The idea of this booklet is to give you the ‘nuts and bolts’ in the process of gaining a position on your chart through celestial navigation without a deep understanding of the underlying theory.

It will be useful for those of you who just want to be able to ‘do it’, and also as an aid memoir to those of you who haven’t done it for a while.

To keep things simple I have only included the process of the sun, which is the main celestial object used by most Astro-Navigators, however, the principal is similar for all the other bodies.

I am grateful for any input, so please let me know of anything you might like to see in these notes, and of course any errors that you may find!

Best Regards

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Falmouth 2011
SUMMARY

1. What do I need?
2. Accuracy
3. Relationships
4. Basic Theory – GP & Position Lines
5. Using the Sextant
6. Taking the Time
7. Sextant Corrections
8. Finding the position (GP) of the sun (GHA & Declination)
9. Calculating Local Hour Angle (LHA)
10. Sight Reduction (Using the Air Tables)
11. Finding the Calculated Sextant angle and bearing of the Sun
12. Calculating the Intercept and Azimuth
13. Plotting
14. Meridian Passage
15. Sun-Run-Sun
What do I need?

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sextant</td>
<td>£90-£1000</td>
</tr>
<tr>
<td>Watch (Digital preferable)</td>
<td>£10</td>
</tr>
<tr>
<td>Nautical Almanac</td>
<td>£20 - £35</td>
</tr>
<tr>
<td>(Annual publication)</td>
<td></td>
</tr>
<tr>
<td>Sight Reduction Tables (Air Tables)</td>
<td>£25 each</td>
</tr>
<tr>
<td>(2 volumes Lat 0°-38° &amp; 38°-89°, lasts forever)</td>
<td></td>
</tr>
</tbody>
</table>

Accuracy

<table>
<thead>
<tr>
<th>Item</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good metal Sextant</td>
<td>3nm</td>
<td>New £400 / Second Hand £200</td>
</tr>
<tr>
<td>Plastic Sextant (EBCO etc)</td>
<td>10 nm</td>
<td>New £90</td>
</tr>
</tbody>
</table>

Relationships

To understand Astro, you need to appreciate the relationship between angles and distance, as well as angles and time.

Angles and distance

A circle has 360°

- Each degree is made up of 60'
- 1' = 1nm

Angles and time

- 360° = 24 hours
- 15° = 1 hour
- 1° = 4 minutes
- 1' = 4 seconds
Basic Theory – GP & Position Lines

Suns GP (Geographical Position)
The sun’s GP (Geographical position) is its position on the earth’s surface in terms of Latitude and Longitude. Imagine a line drawn from the centre of the sun to the centre of the earth. Where this line crosses the earth’s surface is the GP. This point is continually moving as the sun moves across the sky. To avoid confusion with terrestrial co-ordinates (Lat/Long), we use different terms. The Latitude of the sun is called DECLINATION, and like Latitude, is measured north and south of the equator, 0 degrees at the equator and 90 degrees at the poles. The longitude of the sun’s position is called GREENWICH HOUR ANGLE (GHA) and like Longitude is measured from Greenwich (0). However, unlike Longitude that is measured West and East, GHA is always measured West, from 0 to 360.

90 degree – Sextant Angle = Zenith Distance (ZD) (distance from suns GP)
By measuring the angle between the sun and the horizon, you can easily work out how far you are away from the Sun’s GP. The sextant allows you to measure this angle. The simple formulae 90° - Sextant Angle, gives you an angle that can be directly related to distance on the earth's surface.

e.g.
You measure the angle of the sun with your sextant, it reads 60° degrees.
90° – 60° = 30° degrees
We know there are 60’ in a degree, so 30° x 60 = 1,800’
We are 1,800nm away from the sun’s GP.

Finding the GP (based on time)
The position (GP) of the sun is based on time (Universal Time (UT)). When we take our sextant angle on the sun, we also take the time by our watch. Our watch needs to be pretty accurate, so within a few seconds of UT. We can use a special set of tables called a NAUTICAL ALMANAC, to gives us the GHA and DECLINATION of the sun at this precise time.

Circle of position
We can now mark the sun’s GP onto a chart (a very large ocean chart). We can now measure off the distance from the sun’s GP (e.g. 1,800nm), and scribe a large circle around the GP. Our position is somewhere on this circle.
To get a position, we could take the bearing of the sun with our hand-bearing compass, and plot this from the GP (just like we would with a lighthouse). We now have a position.

