Introduction to Celestial Navigation

Basics

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(Kudos to Brendan Couvreux for fixing my frenglish)

In this document, we are going to expose the basics of celestial navigation, used to find your position at sea.

Those basics rely on the following data :

- Accurate time
- Location of the observed celestial body
- Estimated position of the observer
- Altitude of the observed celestial body

The basic idea is to compare what you should observe with the sextant if you are where you think you are with what you actually observe, and correct your dead reckoning accordingly.

The celestial navigation's purpose is to correct your dead reckoning.

And 95% of the required calculations are done only to calculate what you should observe if you are where you think you are.

The principle

The data and the calculation elements

The sextant

- The observation of a celestial body is performed in our case with a sextant. This device's purpose is to measure angles. It is used to measure the angle of the celestial body above the skyline. This angle is called the *altitude* of the celestial body.
- The required precision is the minute of arc.
- To give an idea, a minute of arc, is as thick as a hair at the end of your extended arms.

The data

- Accurate time
  - It is about knowing the exact time, to the closest second. You do need a good watch or chronometer.
    - As a matter of fact, the Earth rotates 360º in one day, which is 15º per hour, 1º in 4 minutes, and 1 minute of arc in 4 seconds of time. One minute of arc is one nautical mile, by definition. An error of 4 seconds on the watch will result with a 1 mile error on the chart…
  - This exact time is used to calculate the location of the observed celestial body.

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The data

- The location of the observed celestial body.
  - Calculated with the nautical or astronomical almanacs (a.k.a. *ephemerid*). These documents give the coordinates of various celestial bodies (sun, moon, planets, stars), for any given moment in time.

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The data

- The estimated position of the observer
  - Obtained through the dead reckoning. As we said before, we are in the process of correcting the dead reckoning. It must be carefully maintained.
  - Dead reckoning is maintained with the log book.

The data

- The observed altitude
  - Read on the sextant, and some corrections have to be applied :
    - Semi-diameter
      - For Moon and Sun
    - Refraction
    - Parallax
    - Horizon depression
  - Considering the required precision, this datum is probably the most delicate to obtain, this requires training.

To summarize the data

- To have the observed altitude, you need a sextant (and to know how to use it).
- To have the accurate time, you need a (good) watch.
- To have your estimated position, you need an up-to-date log book.
- To have the location of the observed celestial body, you need the current nautical almanac.

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First definition

- The location of the celestial body is actually the location on Earth from where this celestial body can be seen vertically (zenith).
- This point is called *Instant Geographic Position* of a celestial body, noted **Pg**

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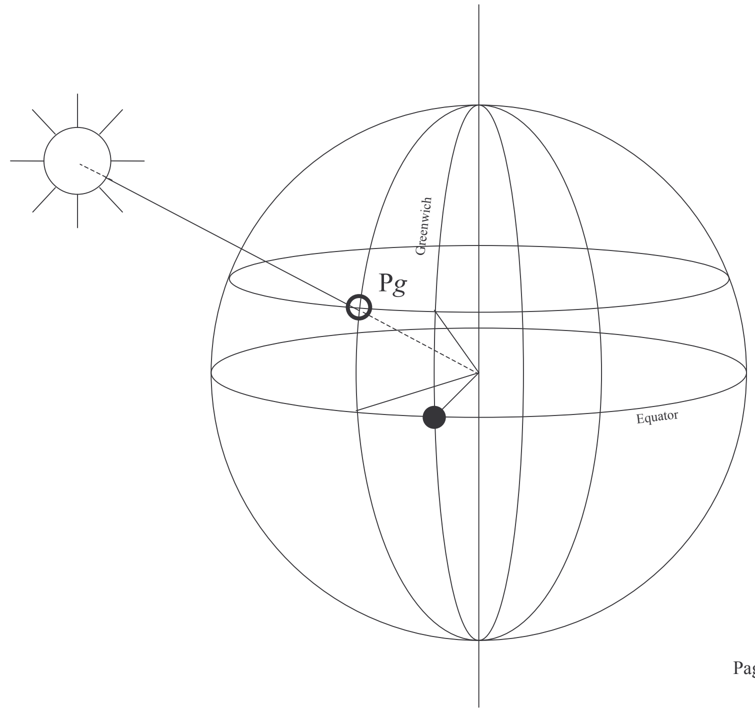
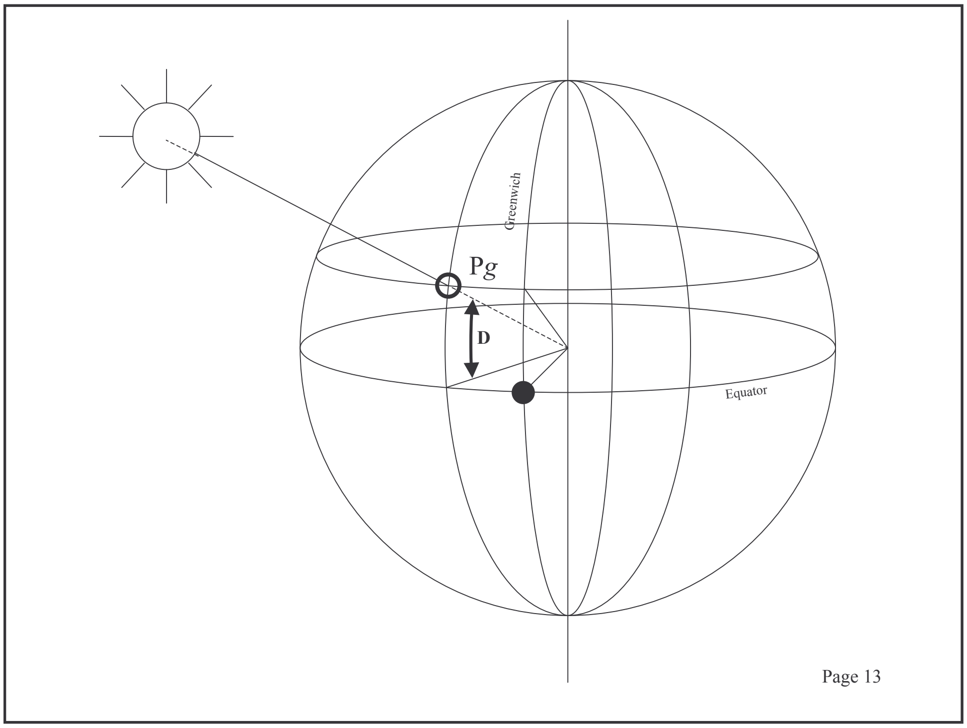


