The Cutterman's Guide to Basic Celestial Navigation

Achieving celestial navigation proficiency within the Coast Guard Navigation Standards

Christopher D. Nolan
www.practicalnavigator.org

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Part 1: Getting Your Bearings

In which we discuss the Coast Guard Navigation Standards requirements for celestial navigation, a small bit of theory that you can't escape knowing, and how to use the various tools necessary for celestial navigation.

Chapter 1: Deciphering Chapter 6 of the USCG Navigation Standards

According to current Coast Guard Navigation Standards (Chapter 6), the required evolutions for WAGBs, WMSLs, WHECs, WMECs, and OCONUS WLBs are:

a. Determine the time of sunrise and sunset.
b. Determine the time of moonrise and moonset.
c. Determine gyro error by azimuth of the sun or other celestial body.
d. Determine gyro error by amplitude of the sun or other celestial body.
e. Obtain an LOP from the sun.
f. Observe Local Apparent Noon. Reduce sighting and determine latitude.
g. Obtain the ship's position by reducing celestial objects to a fix.
h. Compute latitude and gyro error by Polaris.

This can be a daunting list. It is helpful to break it up into the following four "big picture" categories and to approach the problem by learning one category at a time, instead of learning "Celestial Navigation" all at once. Here is the recommended breakdown of tasks, and the order in which they should be learned, and how they are presented in this book:

<u>Time of Phenomenon Problems</u> – This covers section A and B of the Navigation Standards. Sunrise, sunset, moonrise, and moonset are covered in part 2 of this book.

<u>Basic Celestial Problems</u> – This covers section D, F, and H of the Navigation Standards and begins to get into actual measurement of celestial bodies and more complicated math. These problems are covered in part 3 of this book.

<u>Advanced Azimuth Problems</u> – This covers section C of the Navigation Standards and deals exclusively with azimuth, a tedious but straightforward calculation. It is covered in part 4 of this book.

<u>Advanced Sight Reduction Problems</u> – This covers sections E and G of the Navigation Standards and involves the classic sextant observations and sight reductions. These problems are covered in part 5 of this book.

So, we've now broken down our challenge into four basic categories. In this manual, we'll present descriptions of how to complete these tasks with the minimum theory necessary – this is a practical course. However, there are few theoretical items you can't escape knowing. Let's take a look at those in chapter 2.

Chapter 2: The Bare Minimum of Theory

There are a handful of theoretical items you really need to understand in order to succeed in celestial navigation. You don't need to memorize them all right away – instead, refer back to this chapter as you discover a concept you don't know (they are listed in order of presentation in the text).

However, it might help to read through this chapter once or twice before you begin learning celestial navigation so that the terms are a bit familiar.

For an alphabetical listing, see the glossary at the back of the book.

Geographic Position – Imagine the earth as the center of the universe, unmoving and constant. All the heavenly bodies rotate around the earth, rising in the east, and setting in the west. At any point, each heavenly body is directly over a specific point on the surface of the earth. This point is called the object's "Geographic Position." All objects in the sky have a geographic position. For example, if you were in the Caribbean in July around noon, and the sun happened to be directly overhead, the sun's geographic position would be the same as your latitude and longitude. If you were to describe the sun's geographic position, you could use your latitude and longitude as a coordinate system, however it is conventionally referred to in a different way: **Declination** and **Greenwich Hour Angle**.

Declination – The latitude of the celestial body's **geographic position**.

Greenwich Hour Angle (GHA) – the longitude of the celestial body's **geographic position**. It is different from longitude in that hemisphere has nothing to do with it (i.e. there is no eastern and western hemisphere). Greenwich Hour Angle is measured from Greenwich, at longitude zero towards the west, all the way around the planet, back to Greenwich, at longitude zero. For example, one mile to the west of Greenwich, the longitude is 0 degrees and 01 minute West, while the Greenwich Hour Angle is 0 degrees and 01 minute. One mile to the east of Greenwich, the longitude is 0 degrees and 01 minute East, while the Greenwich Hour Angle is 359 degrees and 59 minutes.

Zenith Distance – The "**zenith**" is the spot directly above your head. The distance from the zenith to a celestial body is the "zenith distance," and is the compliment/opposite to the sextant height, or equivalent to 90 minus the sextant height. For example, if you measure a celestial body to be 30 degrees above the horizon, the zenith distance is 60 degrees. In more technical terms, the zenith distance is the angular distance on the earth's surface from the **geographic position** to your position.

Local Hour Angle (LHA) – equivalent to **Greenwich Hour Angle (GHA)** minus longitude in the western hemisphere, and Greenwich Hour Angle (GHA) plus longitude in the eastern hemisphere. Local Hour Angle (LHA) is the angle measured westward around the earth from the longitude of the observer to the Greenwich Hour Angle (GHA), or the longitude of the geographic position. For example, if the observer's longitude is 75° W, and the GHA of the body is 76°, the LHA is 1 degree. If the observer's longitude is 75° W, and the GHA of the body is 200°, LHA is 125 degrees. If the observer's longitude is 75° E, and the GHA of the body is 200°, LHA is 275 degrees. Occasionally you must add or subtract 360 degrees (1 circle), to make the math work in your favor. This is allowed and encouraged. Put concisely:

LHA = GHA – Longitude (western hemisphere)
LHA = GHA + Longitude (eastern hemisphere)

Azimuth (Z) – another word for "bearing." For example, the azimuth of the sun is the exact bearing to the sun's geographic position.

Sidereal Hour Angle – a conversion factor to help determine the **Greenwich Hour Angle (GHA)** of any star. Since there are so many stars in the night sky, and over 40 used regularly for navigation, it is impractical to record the Greenwich Hour Angle (GHA) of each star in the Nautical Almanac. Instead, the GHA of **Aries** is provided for all hours of the year, and the Sidereal Hour Angle for each star is provided. The Sidereal Hour Angle of the star is added to the GHA of Aries to determine the exact GHA of the star for any given time. Put concisely:

SHA + GHA (Aries) = GHA (star)

Assumed Position – when completing a celestial sight reduction, you must assume a position close to yours in order to calculate a "baseline" sight, from which you compare your actual sight to. When assuming a position, you choose the nearest whole degree of latitude, and you choose a nearby longitude, which when added or subtracted from the **Greenwich Hour Angle (GHA)** of the sun, results in a whole number of **Local Hour Angle (LHA).** In the western hemisphere, subtract the assumed longitude from the GHA to result in a whole number of LHA. In the eastern hemisphere, add the assumed longitude to the GHA to result in a whole number of LHA. This enables rapid problem solving, without interpolation, in the **Sight Reduction Tables (HO229).**

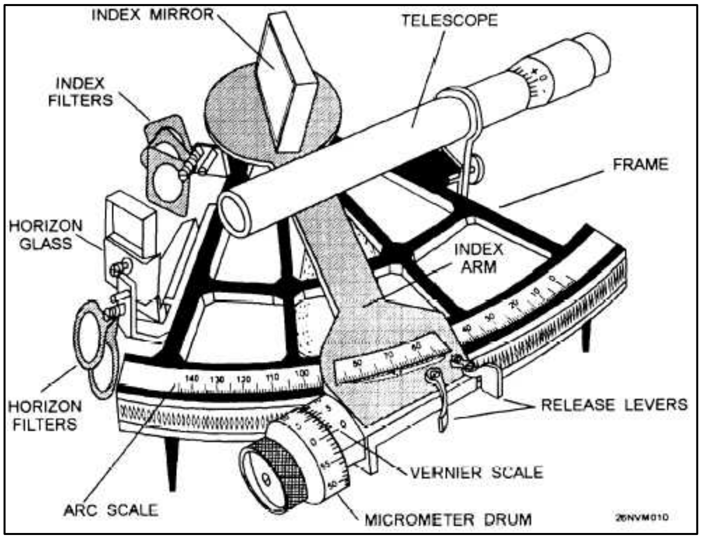
Altitude – Intercept Method – by assuming a nearby position and computing an altitude measurement for a celestial body, and then comparing the computed height, you can determine a line of position from a celestial body. The process, in brief, is: observe the celestial body; determine the geographic position of the body; assume a nearby position; enter HO229 with whole numbers of latitude, declination, and LHA; retrieve a computed height and azimuth; compare the computed height to the observed height; and plot from the assumed position either towards or away (depending on the circumstance) a distance equal to the difference between the computed height and observed height; draw a perpendicular line of position.