THE THEORY IS VERY SIMPLE, HOWEVER, IT IS ALSO VERY IMPRACTICAL. DRAWING A CIRCLE OF THOUSANDS OF MILES IS INACCURATE, AS IS MEASURING THE BEARING OF THE SUN WITH A HAND BEARING COMPASS. WE NEED TO APPROACH THE SOLUTION ANOTHER WAY.

Marq St Hilaire Method
Marq St Hilaire was a French Captain. He reasoned that using trigonometry, it is possible to work out the distance and bearing between 2 points on a sphere (the Earth). This is exactly how a GPS works out the course and distance to a waypoint.

If the 2 points we choose are the GP of the sun and our own E.P, we can work out the bearing to the sun and the distance to the sun’s GP from our E.P position. Remembering the direct relationship between distance and angles, we can convert this distance to an angle and take it away from 90°. The answer is the Sextant angle we would have had if we were at our E.P. This is called a Calculated Sextant Angle (Hc). We can now do a direct comparison with this calculated sextant angle and our actual observed sextant angle. The difference should be relatively small (within 30’), and tells us how far we are away from our E.P. This is called the INTERCEPT. We can now plot our E.P on a normal chart and draw a small position line the same distance as the INTERCEPT. We must be somewhere on this line. The maths to do this are meaty, but we can use a book called SIGHT REDUCTION TABLES to make it easy.
Using the Sextant

Description of the Sextant
The sextant is a simple but precise instrument for measuring angles. It has a mirror on a moving arm that allows the reflection of the sun to be precisely manipulated. This reflected image is reflected through another mirror that allows you to view the horizon at the same time. By adjusting the moving arm, you can bring down the reflected image of the sun onto the surface of the horizon. You can now read off the Sextant angle.

Checking Index Error
Most sextants have a certain amount error within them. When the sextant is set precisely to zero the real and reflected images in the sextant should be identical. They rarely are. To check, set the sextant to zero and look at the horizon. You will probably see 2 images, very close, but not precisely over each other. Use the micrometer (fine tuning) to make the 2 images appear as one. Now re-read the sextant. It will probably show a small difference of up to 5’ of error. This error can either be positive or negative depending whether you have moved forward onto the arc of the sextant or away, off the main scale. If you are ON THE ARC, the error is subtracted, if OFF THE ARC the error is added. You will need to note this error for the calculations.

Finding the Sun
NEVER look directly at the sun without first putting the shades across. Sextants are fitted with a variety of shades for different amounts of cloud cover. Always start off with maximum shading, and slowly remove shades until the sun is clearly visible.

The easiest way to find the sun is as follows. Put the darkest shades over the Index Mirror (the one on the moving arm), and the horizon mirror (the fixed one). Point the sextant directly at the sun. You should see the image clearly. Now gently lower the sextant, at the same time, pushing forward the index arms, aim to keep the image of the sun in the eyepiece.

Once the sun is close to the horizon, flip away the horizon shade so you can clearly see the horizon and the sun simultaneously.

Taking the reading
It is normal to bring the sun down to the horizon (lower limb), but if the lower limb of the sun is obscured by cloud, you can use the upper limb, bringing this up to the horizon. Use the micrometer (fine tuning) to bring the sun so it just ‘kisses’ the horizon. To confirm that the sextant is vertical, rock it gently from side to side. The sun will arc away from the horizon. Bring it back so at its lowest point, it just touches the horizon. Now read off the angle and note the time.
Taking the Time

**Seconds, Minutes, Hours**
The time must be taken precisely at the same time the sextant reading is made. A helper may be useful for this, but not essential. As soon as you have the sun on the horizon, note the time, seconds first, then minutes and hours.

**Correcting watch error (fast or slow)**
Before embarking on your journey, try to establish the accuracy of your watch. Set it to UT against a time signal (i.e. Radio 4 pips), then monitor it on a daily basis to find out how much time it gains or loses. Once you have established a pattern, you will be able to make small corrections to your time readings as you make your journey. Try to avoid resetting your watch, as it can make its movement erratic.

4 seconds error = 1nm
Just remember this fact. If your watch is out by 4 seconds, your position will be out by 1nm. Keep your watch within this tolerance. If your watch is out by 1 minute, you will be 15nm out.

**Checking the watch – time signals**
You can check your watch against regular time signals such as the radio 4 pips. Once a long way offshore, you can still get these transmissions if you have a SSB radio. If desperate, you can always take the time from the GPS!

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**Time Zones**

We live by the sun. We like to get up when the sun rises, have lunch when the sun is overhead and go to bed when the sun sets. Because the sun takes 24 hours to go around the earth, each country needs to work in a different time zone to achieve this.