First definition

- This point **Pg**, as any point on the Earth, has a Latitude and Longitude
- Its Latitude is called Declination, noted ***D***
- Its Longitude is called Greenwich Hour Angle, noted ***GHA***.



Greenwich
Pg
D
Equator
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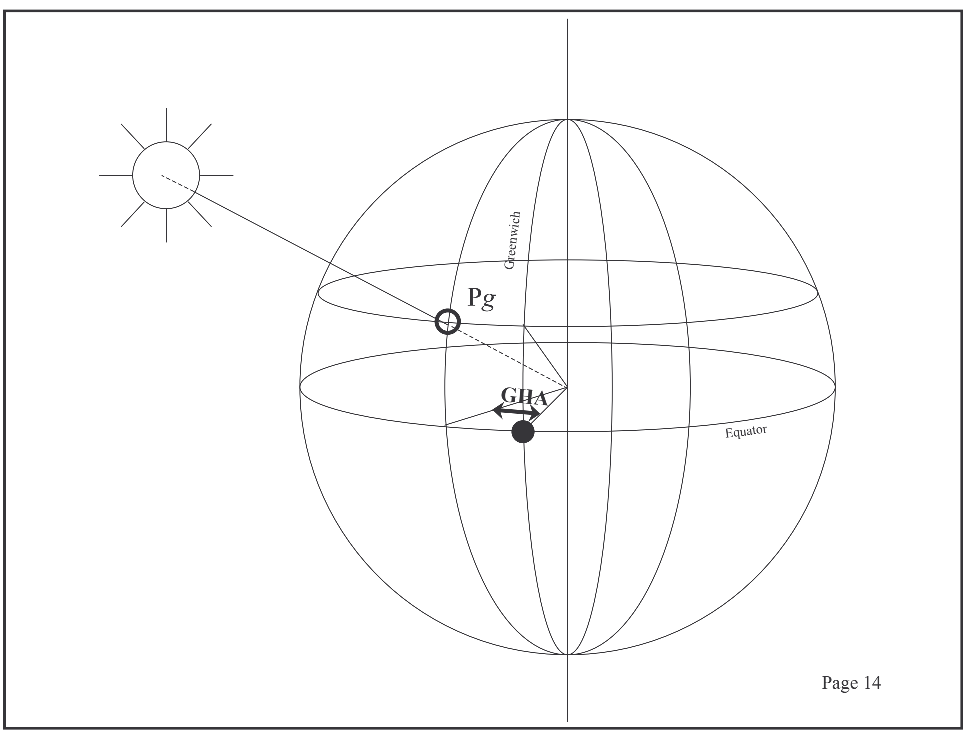

Greenwich
Pg
GHA
Equator
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A specific case

- To illustrate the principle as clearly as possible, we will first consider the specific case where the observer (noted **Obs** on the following figures) is on the same meridian as the point P*g*.
- This principle is called *Meridian Altitude*, as we measure the body altitude as we are on its meridian.