Chapter 3: Using Your Tools

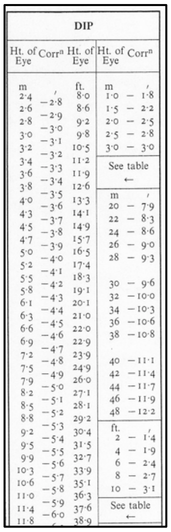
A written text is not the best place for a discussion of how to practically use celestial navigation tools like the sextant. The most efficient way to learn is from a shipmate or local professional. Please visit www.practicalnavigator.org for videos on sextant use. However, a brief discussion of the tools-of-the-trade is appropriate here.

The Marine Sextant

The marine sextant is a device used to measure angles between two objects, like a protractor. The telescope sights the objects, the index and horizon mirrors work together to bring the object to the horizon as you move the index arm and micrometer drum. The idea is to precisely measure the angular distance from an object to the horizon.



When using a sextant, there are three **"standard" corrections** that must be made for nearly all conditions. Any time you observe a celestial body with the sextant, you must apply these three corrections to the sextant height.



DIP

Ht. of Eye	Corrⁿ	Ht. of Eye
m	′	ft.
2·4		8·0
	−2·8	
2·6		8·6
	−2·9	
2·8		9·2
	−3·0	
3·0		9·8
	−3·1	
3·2		10·5
	−3·2	
3·4		11·2
	−3·3	
3·6		11·9
	−3·4	
3·8		12·6
	−3·5	
4·0		13·3
	−3·6	
4·3		14·1
	−3·7	
4·5		14·9
	−3·8	
4·7		15·7
	−3·9	
5·0		16·5
	−4·0	
5·2		17·4
	−4·1	
5·5		18·3
	−4·2	
5·8		19·1
	−4·3	
6·1		20·1
	−4·4	
6·3		21·0
	−4·5	
6·6		22·0
	−4·6	
6·9		22·9
	−4·7	
7·2		23·9
	−4·8	
7·5		24·9
	−4·9	
7·9		26·0
	−5·0	
8·2		27·1
	−5·1	
8·5		28·1
	−5·2	
8·8		29·2
	−5·3	
9·2		30·4
	−5·4	
9·5		31·5
	−5·5	
9·9		32·7
	−5·6	
10·3		33·9
	−5·7	
10·6		35·1
	−5·8	
11·0		36·3
	−5·9	
11·4		37·6
	−6·0	
11·8		38·9

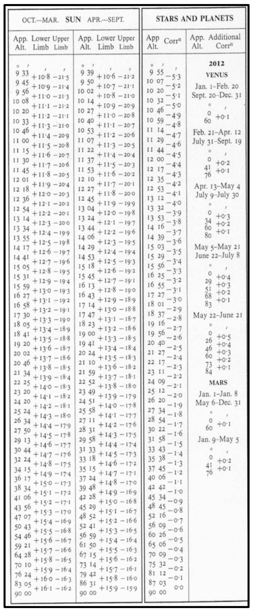
Ht. of Eye	Corrⁿ
m	′
1·0	− 1·8
1·5	− 2·2
2·0	− 2·5
2·5	− 2·8
3·0	− 3·0
See table ←	
m	′
20	− 7·9
22	− 8·3
24	− 8·6
26	− 9·0
28	− 9·3
30	− 9·6
32	− 10·0
34	− 10·3
36	− 10·6
38	− 10·8
40	− 11·1
42	− 11·4
44	− 11·7
46	− 11·9
48	− 12·2
ft.	′
2	− 1·4
4	− 1·9
6	− 2·4
8	− 2·7
10	− 3·1
See table ←	

The first is a correction for your **height of eye** above the surface of the sea using the tables in the Nautical Almanac. All table values are based on sea level – you are not at sea level and therefore must correct for that fact. On the front cover of the Nautical Almanac is a correction table for "**Dip**" which accounts for your height of eye. The Dip correction is always negative.

The second correction you must make accounts for the fact that the sextant may have a bit of error built in to it, either from damage or manufacturing. Set the sextant to zero and look at the horizon. If the horizon is not level, use the micrometer drum to bring it back into a level orientation. Read the sextant and note the value. This value is called "**index error.**" If the value you read is greater than zero, the error is "on the arc." If the value you read is less than zero, the error is "off the arc." For every sight, you must apply this value to your measurements to "correct" the sextant: if the value is on the arc, you must subtract it, and if it is off the arc, you must add it.

The third and final correction you must make accounts for atmospheric refraction (the bending of sunlight/starlight as it passes through the atmosphere). Additionally, there are minor corrections for different bodies and the time of year. These corrections are all wrapped up in the "**altitude correction**" or "**main correction**" located on the front cover of the Nautical Almanac.

In non-standard conditions of temperature, humidity, and elevation of stars and planets, there are a few additional corrections to account for – all of which are summarized at the front of the nautical almanac if you find yourself in these conditions.



