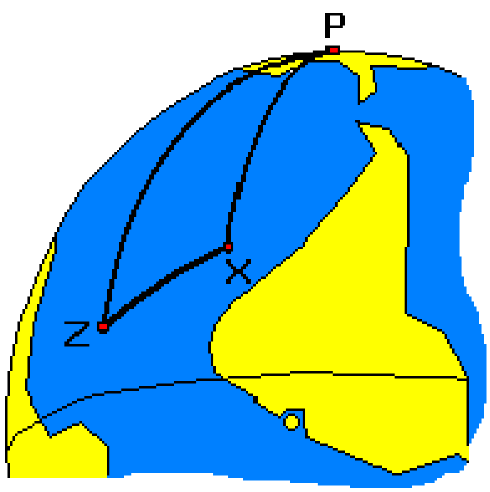

fig. 11 - Triangle de Position PXZ

Navigator Light calcule le PG d'un astre et le triangle de position grâce à quelques formules mathématiques. Tout ce que vous avez à faire est d'entrer la Hauteur lue sur le sextant ainsi que la date de la visée et l'heure exacte, le nom de l' astre et votre position estimée.

Détermination du point Astro.

Il n'est pas nécessaire de dessiner les droites de hauteur quand vous utiliser *Navigator Light*. Mais regardons quand même comment faire. Une droite de hauteur est tracée sur une carte marine (projection de Mercator) de la façon suivante:

1. Tracez votre position estimée.
2. A l'aide de votre règle parallèle, tracez une droite passant par votre position estimée, dans la

direction de l'Azimut de l'étoile.

3. Sur cette droite, tracez la distance de votre intercept - vers l'étoile ou à l'écart - comme l'indique le signe de l'intercept.
4. Tracez la droite de Hauteur, perpendiculairement à l azimut, sur ce point.

Les cartes marines détaillées ne sont en général disponible que pour les régions côtières. Au milieu des océans, nous n'avons pas généralement de cartes d'une précision suffisante pour tracer notre position. On utilise alors des feuilles de calcul de droite de hauteur spéciales ou bien du papier millimétré.

Tracer sur du papier millimétré demande quelques étapes supplémentaires. Une minute de longitude est égale a 1 mille prés de l'équateur. Si nous utilisons 1 carré sur la feuille = 1 MN comme échelle, nous devrons convertir les distances horizontales en minutes en utilisant l'opération suivante:

minutes de longitude = milles horizontaux / Cos (Latitude)

Il est plus simple d'utiliser les feuilles de calculs de droite parce qu'elle comporte une échelle pour opérer cette conversion.

Si l'on utilise Navigator light en navigation, l'ordinateur calcule l'intersection des droites de hauteur ainsi que le point Astro. Une carte simplifiée est dessinée, montrant les parallèles, les méridiens, les droites de hauteur ainsi que le point Astronomique.

Le Sextant

Le sextant est un instrument qui mesure des angles. Le dessin 12 montre un sextant schématisé. **La lunette** est alignée avec le **petit miroir**, qui est fixé au bâti de l'instrument. Ce miroir est à moitié transparent. Par le côté transparent, le navigateur peut voir l'horizon directement. Le petit miroir réfléchi également partiellement l'image du grand miroir où l'on voit l' astre. **Le Grand Miroir** est mobile, et s'incline avec **l'alidade**. En bougeant l'alidade, on change l'angle entre les deux miroirs. La hauteur de l' astre est lue sur le **limbe**. **Un tambour** permet d'affiner la visée. Les degrés entiers sont lus sur le limbe, et les minutes sur le tambour. Comme nous l'avons vu précédemment, chaque minute correspond à 1 mille et chaque degré a 60 milles.