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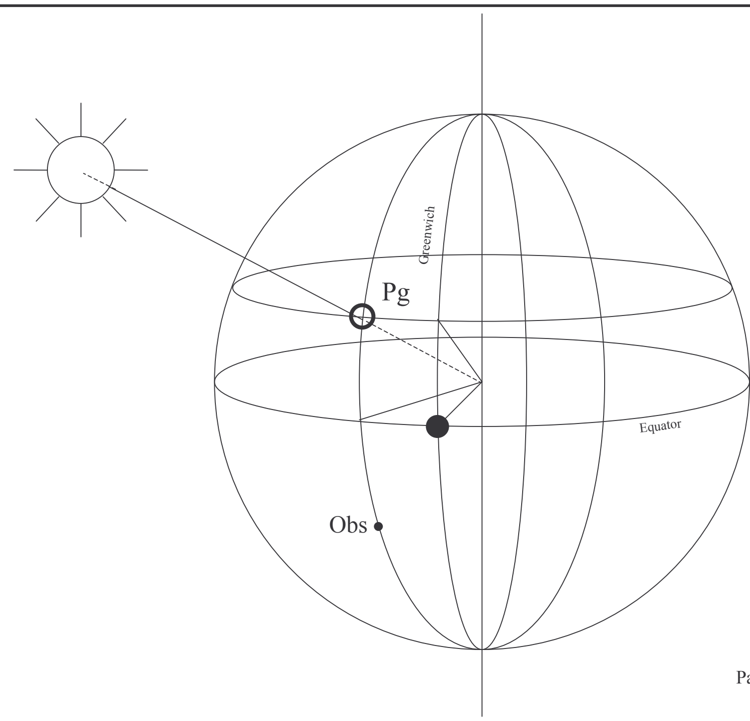

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A specific case

- To simplify the diagrams, we are going to show the meridian of the body and of the observer in the plane of the sheet.

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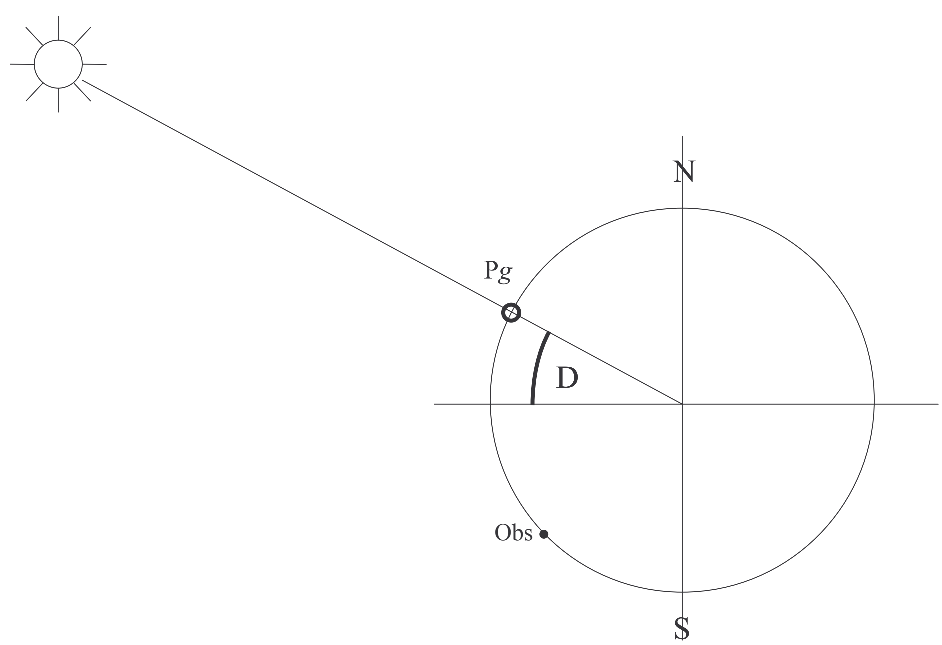

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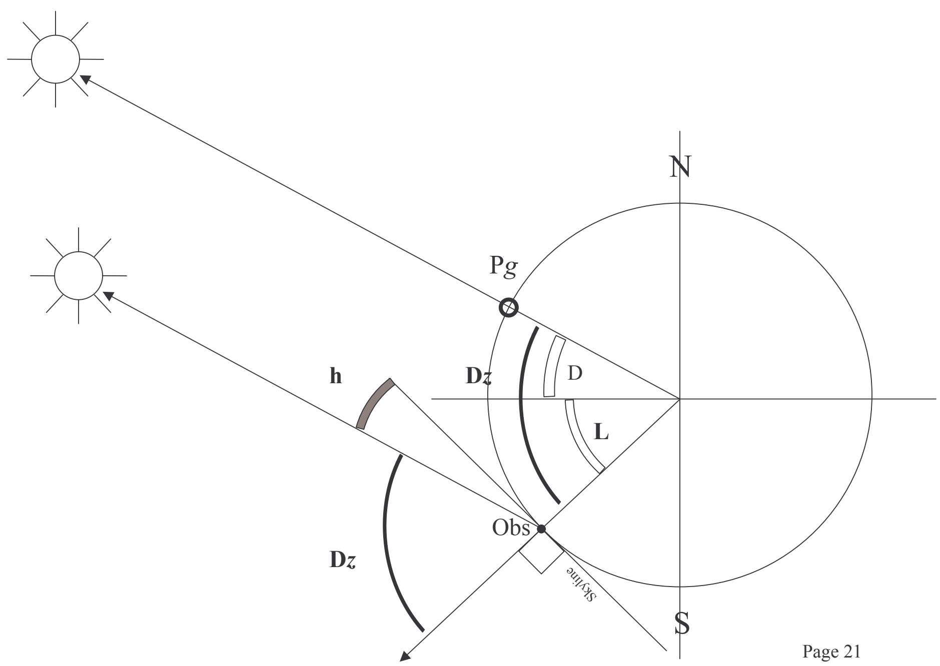
A specific case

- We need to introduce here the Zenithal Distance.
  - The Zenithal Distance, noted **D*z*** or **ξ** is the complement of the altitude, being **`(90°-altitude)`**.
  - You can see on the following diagrams the relationship between altitude and zenithal distance.