OCT.—MAR. SUN			APR.—SEPT.			STARS AND PLANETS	
App. Alt.	Lower Limb	Upper Limb	App. Alt.	Lower Limb	Upper Limb	App Alt.	Corrⁿ
° ′	′	′	° ′	′	′	° ′	′
9 33	+10·8	−21·5	9 39	+10·6	−21·2	9 55	−5·3
9 45	+10·9	−21·4	9 50	+10·7	−21·1	10 07	−5·2
9 56	+11·0	−21·3	10 02	+10·8	−21·0	10 20	−5·1
10 08	+11·1	−21·2	10 14	+10·9	−20·9	10 32	−5·0
10 20	+11·2	−21·1	10 27	+11·0	−20·8	10 46	−4·9
10 33	+11·3	−21·0	10 40	+11·1	−20·7	10 59	−4·8
10 46	+11·4	−20·9	10 53	+11·2	−20·6	11 14	−4·7
11 00	+11·5	−20·8	11 07	+11·3	−20·5	11 29	−4·6
11 15	+11·6	−20·7	11 22	+11·4	−20·4	11 44	−4·5
11 30	+11·7	−20·6	11 37	+11·5	−20·3	12 00	−4·4
11 45	+11·8	−20·5	11 53	+11·6	−20·2	12 17	−4·3
12 01	+11·9	−20·4	12 10	+11·7	−20·1	12 35	−4·2
12 18	+12·0	−20·3	12 27	+11·8	−20·0	12 53	−4·1
12 36	+12·1	−20·2	12 45	+11·9	−19·9	13 12	−4·0
12 54	+12·2	−20·1	13 04	+12·0	−19·8	13 32	−3·9
13 14	+12·3	−20·0	13 24	+12·1	−19·7	13 53	−3·8
13 34	+12·4	−19·9	13 44	+12·2	−19·6	14 16	−3·7
13 55	+12·5	−19·8	14 06	+12·3	−19·5	14 39	−3·6
14 17	+12·6	−19·7	14 29	+12·4	−19·4	15 03	−3·5
14 41	+12·7	−19·6	14 53	+12·5	−19·3	15 29	−3·4
15 05	+12·8	−19·5	15 18	+12·6	−19·2	15 56	−3·3
15 31	+12·9	−19·4	15 45	+12·7	−19·1	16 25	−3·2
15 59	+13·0	−19·3	16 13	+12·8	−19·0	16 55	−3·1
16 27	+13·1	−19·2	16 43	+12·9	−18·9	17 27	−3·0
16 58	+13·2	−19·1	17 14	+13·0	−18·8	18 01	−2·9
17 30	+13·3	−19·0	17 47	+13·1	−18·7	18 37	−2·8
18 05	+13·4	−18·9	18 23	+13·2	−18·6	19 16	−2·7
18 41	+13·5	−18·8	19 00	+13·3	−18·5	19 56	−2·6
19 20	+13·6	−18·7	19 41	+13·4	−18·4	20 40	−2·5
20 02	+13·7	−18·6	20 24	+13·5	−18·3	21 27	−2·4
20 46	+13·8	−18·5	21 10	+13·6	−18·2	22 17	−2·3
21 34	+13·9	−18·4	21 59	+13·7	−18·1	23 11	−2·2
22 25	+14·0	−18·3	22 52	+13·8	−18·0	24 09	−2·1
23 20	+14·1	−18·2	23 49	+13·9	−17·9	25 12	−2·0
24 20	+14·2	−18·1	24 51	+14·0	−17·8	26 20	−1·9
25 24	+14·3	−18·0	25 58	+14·1	−17·7	27 34	−1·8
26 34	+14·4	−17·9	27 11	+14·2	−17·6	28 54	−1·7
27 50	+14·5	−17·8	28 31	+14·3	−17·5	30 22	−1·6
29 13	+14·6	−17·7	29 58	+14·4	−17·4	31 58	−1·5
30 44	+14·7	−17·6	31 33	+14·5	−17·3	33 43	−1·4
32 24	+14·8	−17·5	33 18	+14·6	−17·2	35 38	−1·3
34 15	+14·9	−17·4	35 15	+14·7	−17·1	37 45	−1·2
36 17	+15·0	−17·3	37 24	+14·8	−17·0	40 06	−1·1
38 34	+15·1	−17·2	39 48	+14·9	−16·9	42 42	−1·0
41 06	+15·2	−17·1	42 28	+15·0	−16·8	45 34	−0·9
43 56	+15·3	−17·0	45 29	+15·1	−16·7	48 45	−0·8
47 07	+15·4	−16·9	48 52	+15·2	−16·6	52 16	−0·7
50 43	+15·5	−16·8	52 41	+15·3	−16·5	56 09	−0·6
54 46	+15·6	−16·7	56 59	+15·4	−16·4	60 26	−0·5
59 21	+15·7	−16·6	61 50	+15·5	−16·3	65 06	−0·4
64 28	+15·8	−16·5	67 15	+15·6	−16·2	70 09	−0·3
70 10	+15·9	−16·4	73 14	+15·7	−16·1	75 32	−0·2
76 24	+16·0	−16·3	79 42	+15·8	−16·0	81 12	−0·1
83 05	+16·1	−16·2	86 31	+15·9	−15·9	87 03	0·0
90 00			90 00			90 00	

App. Alt.	Additional Corrⁿ
2012	
VENUS	
Jan. 1–Feb. 20 Sept. 20–Dec. 31	
°	′
0	+0·1
60	
Feb. 21–Apr. 12 July 31–Sept. 19	
°	′
0	+0·2
41	+0·1
76	
Apr. 13–May 4 July 9–July 30	
°	′
0	+0·3
34	+0·2
60	+0·1
80	
May 5–May 21 June 22–July 8	
°	′
0	+0·4
29	+0·3
51	+0·2
68	+0·1
83	
May 22–June 21	
°	′
0	+0·5
26	+0·4
46	+0·3
60	+0·2
73	+0·1
84	
MARS	
Jan. 1–Jan. 8 May 6–Dec. 31	
°	′
0	+0·1
60	
Jan. 9–May 5	
°	′
0	+0·2
41	+0·1
76	

The Telescopic Alidade

The telescopic alidade is made to fit over the gyro compass repeaters on the bridge and is used to quickly and accurately measure the true bearing to any object.

In celestial navigation, it is most often used for measuring the angle of the sun near the horizon for gyrocompass error by amplitude of the sun measurements. This topic is covered in chapter 6 of this text.

The Azimuth Circle

Another word for "bearing" is "**azimuth.**" As such, the azimuth circle is another device used for measuring bearings to objects. In this case, it is most commonly used to measure the bearing of the sun and other celestial objects when they are not near the horizon. Utilizing a system of mirrors, the light emitted from an astronomical body is reflected onto the gyroscopic compass repeater in order to obtain a highly accurate bearing. It is most often used in gyroscopic error by azimuth calculations. This topic is covered in chapter 9 and 10 of this text.

Part 2: Time of Phenomenon Problems

In which we solve sunrise, sunset, moonrise, and moonset problems, enabling successful completion of two tasks in the Coast Guard Navigation Standards.

Chapter 4: Determine the Time of Sunrise and Sunset

The Basic Idea Behind Sunrise and Sunset Problems

Times of sunrise or sunset are given in the **Nautical Almanac**. However, in order to avoid the almanac being unmanageably thick, solutions are only given for certain latitudes and "standard" longitudes. This means that you must determine the time of sunrise/sunset at the listed locations, and then adjust the times for the difference in your position from the standard position.

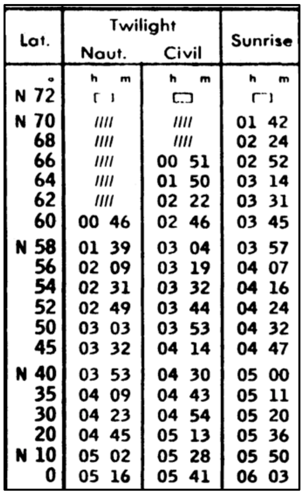
The key difficulty behind solving these problems is to determine how far away your ship is from a **standard meridian**. The earth is divided into standard meridians (or longitude lines) every 15 degrees of longitude around the earth. By determining the time of sunrise or sunset at a standard meridian, and then accounting for the difference between the standard meridian and your position, you have solved the problem.

Fortunately, it is fairly easy to calculate time of phenomena at standard meridians, and this is the first step in solving time problems. Since the earth is divided into 360 degrees, and takes one day to rotate on it's axis, it has been broken up in 24 time zones of 15 degrees each. Standard meridians are therefore every 15 degrees around the surface of the earth, at 0°, 15° W, 30° W, 45° W, 60° W, etc.

The nautical almanac enables you to calculate time of phenomena at standard meridians. However, the first step is to look in the almanac for the time of phenomenon at your latitude. If your latitude isn't one of the conveniently tabled latitudes, you must either use Table 1 in the Nautical Almanac, or interpolate for the answer.

Manual Calculation of Sunrise and Sunset

<u>Problem 4-1.</u> This basic example illustrates how to calculate sunrise at a known location.



Lat.	Twilight		Sunrise
	Naut.	Civil	
°	h m	h m	h m
N 72	□	□	□
N 70	////	////	01 42
68	////	////	02 24
66	////	00 51	02 52
64	////	01 50	03 14
62	////	02 22	03 31
60	00 46	02 46	03 45
N 58	01 39	03 04	03 57
56	02 09	03 19	04 07
54	02 31	03 32	04 16
52	02 49	03 44	04 24
50	03 03	03 53	04 32
45	03 32	04 14	04 47
N 40	03 53	04 30	05 00
35	04 09	04 43	05 11
30	04 23	04 54	05 20
20	04 45	05 13	05 36
N 10	05 02	05 28	05 50
0	05 16	05 41	06 03

You are aboard CGC ESCANABA, en route from Boston to San Juan. Your position is latitude 25° 00.0' N and longitude 65° 00.0' W. The ship is holding position and is not moving. The date is 4 August and you are observing (+4) zone time. What is the zone time of sunrise at your ship's location?