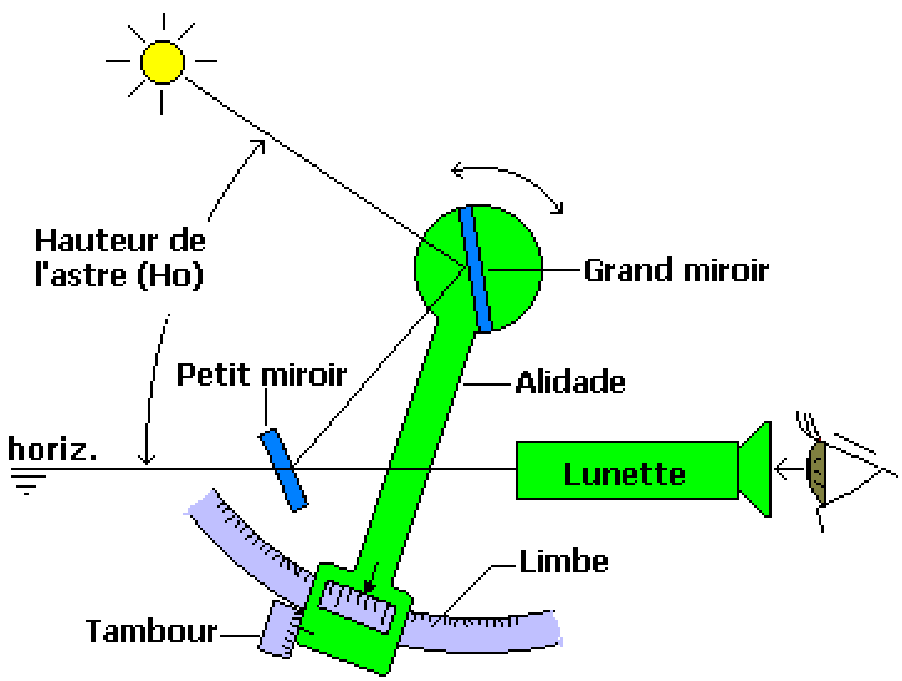

fig. 12 - Le Sextant

Le sextant a également deux sets de filtre de façon à éliminer la lumière excessive, particulièrement lorsque l'on observe le soleil. **L'utilisation de deux filtres ou plus, devant le grand miroir lorsqu'on observe le soleil est obligatoire**. **De sérieuses lésions oculaires peuvent résulter d'une observation du soleil sans l'utilisation des filtres.**

Lorsque l'on regarde à travers la lunette et en ajustant le sextant, vous verrez l'image suivante:

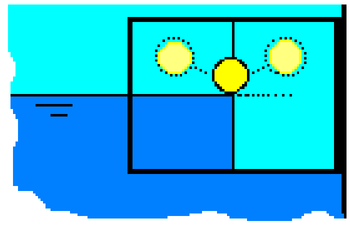

Fig. 13 - Image du soleil au travers du sextant.

Les observations au sextant doivent être faites avec le sextant dans une position la plus verticale possible. Incliner (balancer le sextant sur son axe de droite a gauche) doucement l'instrument ajusté, et l'image du corps céleste décrit un petit arc qui vient toucher l'horizon en un point près du centre du miroir. C'est alors, et alors seulement, que vous pouvez lire la hauteur en degrés directement sur le limbe.

Les Corrections de Hauteur

Mais avant de pouvoir utiliser ce relevé dans nos calculs, quelques corrections doivent être appliquées. Ces corrections sont: La hauteur de l'oeil, le semi-diamètre de l'astre (seulement pour le soleil et la lune), l'erreur instrumentale, la réfraction de l'atmosphère et la parallaxe.

Puisque la plupart de ces corrections dépendent seulement de l'astre sélectionné et de la hauteur, elles sont effectuées automatiquement par ***Navigator Light***. La seule information que vous aurez à fournir au programme est la **Hauteur de l'oeil** (c.a.d l'élévation de l'oeil au-dessus de la mer, en général 2 mètres sur le pont d'un bateau) et **l'erreur instrumentale.** L'ajout de ces corrections à la hauteur relevée sur le sextant donne la **Hauteur Corrigée,** celle utilisée dans les calculs.

Un observateur situé en altitude verra un astre avec une hauteur supérieure a celle observée s'il était au niveau de la mer, tout en restant au même endroit. Cette erreur est appelée Elévation de l'oeil. Sur les petits bateaux, la chose n'est pas critique. Mais si vous êtes sur le pont d'un navire important, cela le devient.

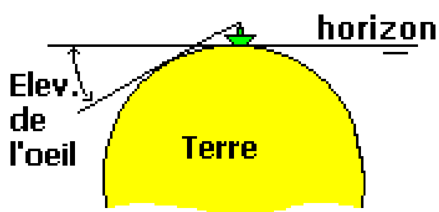

Fig. 14 - Erreur due a l'élévation de l Sil.

L'erreur instrumentale du sextant est due à un mauvais alignement des graduations du sextant. Il est possible de corriger cette erreur par des ajustements, mais elle varie suivant le soin apporte à son utilisation. Il est plus facile de lire cette erreur, et de la retrancher de la hauteur observée. Pour lire l'erreur du sextant, réglez le curseur sur 0°00.0' et visez l'horizon. Sur le shema 15, on peut voir cette erreur. Tournez le tambour jusqu'a ce que l'horizon forme une ligne continue. (Shéma de droite). Puis lisez l'erreur instrumentale directement sur le tambour.

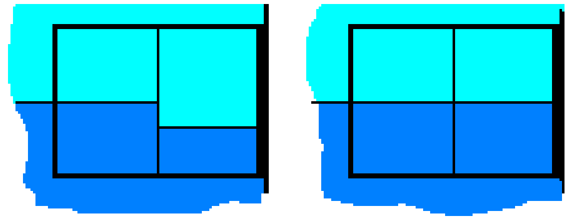

Fig. 15 - Image de l'erreur instrumentale vue dans la lunette. L'erreur Instrumentale peut être positive ou négative, (voir shema16).