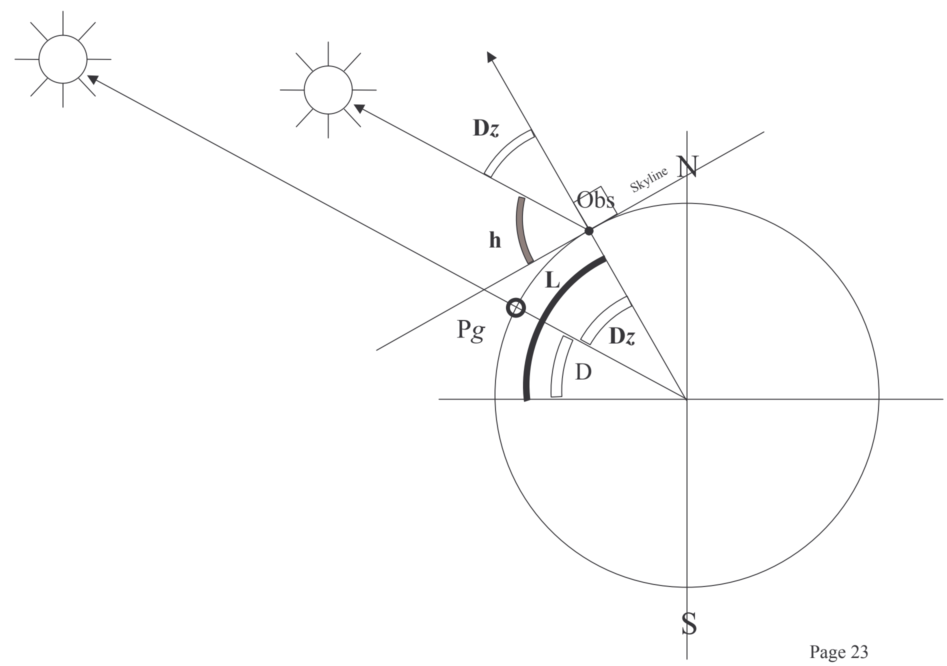
A specific case

- On the following diagram, the sun has been represented twice, this is only so its beams remain parallel.
- In the case of the next figure, the Zenithal Distance is the *sum* of the Latitude and the Declination.
- Knowing the Zenithal Distance immediately leads to the knowledge of the Altitude.



A specific case

- On the next diagram, the Zenithal Distance is the *difference* between Latitude and Declination.
- It is then very important to consider the respective signs of the observer's Latitude and the Declination of the body.



A specific case

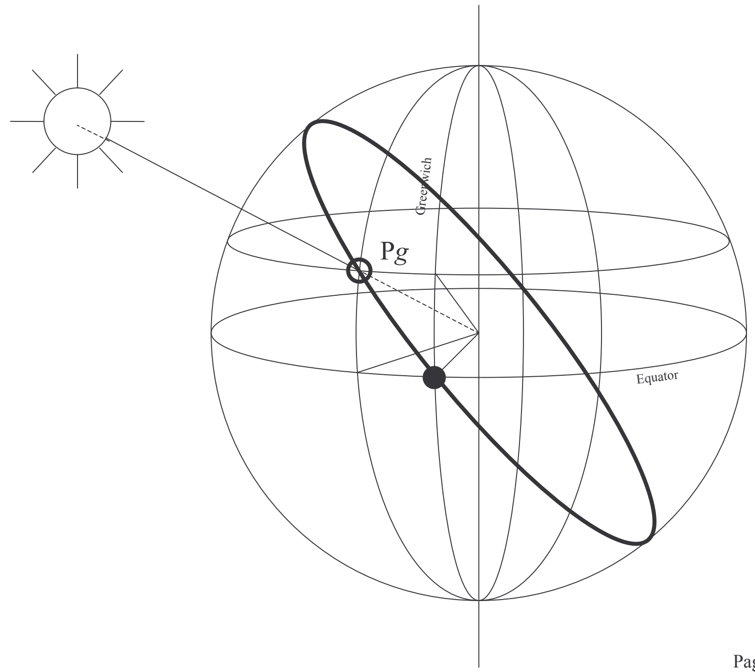
- So, in the particular case where the observer and the body are on the same meridian, it is easy to calculate the altitude of the body for this given time at the observer's estimated position.