Answer: 0548.

Step 1: Locate the tabular values in the Nautical Almanac. Find the latitudes which bracket the desired latitude and note the time of sunrise at those latitudes:

30° N: 0520
20° N: 0536

Note that the interval between the bracketing latitudes is 10°.

Step 2: Identify the latitude difference between the bracketing latitudes and the desired latitude (your latitude), and the time difference between the tabular latitudes.

30° N: 0520
25° N: this is the unknown value you seek.
20° N: 0536

Differences:
Latitude difference: 20° N to 25° = 5°
Time difference: 20° N to 30° N = 0536 – 0520 = 16 minutes.

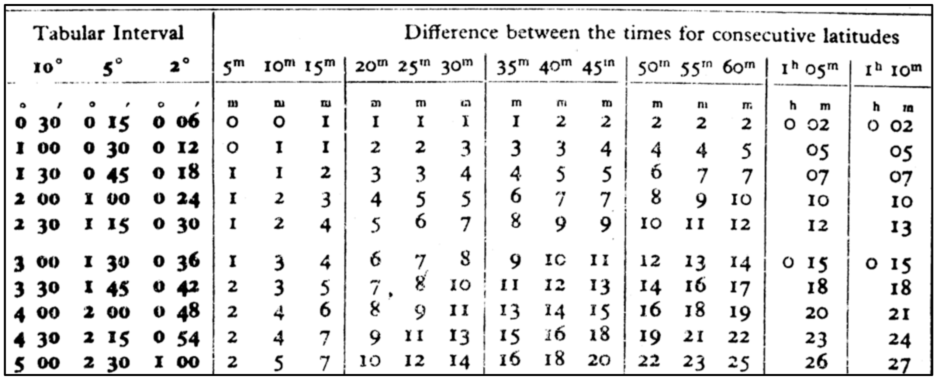
Step 3: Complete the latitude correction. The two options for this step are to use arithmetic to do a manual calculation (ratios), or to use Table 1 in the Nautical Almanac. A portion of the table is re-created here. Remember to mentally check the results to ensure addition/subtraction was performed correctly.

Option 1: manual calculation:

$$\frac{x}{16\,minutes} = \frac{5°}{10°}$$
$$\frac{x}{16\,minutes} = 0.500$$
$$x = (0.5000)\ (16)$$
$x = 8$ minutes (earlier than base latitude)

Calculate corrected time = 0536 – 8 minutes = 0528

Option 2: “Table 1” correction:



Tabular Interval			Difference between the times for consecutive latitudes													
10°	5°	2°	5m	10m	15m	20m	25m	30m	35m	40m	45m	50m	55m	60m	1h 05m	1h 10m
° ′	° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m
0 30	0 15	0 06	0	0	1	1	1	1	1	2	2	2	2	2	0 02	0 02
1 00	0 30	0 12	0	1	1	2	2	3	3	3	4	4	4	5	05	05
1 30	0 45	0 18	1	1	2	3	3	4	4	5	5	6	7	7	07	07
2 00	1 00	0 24	1	2	3	4	5	5	6	7	7	8	9	10	10	10
2 30	1 15	0 30	1	2	4	5	6	7	8	9	9	10	11	12	12	13
3 00	1 30	0 36	1	3	4	6	7	8	9	10	11	12	13	14	0 15	0 15
3 30	1 45	0 42	2	3	5	7	8	10	11	12	13	14	16	17	18	18
4 00	2 00	0 48	2	4	6	8	9	11	13	14	15	16	18	19	20	21
4 30	2 15	0 54	2	4	7	9	11	13	15	16	18	19	21	22	23	24
5 00	2 30	1 00	2	5	7	10	12	14	16	18	20	22	23	25	26	27

a. Note that the tabular interval is 10° (from step 1).
b. Proceed down the “Tabular Interval” column until you reach the difference between the tabular latitude and your desired latitude (5° in this case).

c. The time difference determined in the previous step was 16 minutes. There is no “16 minutes” column in the “difference between the times for consecutive latitudes” section, so note the values for the nearest headings (15m and 20m). In this case, the necessary values are 7 and 10 minutes.

d. Mentally interpolate the actual value (8 minutes in this case).

Table 1 corrected time = 0536 – 8 minutes = 0528.

Either option (arithmetic or Table 1 correction) will work…it’s just a matter of preference.

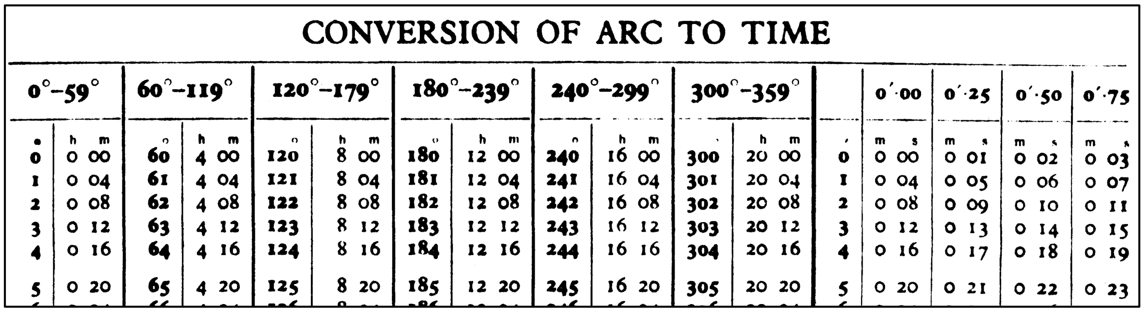
Step 4: Determine the difference in longitude from the standard meridian of the time being observed.

Longitude = 065° W.

If you are observing (+4) zone time, the associated standard meridian is 60° W (this can be determined by multiplying the zone descriptor by 15°…e.g. 4 x 15° = 60°).

65° W – 60° W = 5° difference (to the west) from standard meridian.

Step 5: Convert the difference in longitude arc to time. Use the Conversion of Arc to Time table in the Nautical Almanac. A portion of the table is re-created here.



CONVERSION OF ARC TO TIME

0°–59°		60°–119°		120°–179°		180°–239°		240°–299°		300°–359°			0′·00	0′·25	0′·50	0′·75
°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	′	m s	m s	m s	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00	0 01	0 02	0 03
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04	0 05	0 06	0 07
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08	0 09	0 10	0 11
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12	0 13	0 14	0 15
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16	0 17	0 18	0 19
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20	0 21	0 22	0 23

5° of arc to the west = 20 minutes (added, since difference is “to the west”).

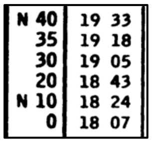
Step 6: Apply the longitude correction to the latitude-corrected time to determine time of sunset.

0528 + 0020 = **0548 = Answer**

Problem 4-2. This example is slightly more difficult and illustrates how to solve sunset problems at a known location.

You are on watch aboard CGC EAGLE, on passage from Europe to the Caribbean. The ship's position is latitude 16° 03.1' N and longitude 031° 03.8' W. The ship is holding position and not moving. The date is 28 June. What is the zone time of sunset at your ship's location?

Answer: 18:39:45 zone time.



N 40	19 33
35	19 18
30	19 05
20	18 43
N 10	18 24
0	18 07

Step 1: Locate the tabular values in the Nautical Almanac.

The nearest bracketing latitudes are:

20° N: 1843
10° N: 1824

Note the tabular interval is 10°.

Step 2: Convert local latitude to decimal notation and identify the difference from the nearest bracketing latitudes.