When we sail across an ocean, we tend to sail West-East or East-West. As we sail through these time zones, we need to keep adjusting out Ships clock to keep our body clocks in tune. The ships clock is normally the nice brass one next to the barometer on the bulkhead. This is the time we live by. This is obviously different from out digital watch that shows UT and is used for our navigation.

As we sail westwards, every time we cross 15° we cross a time zone. When this happens, we put our clock back one hour and make a note in our logbook that we have moved into Zone +1, +2, +3 etc. as we travel on our journey.

Going eastwards we do the opposite, the clock goes forward 1 hour and we note in our logbook that we have moved into Zone –1, -2, -3 etc.

Greenwich marks Zone 0, and this zone spans 7.5° west to 7.5° east.
Zone +1 starts at 7.5° west and will finish at 22.5°
Zone +2 starts at 22.5° and will finish at 37.5° etc…
Sextant Corrections

Index Error
Add or subtract any index error found when you took your sight
IE on the arc (subtract), IE off the arc (add)

Height of Eye (DIP)
The higher you are, the further away is the horizon. Use the correction table (*Altitude Correction Table*) either on the loose card, or printed in the front of the Nautical Almanac. This figure is always subtracted. Typically, your height of eye is around 2m.

Altitude Correction
There are other errors to contend with, namely refraction, the diameter of the sun and whether you have used the upper limb or lower limb. These corrections are also found in the (*Altitude Correction Table*) either on the loose card, or printed in the front of the Nautical Almanac.
Finding the position (GP) of the sun (GHA & Declination)

Using date and time to extract GHA and Declination

Hours

Look in the **NAUTICAL ALMANAC**. Find the page for the relevant date. Look up the whole hours of UT and extract both GHA and Dec. Be cautious with Dec, as the table does not always show the whole degrees so you need to look up or down the column. Remember you also need to note whether the Dec is N or S.

Example

24th Feb 10.00 UT
GHA 326° 39’.3  Dec S9° 41’.8

Minutes and Seconds

Minutes and seconds are at the back of the **NAUTICAL ALMANAC**. Each page shows 2 columns for 2 minutes, each minute is broken down into 60 seconds. Look up in the first column called SUN PLANETS. This figure is always added to the hours figure.

Example

28 minutes 12 seconds
Correction 7° 03’.0

d correction

The d correction is required as the change in the declination of the sun is irregular. Note down the d value found at the bottom of the daily pages. d can be either positive or negative. To determine, if the declination is getting larger, d is positive, if decreasing d is negative.

Look at the minutes and seconds page again. Find the relevant minute and note the 3 columns to the right called v or d cor. Look up the value of d (ignore seconds) and extract the correction. It takes the same sign as d. Apply the correction to the declination.

Example

d = 0.5
Correction 0.2’
Calculating Local hour Angle (LHA)

LHA is the angular difference between your E.P longitude and the Sun’s GHA. The rules are as follows;

\[ \text{LHA} = \text{GHA} - \text{Westerly Longitude} \quad \text{(Add 360 if answer is negative)} \]
\[ \text{LHA} = \text{GHA} + \text{Easterly Longitude} \quad \text{(Subtract 360 if answer more than 360)} \]

**Changing your EP longitude to make the maths easier**

The LHA need to be a whole number (no minutes or decimals). To achieve this, you will need to manipulate your E.P Longitude to make the sums work out. We are able to do this because by nature, the E.P is an estimated position, so moving it a little makes no difference.

**Example 1**

<table>
<thead>
<tr>
<th>GHA</th>
<th>325° 12’.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP Longitude</td>
<td>7° 15’.3W change EP to</td>
</tr>
<tr>
<td>Because we are west we subtract</td>
<td>LHA</td>
</tr>
</tbody>
</table>

**Example 2**

<table>
<thead>
<tr>
<th>GHA</th>
<th>225° 45’.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Because we are east we add</td>
<td>LHA</td>
</tr>
</tbody>
</table>
Sight Reduction (Using the Air Tables)

Enter **AIR TABLES** with;

- **Chosen Latitude** (EP latitude rounded to whole number)
  e.g. 49° 27’ = 49°
  50° 15’ = 50°

- **LHA** (as described above)

- **Same/Contrary**
  If you are in the northern hemisphere and the sun is in the northern hemisphere then **SAME**.
  If you are in the northern hemisphere and sun is in the southern hemisphere then **CONTRARY**
  *(and vice versa)*

- **Declination** (only whole degrees)
  Do not round, e.g. 22°32’.1 = 22°

and extract;

<table>
<thead>
<tr>
<th>HC</th>
<th>Calculated Sextant angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>correction for minutes of declination (note the sign; + or -)</td>
</tr>
<tr>
<td>Z</td>
<td>zenith</td>
</tr>
</tbody>
</table>
Finding the Calculated Sextant angle and bearing of the Sun

Correction for minutes of declination
Remember we only took the whole degrees of declination. We cannot forget the minutes. Take the minutes of declination and combine with the d figure from the AIR TABLES using the table at the back of the book or the loose card. Apply the correction using the same sign as d.