A specific case

- To summarize
  - If L & D have the same sign
    - **He = 90° - (L-D) = 90° - L + D**
  - If L & D have different signs
    - **He = 90° - (L+D) = 90° - L - D**

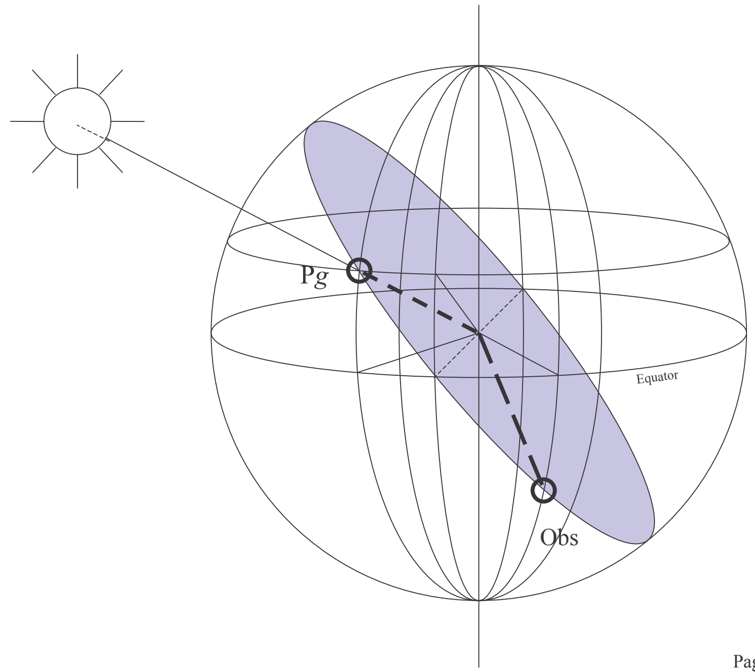
Second definition

- Great Circle
  - A Great Circle is a circle that divides the Earth in two equal parts.
    - All meridians are great circles
    - The equator is the only parallel that is a great circle
    - Through two given points on the Earth, there is only one great circle that fits.
      - Except if they are at each end of the same diameter, of course…
    - The shortest path between two points on Earth is an arc of a great circle.



Generalization

- In the – frequent – case where the observer and P*g* are not on the same meridian, you have to consider the – unique – great circle that goes through the observer's estimated position and P*g*.

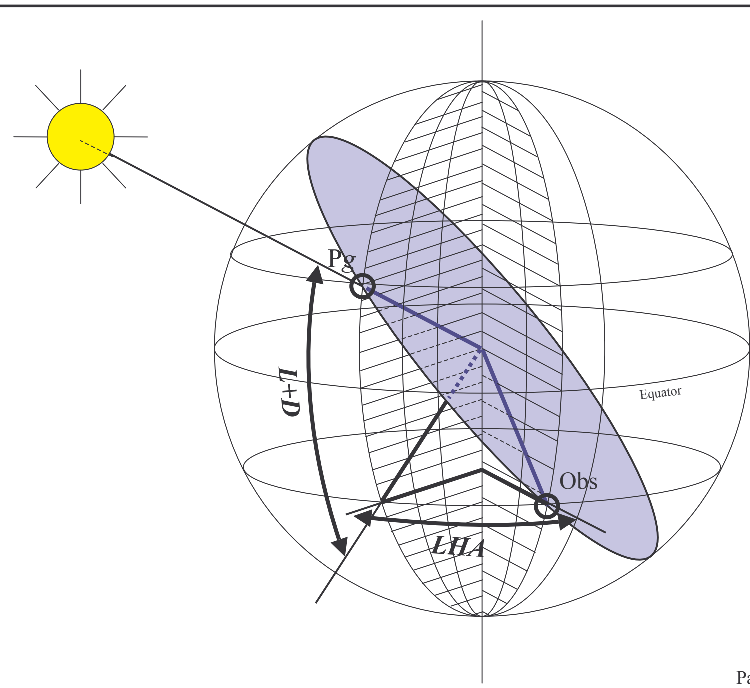


Generalization

- The calculation trick, to find the body's estimated altitude, is to "*rotate*" this great circle so that it ends up in the plane of the sheet.
- This brings you back to the situation previously described for the meridian altitude.

Generalization

- From plane trigonometry,we go to spherical trigonometry. Calculations are more complicated, but the principle remains simple…
- Calculating this "*rotation*" implies two major data:
  - The sum **L±D**
  - The longitude difference between observer and P*g*, called Local Hour Angle, noted **LHA**.
- Those two data are actually
  - The latitude difference between P*g* and Obs
  - The longitude difference between P*g* and Obs



Generalization

- Once this rotation is completed, you have all the required elements to calculate the estimated altitude.
- Those calculations will be detailed in another document, not here.

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Third definition

- Azimuth
  - The Azimuth – noted ***Z*** – is nothing else than the bearing of the observed celestial body..
  - It is also the bearing of P*g*, in other words, the direction to take in order to reach it.
  - Azimuth is counted from 0º to 360º
- *Note*: in the case of the meridian altitude, azimuth is 0 º or 180 º