20° N: 1843
16° 03.1' N = 16.052° (this is the latitude value for your position)
10° N: 1824

Differences:
10° N to 16.052° = 6.052°
10° N to 20° N = 19 minutes

Step 3: Complete the latitude correction (using mental interpolation or Table 1 in the Nautical Almanac).

$$\frac{x}{19\ minutes} = \frac{6.052°}{10°}$$
$$\frac{x}{19\ minutes} = 0.6052$$
$$x = (0.6052)\ (19)$$
$$x = 11.499 \text{ minutes (later)}$$

Latitude corrected time = 1824 (base) + 11.5 minutes = 18:35:30

Table 1 correction (from the Nautical Almanac)
= 1824 (base) + approximately 12 min = 18:36

Step 4: Determine the difference in longitude from the standard meridian of the time being observed.

Longitude = 031° 03.8’ W

The problem does not mention a specific time zone being observed, so assume that the vessel is observing (+2) = standard meridian of 30°, the closest meridian to the DR longitude.

031° 03.8’ W – 30° = 1° 03.8’ difference from standard meridian.

Step 5: Convert the difference in longitude arc to time (use the Conversion of Arc to Time in the Nautical Almanac).

1° 03.8’ of arc to the west = 4 minutes 15 seconds (added).

Step 6: Apply the longitude correction to the latitude-corrected time to determine time of sunset.

18:35:30 + 00:04:15 = **18:39:45 = Answer**

<u>In summary, the steps to calculate sunrise or sunset manually are:</u>

Step 1: Locate bracketing values for your latitude from the Nautical Almanac.

Step 2: Identify the difference from the bracketing values to your latitude.

Step 3: Correct the sunrise/sunset values for latitude, either using mental interpolation or Table 1 in the Nautical Almanac.

Step 4: Determine the difference in longitude from your DR position to the standard meridian being observed by your ship’s clocks.

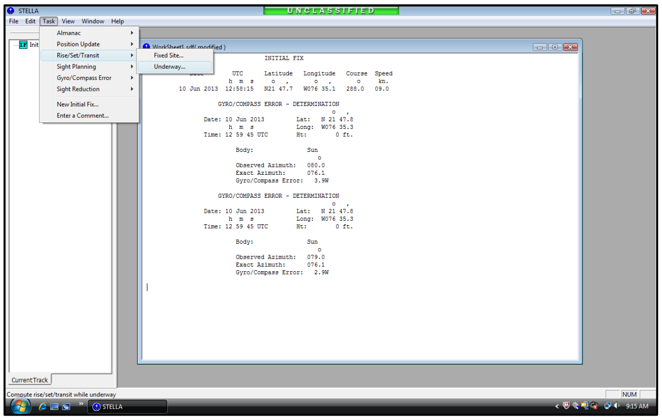
Step 5: Convert the difference obtained in step 4 to time using the Conversion of Arc to Time table in the Nautical Almanac.

Step 6: Correct the value from step 3 for longitude to obtain your answer.

STELLA Calculations for Sunrise and Sunset

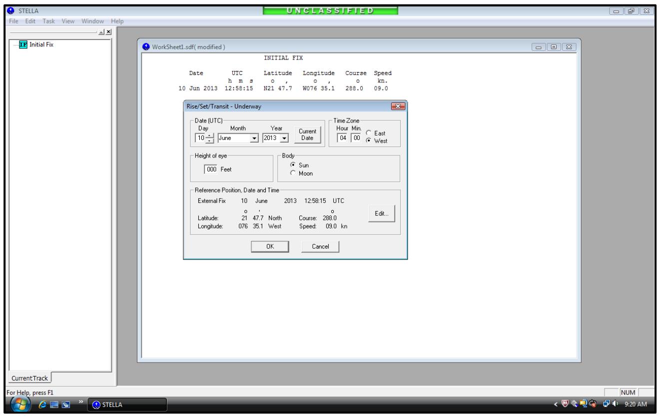
To determine the time of rise, set, or transit for any body using the STELLA program, first establish a DR position (Initial Fix). Then follow:

Step 1:
Task > Rise/Set/Transit >Underway



```
                    INITIAL FIX

          UTC      Latitude   Longitude   Course  Speed
         h  m  s     o  ,       o  ,        o      kn.
10 Jun 2013  12:58:15  N21 47.7   W076 35.1   288.0   09.0

         GYRO/COMPASS ERROR - DETERMINATION
                                        o  ,
   Date: 10 Jun 2013        Lat:   N 21 47.8
         h  m  s            Long:  W076 35.3
   Time: 12 59 45 UTC       Ht:        0 ft.

            Body:               Sun
                                   o
            Observed Azimuth:   080.0
            Exact Azimuth:      076.1
            Gyro/Compass Error:   3.9W

         GYRO/COMPASS ERROR - DETERMINATION
                                        o  ,
   Date: 10 Jun 2013        Lat:   N 21 47.8
         h  m  s            Long:  W076 35.3
   Time: 12 59 45 UTC       Ht:        0 ft.

            Body:               Sun
                                   o
            Observed Azimuth:   079.0
            Exact Azimuth:      076.1
            Gyro/Compass Error:   2.9W
```

Step 2:
Enter data in all appropriate fields.



```
                    INITIAL FIX

   Date        UTC      Latitude   Longitude   Course  Speed
              h  m  s     o  ,       o  ,        o      kn.
10 Jun 2013  12:58:15  N21 47.7   W076 35.1   288.0   09.0
```

Date (UTC): Day 10, Month June, Year 2013

Time Zone: Hour 04, Min. 00 ○ East ● West

Height of eye: 000 Feet

Body: ● Sun ○ Moon

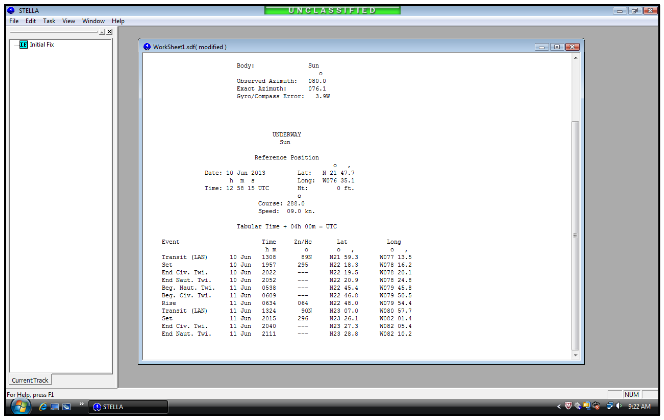
Reference Position, Date and Time

External Fix 10 June 2013 12:58:15 UTC

Latitude: 21° 47.7' North Course: 288.0°

Longitude: 076 35.1 West Speed: 09.0 kn

Step 3:
Retrieve appropriate data.