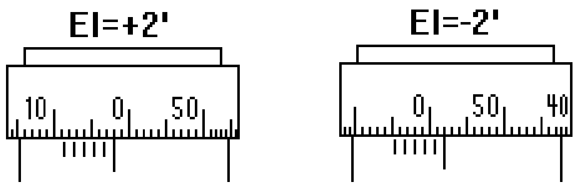

fig. 16 - Signe de l'erreur instrumentale

[Fin du chapitre 1]

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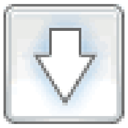

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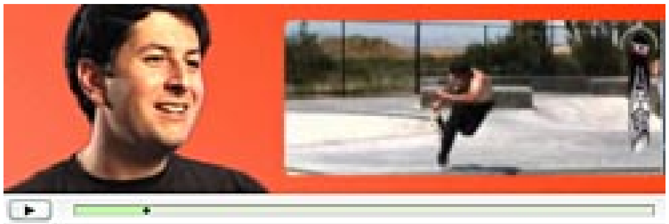

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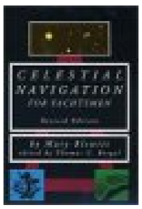

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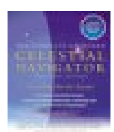

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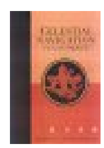

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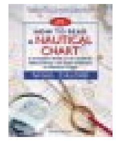

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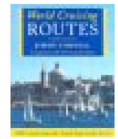

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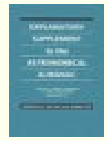

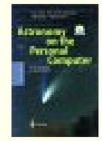

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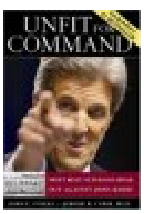

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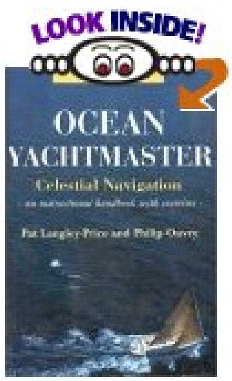

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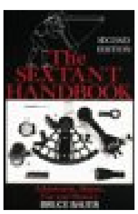

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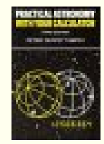

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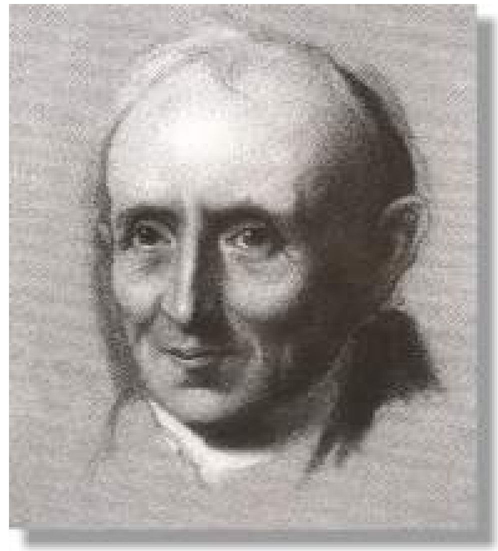

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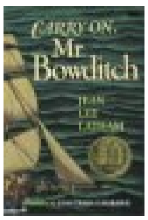

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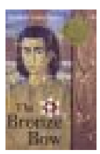

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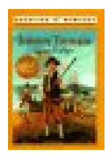

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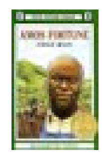

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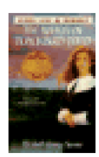

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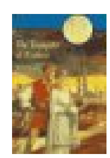

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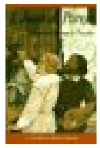

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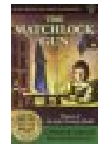

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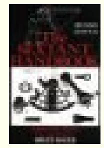

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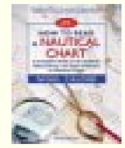

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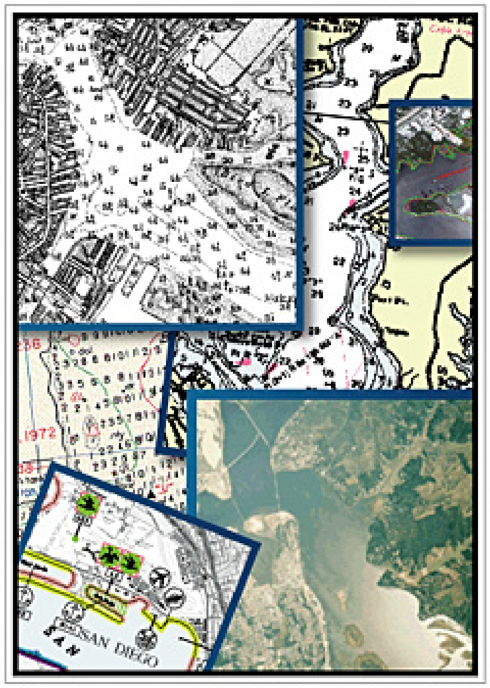

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