Rules for calculating Azimuth
Look at the rules given at the top and bottom pages of the AIR TABLES. Top of the page is for the northern hemisphere. Bottom of the page is for the southern hemisphere. Apply the rules to calculate the Azimuth (Bearing to the Sun).
Calculating the Intercept and Azimuth

**Intercept (difference between $H_O$ & $H_C$)**
The Intercept is the difference between the actual sextant angle ($H_O$) and the calculated angle ($H_C$). Take the smaller number from the bigger one. This tells you how far away you are from your EP.

**Towards or Away (GOAT Rule)**
Your Intercept is along the bearing to the sun (the Azimuth). However, you need to decide whether you are towards the sun or away from it. The GOAT rule tell you this;

**GREATER OBSERVED ALTITUDE TOWARDS**
If the observed (actual sextant angle $H_O$) is greater than the calculated sextant angle ($H_C$) then you are **TOWARDS** the sun (and vice versa)
Plotting

Plotting Sheets
Though you can plot straight onto your working chart, it is more normal to use a PLOTTING SHEET. This is a blank chart with a variety of scales. They are easily purchased from a Hydrographic Agent such as Kelvin Hughes. PLOTTING SHEETS are produced for a range of latitudes, so make sure you have the correct ones for your journey.

Putting on the scale
Select the latitude you are at, at the bottom of the chart, draw in the whole degrees relevant to your current position.

Plotting CP (Chosen Position)
Plot your CP onto the chart. Remember this is not you EP, but your Latitude rounded to whole degrees and your chosen longitude, the one you modified to make the LHA a whole number. The CP is marked with a square like a waypoint.

Plotting Azimuth
From the CP, use a plotter to draw in the Azimuth (Zn)

Plotting Intercept
Make a note of whether you are Towards or Away from the sun. Set your dividers to the Intercept and measure along the Azimuth in the right direction. Make a mark.

Plotting Position Line
From the mark above, draw a line at right angles. This is the Position Line. You are somewhere on this line. It is usual to mark the ends of this line with 2 arrows pointing in the direction of the sun.
Meridian Passage (mer pas)

A Meridian Passage is a quick method of getting a position line that happens to be your Latitude. This occurs once a day at your local noon, when the sun is directly overhead. In fact, its GHA will be the same as your Longitude. It is a lot simpler to work out, and does not require precise time.

The first step is to find the time of the ‘mer pas’. This is always around noon, but not precisely, as the sun is an irregular timekeeper. In fact ‘noon’ varies from around 15 minutes before 12.00 to 15 minutes after 12.00. Look in the NAUTICAL ALMANAC for the day in question. At the bottom of the right hand page, you will see a table giving the time of ‘mer pas’ for the 3 days on the page.

This is the time the sun passes overhead at Greenwich, and also the same time it passes overhead your position by your LOCAL TIME (see time zones).

Take your Sextant on deck approximately 20 minutes before your local mer pas. Bring the sun down to the horizon, and keep monitoring it. As the sun rises slowly, keep bringing it down to the horizon. Eventually, the sun will appear to stop moving, and will stay this way for 5 minutes or so. Eventually you will note the sun start to drop back into the horizon. DO NOT ADJUST THE SEXTANT! Write down the maximum sextant reading. Now correct the sextant reading for the normal errors (IE, Height of Eye, Altitude Correction)

The maths is relatively simple.

\[
\text{Latitude} = (90^\circ - \text{Sextant Angle}) + \text{Declination of the Sun if SAME}
\]

\[
\text{Latitude} = (90^\circ - \text{Sextant Angle}) - \text{Declination of the Sun if CONTRARY}
\]

The Declination of the sun is found in the daily pages of the NAUTICAL ALMANAC for the time and date of the mer pas. Time to the closest minute is good enough.