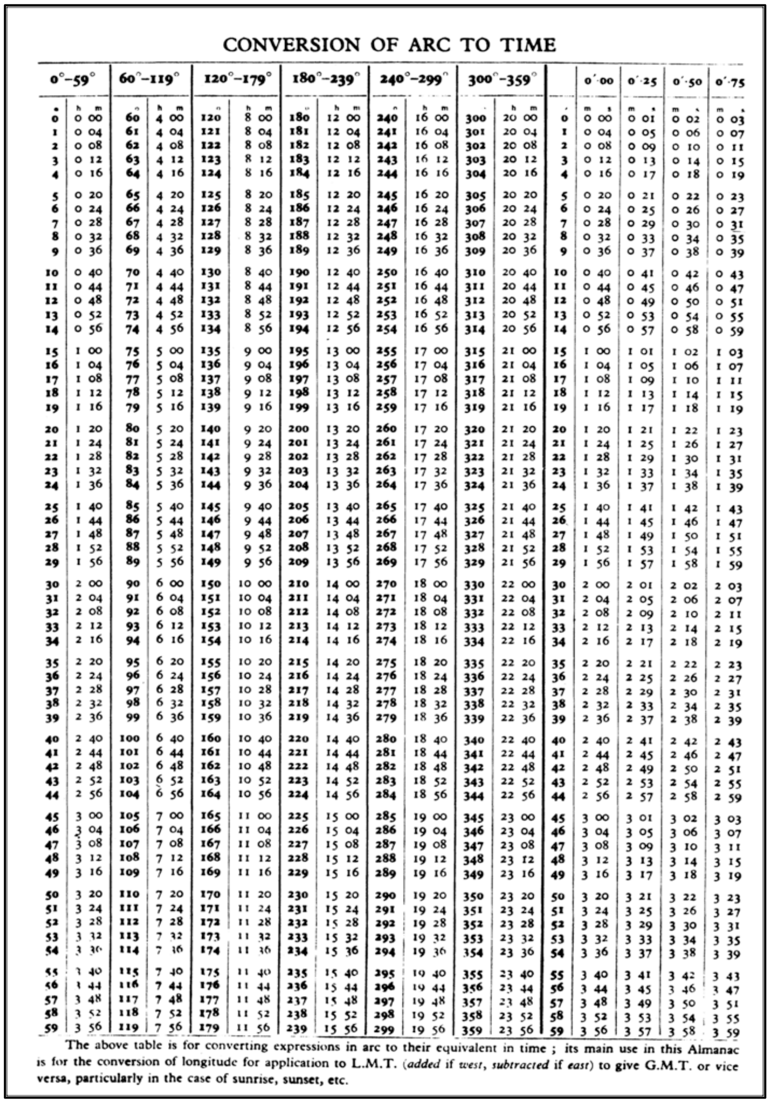
```
            Body:               Sun
                                   o
            Observed Azimuth:   080.0
            Exact Azimuth:      076.1
            Gyro/Compass Error:   3.9W



                       UNDERWAY
                         Sun

                  Reference Position
                                        o  ,
   Date: 10 Jun 2013        Lat:   N 21 47.7
         h  m  s            Long:  W076 35.1
   Time: 12 58 15 UTC       Ht:        0 ft.
                            o
                  Course: 288.0
                  Speed:  09.0 kn.

            Tabular Time + 04h 00m = UTC

Event                        Time    Zn/Hc    Lat        Long
                              h m      o      o  ,       o  ,
Transit (LAN)      10 Jun   1308     89N    N21 59.3   W077 13.5
Set                10 Jun   1957    295     N22 18.3   W078 16.2
End Civ. Twi.      10 Jun   2022    ---     N22 19.5   W078 20.1
End Naut. Twi.     10 Jun   2052    ---     N22 20.9   W078 24.8
Beg. Naut. Twi.    11 Jun   0538    ---     N22 45.4   W079 45.8
Beg. Civ. Twi.     11 Jun   0609    ---     N22 46.8   W079 50.5
Rise               11 Jun   0634    064     N22 48.0   W079 54.4
Transit (LAN)      11 Jun   1324     90N    N23 07.0   W080 57.7
Set                11 Jun   2015    296     N23 26.1   W082 01.4
End Civ. Twi.      11 Jun   2040    ---     N23 27.3   W082 05.4
End Naut. Twi.     11 Jun   2111    ---     N23 28.8   W082 10.2
```

Advanced Theory and Other Matters for Sunrise and Sunset

Approximate times of sunrise and sunset (within 5 minutes or so) are generally sufficient for most operations. However, maximum precision can be obtained with more detailed calculations.

The explanations provided in this text are for stationary ships. In order to be precise on a moving ship, the time of sunrise or set must be calculated not for the position the ship is in at the time of calculation, but for the position the ship will be in at the time of phenomenon…this means doing two calculations for maximum precision.

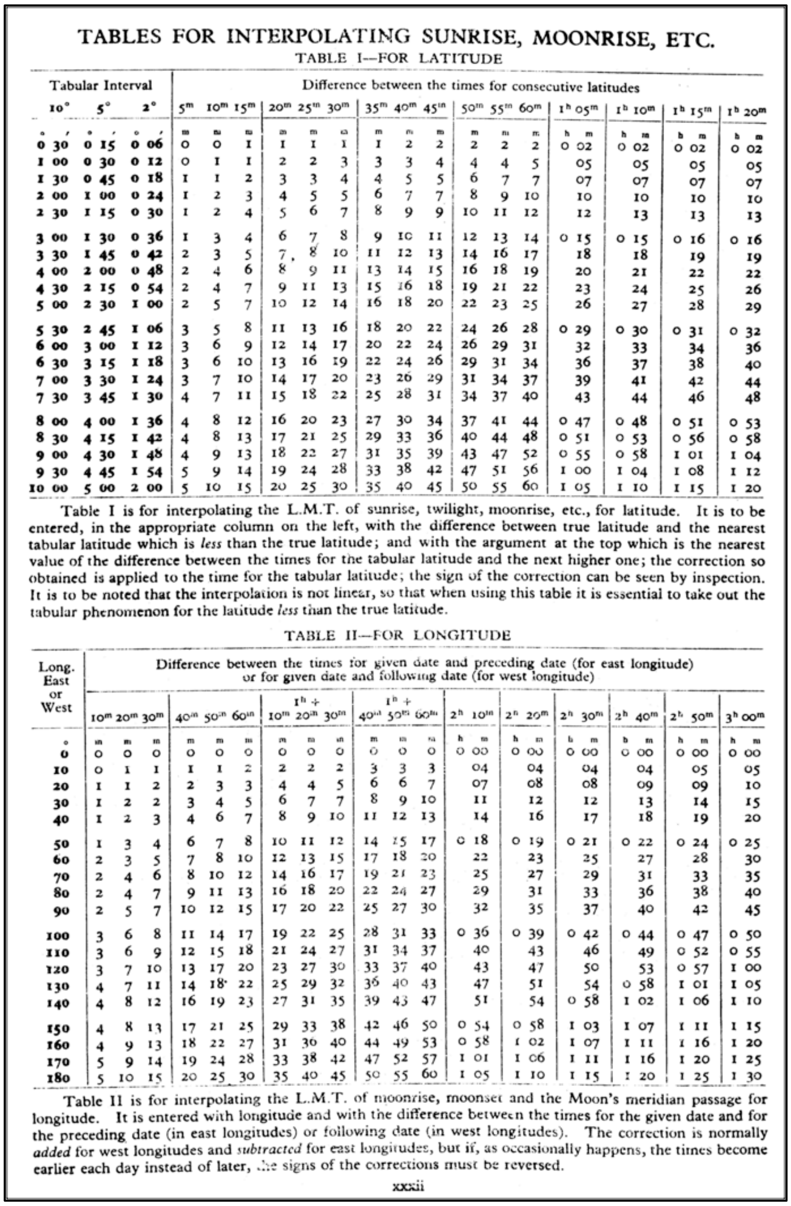
For more detailed explanations of time of phenomenon problems, including problems for moving ships and second-estimate problems, refer to Part 9 of *The Cutterman's Guide to Navigation Problems*, which is available at www.practicalnavigator.org.