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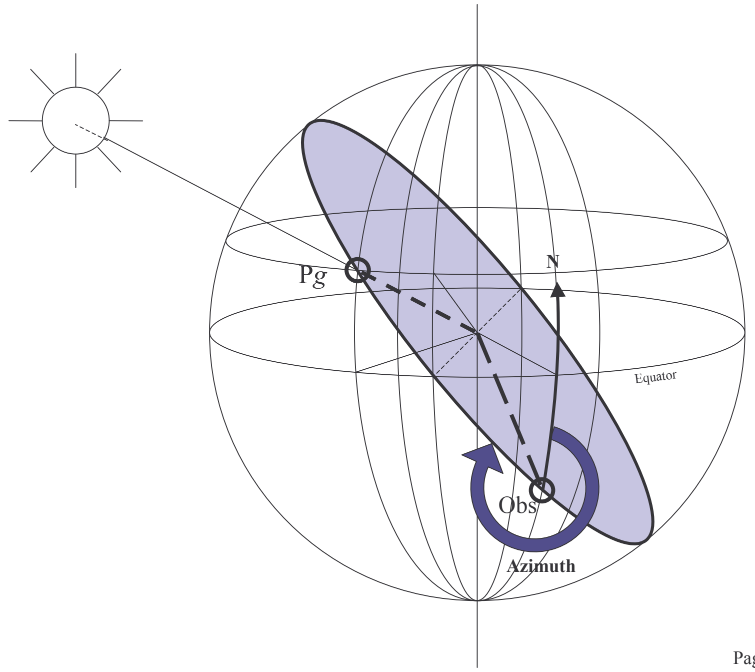

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What we’re looking for…

- All the figures and all the calculations previously described have only two goals:
  - Calculate, for the estimated position of the observer, at the exact time of the observation
    - The estimated altitude
    - The azimuth of the body

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Generalization

- Those data are obtained with the following formulas:

```
He = arcSin[ sin(L).sin(D) + cos(L).cos(D).cos(AHL) ]
```

$$Z = \arctan\left(\frac{\sin(AHL)}{(\cos(L).\mathrm{tg}(D)) - (\sin(L).\cos(AHL))}\right)$$

- This is not funny.

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Using the results

Correcting the dead reckoning, and determining the actual position

Using the results

- So, we have calculated the estimated altitude for a given body, which is the altitude you should observe if you were actually where you think you are.
- All the points of a circle, centered on P*g*, see the body at the same altitude.

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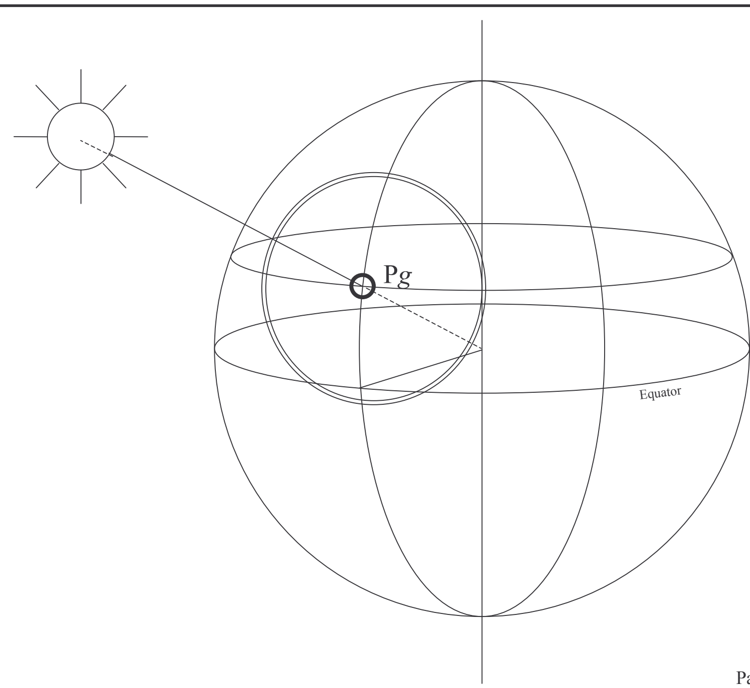