Example 1

In this example we assume that we are in the Northern Hemisphere and the Sun is in the Northern Hemisphere (SAME)

\[
\begin{align*}
\text{Sextant Angle} & \quad -45^\circ 12'.5 \\
\text{Declination} & \quad +06^\circ 11'.1 \quad \text{(SAME)} \\
\text{Latitude} & \quad 50^\circ 58'.6 \ N
\end{align*}
\]

Example 2

In this example we assume that we are in the Northern Hemisphere and the Sun is in the Southern Hemisphere (CONTRARY)

\[
\begin{align*}
\text{Sextant Angle} & \quad -45^\circ 12'.5 \\
\text{Declination} & \quad -06^\circ 11'.1 \quad \text{(CONTRARY)} \\
\text{Latitude} & \quad 39^\circ 01'.4 \ N
\end{align*}
\]
Sun-Run-Sun
If you can see 2 celestial bodies (or more) at the same instance in time, you can take 2 readings, reduce them and then plot them. This will give you a position. Ideally, 3 bodies or more will give you a very accurate fix, Just like doing a coastal 3 point fix with a hand bearing compass.

However, many people choose to use only the sun. The sun will only give you a single position line at any one time, however, using the principal of a ‘Running fix / Transferred Position Line’, it is possible to fix your position by taking 2 observations of the sun at different times.

You could choose to do a morning and then afternoon sight, however, it is the norm to make one of the sights a Meridian Passage, as this is easier to process.

Once you have the 2 sights, plot them on the same plotting sheets, transferring the earlier one to the later one.

1. Plot morning Chosen Position (CP)
2. Plot Azimuth (Zn)
3. Plot Morning Position Line
4. Plot Noon (Mer Pas) Position Line – A line of Latitude
5. From your morning sight, mark on the course steered and distance run of the boat.
6. Transfer your morning position line along the boats track and redraw.
7. Where this position line crosses the Mer Pas is your position.
Deck Watch: ___ h ___  m ___ s | Ships Clock: ___ : ___
Correction (+/-): ___ m ___ s | Zone (+/-): ___ = ___ : ___ UT
UT: ___ h ___  m ___ s | Greenwich Date: ______________________

Hours: ___ | GHA: ______°.____.'__ | Dec N / S: ___°.____.'__ d +/- ___
Min/Sec: ___ m ___ s + ___°.____.'__ | Correction: __'.__

GHA: ______°.____.'__ | True Dec: ___°.____.'__

Chosen Longitude: ___°.___.'__ (---- W / +E)
LHA: ___° 0 0.0
(+/ - 360 if required)

Chosen Latitude: ___° N / S
LHA: ___°.____.'__
Same / Contrary: ___
Declination: ___°___

Enter Air Tables with these...

...and extract these
Hc ___° ___ d +/- ___ | Z ___°
Correction: ___

Calculated Sextant Angle (Hc ___° ___':__ (Observed Altitude)
subtract from 180 / 360 as required

True Sextant Angle (Ho) ___° ___':__ (Observed Altitude)
Intercept: ___':__ Towards / Away: Zn ___°

Use these to plot Chosen Position

GOAT – Greater Observed Altitude Towards
**Meridian Passage Pro - Forma**

Date: ___________________________

**E.P.**

**Latitude** ___ ° ___ . ___ N / S

**Longitude** ___ ___ ° ___ . ___ W / E

**Sextant Angle**  ○ ___ ° ___ . ___

**Index error (On(-)/Off(+))** ___ . ___

**Height of Eye** __ . ___ m  __  __

**Apparent Altitude** ___ ° ___ . ___

**Altitude Correction** ___ ___

**True (Ho) Sextant Angle** ___ ° ___ . ___

**Zenith Distance (ZD)** ___ ° ___ . ___

**/+/- Declination** ___ ° ___ . ___

**Latitude** ___ ° ___ . ___ N / S

---

**Local Mer Pass Greenwich** ___ h ___ m

**Ships Clock** ___ : ___

**Long Arc to time Correction** ___ h ___ m

(+ W long / - E long)

**Zone (+/-) ___ = ___ : ___ UT**

**UT of Mer Pass** ___ h ___ m

**Greenwich Date**________________

---

**UT**

**Declination**

**Hours** ___

**N / S** ___ ° ___ . ___

**Minutes** ___

**Declination** ___ ° ___ . ___

---

**90° 00'. 0**

**True (Ho) Sextant Angle** ___ ° ___ . ___ =

**Zenith Distance (ZD)** ___ ° ___ . ___ =

**/+/- Declination** ___ ° ___ . ___

(see Rules below)

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**Rules**

- **Latitude GREATER than Declination (SAME Name)**: LAT = ZD + Declination
- **Latitude LESS than Declination (SAME Name)**: LAT = Declination – ZD
- **Latitude CONTRARY name to Declination**: LAT = ZD - Declination