CONVERSION OF ARC TO TIME

0°–59°		60°–119°		120°–179°		180°–239°		240°–299°		300°–359°			0'·00	0'·25	0'·50	0'·75
°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	'	m s	m s	m s	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00	0 01	0 02	0 03
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04	0 05	0 06	0 07
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08	0 09	0 10	0 11
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12	0 13	0 14	0 15
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16	0 17	0 18	0 19
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20	0 21	0 22	0 23
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24	0 25	0 26	0 27
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28	0 29	0 30	0 31
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32	0 33	0 34	0 35
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36	0 37	0 38	0 39
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40	0 41	0 42	0 43
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44	0 45	0 46	0 47
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48	0 49	0 50	0 51
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52	0 53	0 54	0 55
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56	0 57	0 58	0 59
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00	1 01	1 02	1 03
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04	1 05	1 06	1 07
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08	1 09	1 10	1 11
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12	1 13	1 14	1 15
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16	1 17	1 18	1 19
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20	1 21	1 22	1 23
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24	1 25	1 26	1 27
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28	1 29	1 30	1 31
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32	1 33	1 34	1 35
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36	1 37	1 38	1 39
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40	1 41	1 42	1 43
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44	1 45	1 46	1 47
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48	1 49	1 50	1 51
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52	1 53	1 54	1 55
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56	1 57	1 58	1 59
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00	2 01	2 02	2 03
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04	2 05	2 06	2 07
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08	2 09	2 10	2 11
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12	2 13	2 14	2 15
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16	2 17	2 18	2 19
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20	2 21	2 22	2 23
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24	2 25	2 26	2 27
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28	2 29	2 30	2 31
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32	2 33	2 34	2 35
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36	2 37	2 38	2 39
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40	2 41	2 42	2 43
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44	2 45	2 46	2 47
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48	2 49	2 50	2 51
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52	2 53	2 54	2 55
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56	2 57	2 58	2 59
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00	3 01	3 02	3 03
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04	3 05	3 06	3 07
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08	3 09	3 10	3 11
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12	3 13	3 14	3 15
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16	3 17	3 18	3 19
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20	3 21	3 22	3 23
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24	3 25	3 26	3 27
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28	3 29	3 30	3 31
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32	3 33	3 34	3 35
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36	3 37	3 38	3 39
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40	3 41	3 42	3 43
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44	3 45	3 46	3 47
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48	3 49	3 50	3 51
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52	3 53	3 54	3 55
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56	3 57	3 58	3 59

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added* if *west*, *subtracted* if *east*) to give G.M.T. or vice versa, particularly in the case of sunrise, sunset, etc.



TABLES FOR INTERPOLATING SUNRISE, MOONRISE, ETC.

TABLE I—FOR LATITUDE

Tabular Interval			Difference between the times for consecutive latitudes															
10°	5°	2°	5^m	10^m	15^m	20^m	25^m	30^m	35^m	40^m	45^m	50^m	55^m	60^m	$1^h 05^m$	$1^h 10^m$	$1^h 15^m$	$1^h 20^m$
° ′	° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m
0 30	0 15	0 06	0	0	1	1	1	1	1	2	2	2	2	2	0 02	0 02	0 02	0 02
1 00	0 30	0 12	0	1	1	2	2	3	3	3	4	4	4	5	05	05	05	05
1 30	0 45	0 18	1	1	2	3	3	4	4	5	5	6	7	7	07	07	07	07
2 00	1 00	0 24	1	2	3	4	5	5	6	7	7	8	9	10	10	10	10	10
2 30	1 15	0 30	1	2	4	5	6	7	8	9	9	10	11	12	12	13	13	13
3 00	1 30	0 36	1	3	4	6	7	8	9	10	11	12	13	14	0 15	0 15	0 16	0 16
3 30	1 45	0 42	2	3	5	7	8	10	11	12	13	14	16	17	18	18	19	19
4 00	2 00	0 48	2	4	6	8	9	11	13	14	15	16	18	19	20	21	22	22
4 30	2 15	0 54	2	4	7	9	11	13	15	16	18	19	21	22	23	24	25	26
5 00	2 30	1 00	2	5	7	10	12	14	16	18	20	22	23	25	26	27	28	29
5 30	2 45	1 06	3	5	8	11	13	16	18	20	22	24	26	28	0 29	0 30	0 31	0 32
6 00	3 00	1 12	3	6	9	12	14	17	20	22	24	26	29	31	32	33	34	36
6 30	3 15	1 18	3	6	10	13	16	19	22	24	26	29	31	34	36	37	38	40
7 00	3 30	1 24	3	7	10	14	17	20	23	26	29	31	34	37	39	41	42	44
7 30	3 45	1 30	4	7	11	15	18	22	25	28	31	34	37	40	43	44	46	48
8 00	4 00	1 36	4	8	12	16	20	23	27	30	34	37	41	44	0 47	0 48	0 51	0 53
8 30	4 15	1 42	4	8	13	17	21	25	29	33	36	40	44	48	0 51	0 53	0 56	0 58
9 00	4 30	1 48	4	9	13	18	22	27	31	35	39	43	47	52	0 55	0 58	1 01	1 04
9 30	4 45	1 54	5	9	14	19	24	28	33	38	42	47	51	56	1 00	1 04	1 08	1 12
10 00	5 00	2 00	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20

Table I is for interpolating the L.M.T. of sunrise, twilight, moonrise, etc., for latitude. It is to be entered, in the appropriate column on the left, with the difference between true latitude and the nearest tabular latitude which is *less* than the true latitude; and with the argument at the top which is the nearest value of the difference between the times for the tabular latitude and the next higher one; the correction so obtained is applied to the time for the tabular latitude; the sign of the correction can be seen by inspection. It is to be noted that the interpolation is not linear, so that when using this table it is essential to take out the tabular phenomenon for the latitude *less* than the true latitude.

TABLE II—FOR LONGITUDE

Long. East or West	Difference between the times for given date and preceding date (for east longitude) or for given date and following date (for west longitude)																	
							1^h +			1^h +								
	10^m	20^m	30^m	40^m	50^m	60^m	10^m	20^m	30^m	40^m	50^m	60^m	$2^h 10^m$	$2^h 20^m$	$2^h 30^m$	$2^h 40^m$	$2^h 50^m$	$3^h 00^m$
°	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m	h m	h m
0	0	0	0	0	0	0	0	0	0	0	0	0	0 00	0 00	0 00	0 00	0 00	0 00
10	0	1	1	1	1	2	2	2	2	3	3	3	04	04	04	04	05	05
20	1	1	2	2	3	3	4	4	5	6	6	7	07	08	08	09	09	10
30	1	2	2	3	4	5	6	7	7	8	9	10	11	12	12	13	14	15
40	1	2	3	4	6	7	8	9	10	11	12	13	14	16	17	18	19	20
50	1	3	4	6	7	8	10	11	12	14	15	17	0 18	0 19	0 21	0 22	0 24	0 25
60	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30
70	2	4	6	8	10	12	14	16	17	19	21	23	25	27	29	31	33	35
80	2	4	7	9	11	13	16	18	20	22	24	27	29	31	33	36	38	40
90	2	5	7	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45
100	3	6	8	11	14	17	19	22	25	28	31	33	0 36	0 39	0 42	0 44	0 47	0 50
110	3	6	9	12	15	18	21	24	27	31	34	37	40	43	46	49	0 52	0 55
120	3	7	10	13	17	20	23	27	30	33	37	40	43	47	50	53	0 57	1 00
130	4	7	11	14	18	22	25	29	32	36	40	43	47	51	54	0 58	1 01	1 05
140	4	8	12	16	19	23	27	31	35	39	43	47	51	54	0 58	1 02	1 06	1 10
150	4	8	13	17	21	25	29	33	38	42	46	50	0 54	0 58	1 03	1 07	1 11	1 15
160	4	9	13	18	22	27	31	36	40	44	49	53	0 58	1 02	1 07	1 11	1 16	1 20
170	5	9	14	19	24	28	33	38	42	47	52	57	1 01	1 06	1 11	1 16	1 20	1 25
180	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20	1 25	1 30

Table II is for interpolating the L.M.T. of moonrise, moonset and the Moon's meridian passage for longitude. It is entered with longitude and with the difference between the times for the given date and for the preceding date (in east longitudes) or following date (in west longitudes). The correction is normally *added* for west longitudes and *subtracted* for east longitudes, but if, as occasionally happens, the times become earlier each day instead of later, the signs of the corrections must be reversed.

Chapter 5: Determine the Time of Moonrise and Moonset

The Basic Idea Behind Moonrise and Moonset Problems

Moonrise and moonset problems are nearly identical to sunrise and sunset problems (Chapter 4 of this text).