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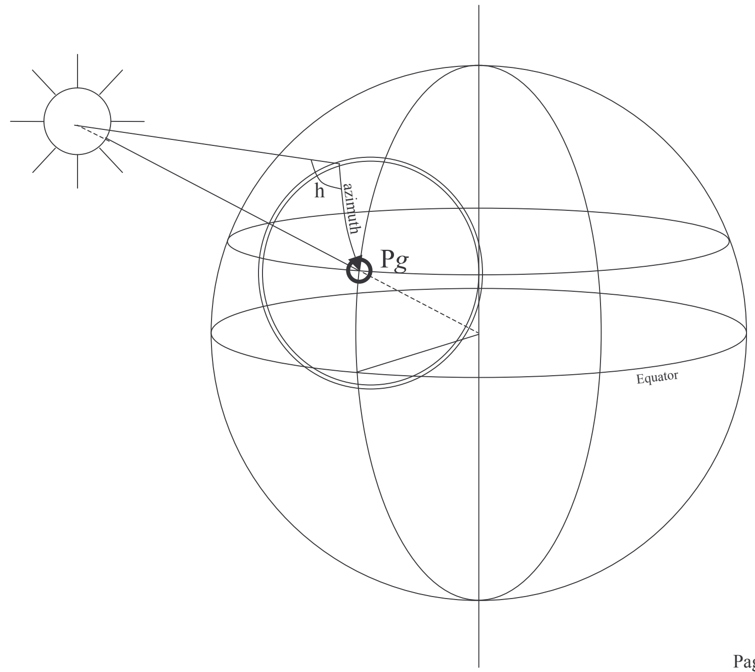
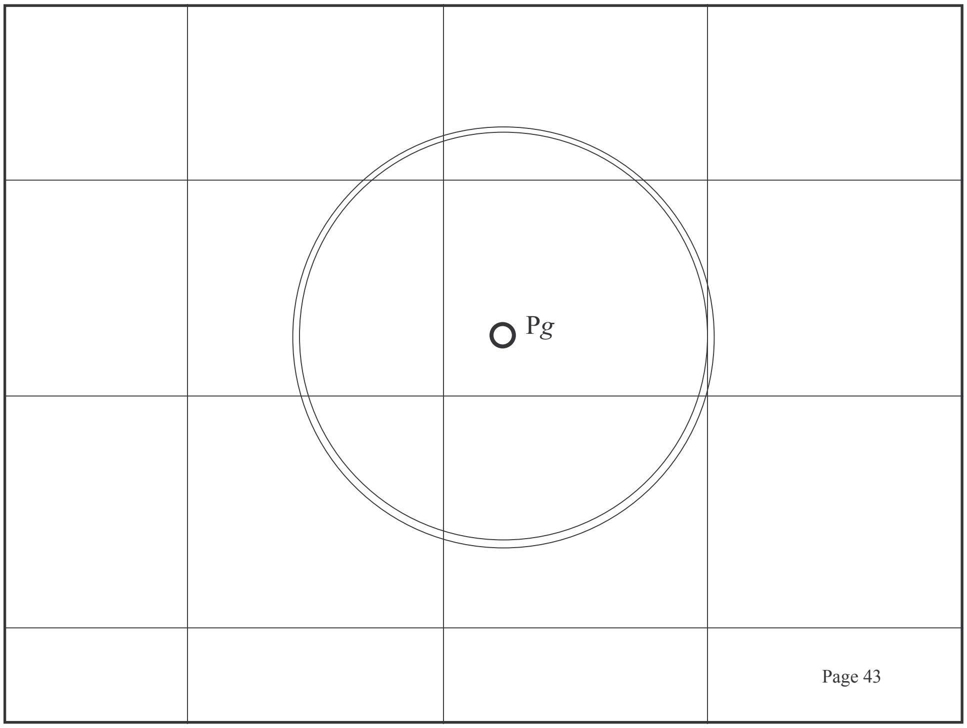


Using the results

- Put the previous diagram on the chart, and you obtain the following one



Using the results

- Practically, it is very rare to be close enough to P*g* for such an *equal altitudes circle* to fit on the chart.
- This circle is generally so big that 20 or 30 miles on its circumference can be assimilated to a line, called a *line of positions*.

Using the results

- So far, we have:
  - The estimated altitude of the body
  - The azimuth of the body
  - The estimated position of the observer

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Fourth definition

- Intercept
  - The intercept is the difference between estimated altitude (calculated) and the observed altitude (with the sextant).
  - It can then be positive or negative
  - It is expressed in minutes of arc
    - A reminder of the nautical mile definition:
      - One minute of arc at the center of the Earth projected on its surface.
    - There is a direct correlation between the value of the intercept (in minutes) and the value to correct the dead reckoning with in miles.

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Using the results

- On the chart, draw the estimated position of the observer
- Draw the azimuth, going through this position
- If the observed altitude is greater than the estimated one, it means that you are actually ***closer*** to the body than what the dead reckoning was predicting, and this is of as many miles as there are minutes in the intercept.
- If the observed altitude is smaller than the estimated one, it means that you are actually ***further*** from the body than what the dead reckoning was predicting, and this is of as many miles as there are minutes in the intercept.

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Using the results

- Draw the intercept on the chart, along the azimuth, in the appropriate direction.
- Perpendicularly to the azimuth, from the point found that way, draw the *line of positions*.

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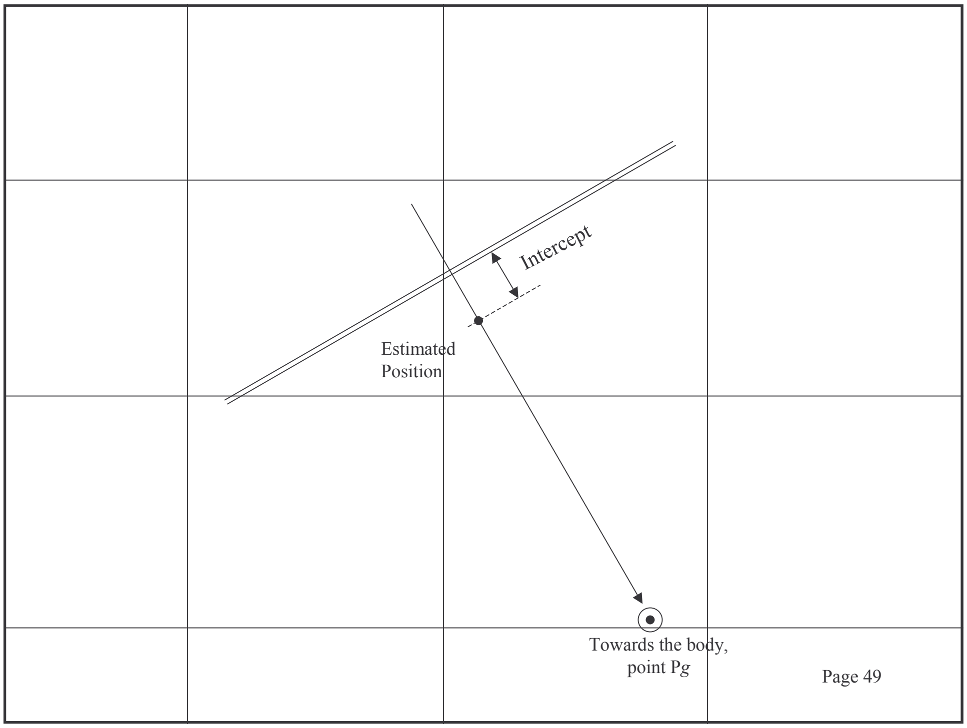

Using the results

- All we now know is that we are somewhere along this line.
- To refine this information, draw another line of positions, some hours later, so that the new one does not have the same azimuth as the old one.

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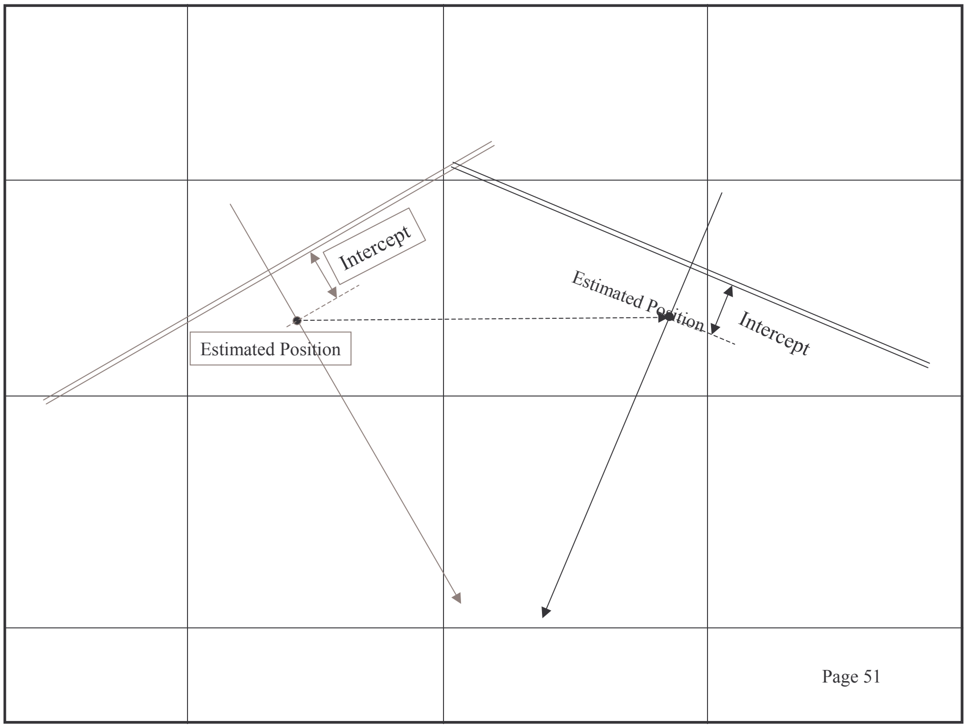

Using the results

- Then you translate the first line, of the distance traveled between the two observations, in the followed bearing.
- Thus you have an intersection between the two lines, which happens to be the *corrected position*, as it belongs to both lines of positions.

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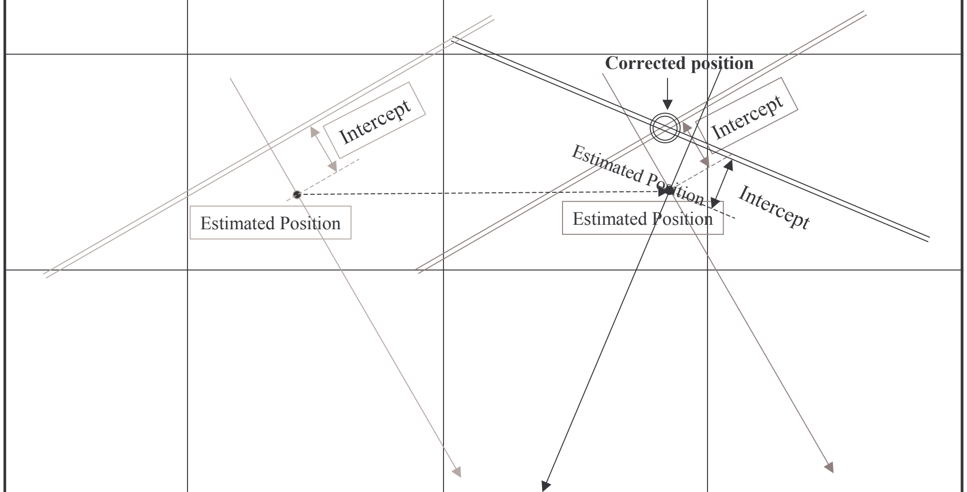

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Conclusion

- The path and rationale described in this document are simple, but the calculations to follow them are not trivial.
- However, a good understanding of the principle is necessary, at least to be able to detect calculation errors, which will certainly happen.

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