The key difference in moon calculations is that time calculations must be carried out for the day in question, as well as the following day (preceding day in eastern hemisphere) in order to use Table 2 in the Nautical Almanac. Moonrise and moonset are calculated in the same way.

Times of moonrise or moonset are given in the **Nautical Almanac**. However, in order to avoid the almanac being unmanageably thick, solutions are only given for certain latitudes and "standard" longitudes. This means that you must determine the time of sunrise/sunset at the listed locations, and then adjust the times for the difference in your position from the standard position.

The key difficulty behind solving these problems is to determine how far away your ship is from a **standard meridian**. The earth is divided into standard meridians (or longitude lines) every 15 degrees of longitude around the earth. By determining the time of sunrise or sunset at a standard meridian, and then accounting for the difference between the standard meridian and your position, you have solved the problem.

Fortunately, it is fairly easy to calculate time of phenomena at standard meridians, and this is the first step in solving time problems. Since the earth is divided into 360 degrees, and takes one day to rotate on it's axis, it has been broken up in 24 time zones of 15 degrees each. Standard meridians are therefore every 15 degrees around the surface of the earth, at 0°, 15° W, 30° W, 45° W, 60° W, etc.

The nautical almanac enables you to calculate time of phenomena at standard meridians. However, the first step is to look in the almanac for the time of phenomenon at your latitude. If your latitude isn't one of the conveniently tabled latitudes, you must either use Table 1 in the Nautical Almanac, or interpolate for the answer.

Manual Calculation of Moonrise and Moonset

Problem 5-1. The following question illustrates the process of calculating moonset.

You are aboard CGC RELIANCE, returning home after a D7 patrol and are to rendezvous with a helicopter for night evolutions. The ship's position is latitude 42° 30' N and longitude 070° 00' W. The ship is holding position and not moving. The date is 2 August and you are observing (+4) zone time. What is the zone time of moonset?

Answer: Approximately 2103

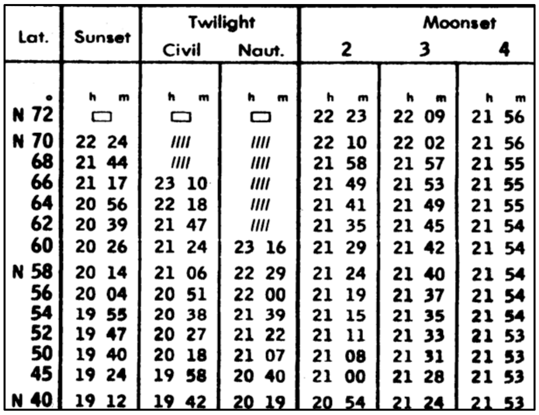
Step 1: Locate the tabular values in the Nautical Almanac.

Locate the nearest tabular latitudes which bracket the desired position and record the time of moonset at each:

45° N: 2100
40° N: 2054

Note the tabular interval is 5°.

Step 2: Convert local latitude to decimal notation and identify the time difference between consecutive latitudes as well as the angular distance from the desired latitude to the base latitude.



Lat.	Sunset	Twilight		Moonset		
		Civil	Naut.	2	3	4
°	h m	h m	h m	h m	h m	h m
N 72	▭	▭	▭	22 23	22 09	21 56
N 70	22 24	////	////	22 10	22 02	21 56
68	21 44	////	////	21 58	21 57	21 55
66	21 17	23 10	////	21 49	21 53	21 55
64	20 56	22 18	////	21 41	21 49	21 55
62	20 39	21 47	////	21 35	21 45	21 54
60	20 26	21 24	23 16	21 29	21 42	21 54
N 58	20 14	21 06	22 29	21 24	21 40	21 54
56	20 04	20 51	22 00	21 19	21 37	21 54
54	19 55	20 38	21 39	21 15	21 35	21 54
52	19 47	20 27	21 22	21 11	21 33	21 53
50	19 40	20 18	21 07	21 08	21 31	21 53
45	19 24	19 58	20 40	21 00	21 28	21 53
N 40	19 12	19 42	20 19	20 54	21 24	21 53

45° N: 2100
42° 30’ N = 42.5° = unknown value
40° N: 2054

Differences:
40° N to 42.5° = 2.5°
40° N to 45° N = 6 minutes

Step 3: Complete the latitude correction. The two options for this step are to use arithmetic to do a manual calculation (ratios), or to use Table 1 in the Nautical Almanac. A portion of the table is re-created here. Remember to mentally check the results to ensure addition/subtraction was performed correctly, as required.

<u>Option 1: Manual Calculation</u>

$$\frac{x}{6\,minutes} = \frac{2.5°}{5°}$$

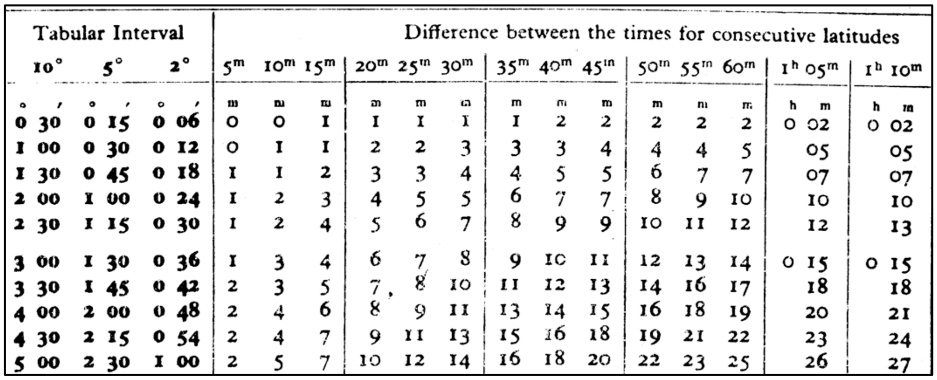
$$\frac{x}{6\,minutes} = 0.5$$

$$x = (0.5)\,(6)$$

$x =$ 3 minutes (later)

Latitude corrected time = 2054 (base) + 3 minutes = <u>2057</u>

<u>Option 2: Table 1</u>



Tabular Interval			Difference between the times for consecutive latitudes													
10°	5°	2°	5^{m}	10^{m}	15^{m}	20^{m}	25^{m}	30^{m}	35^{m}	40^{m}	45^{m}	50^{m}	55^{m}	60^{m}	$1^{h}\,05^{m}$	$1^{h}\,10^{m}$
° ′	° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m
0 30	0 15	0 06	0	0	1	1	1	1	1	2	2	2	2	2	0 02	0 02
1 00	0 30	0 12	0	1	1	2	2	3	3	3	4	4	4	5	05	05
1 30	0 45	0 18	1	1	2	3	3	4	4	5	5	6	7	7	07	07
2 00	1 00	0 24	1	2	3	4	5	5	6	7	7	8	9	10	10	10
2 30	1 15	0 30	1	2	4	5	6	7	8	9	9	10	11	12	12	13
3 00	1 30	0 36	1	3	4	6	7	8	9	10	11	12	13	14	0 15	0 15
3 30	1 45	0 42	2	3	5	7	8	10	11	12	13	14	16	17	18	18
4 00	2 00	0 48	2	4	6	8	9	11	13	14	15	16	18	19	20	21
4 30	2 15	0 54	2	4	7	9	11	13	15	16	18	19	21	22	23	24
5 00	2 30	1 00	2	5	7	10	12	14	16	18	20	22	23	25	26	27

a. Note that the tabular interval is 5°.

b. Proceed down the "Tabular Interval" column until you reach the difference between the tabular latitude and your desired latitude (2° 30′ in this case).

c. The time difference determined in the previous step was 6 minutes. There is no "6 minutes" column in the "difference between the times for consecutive latitudes" section, so note the values for the nearest headings (5m and 10m). In this case, the necessary values are 2 and 5 minutes.

d. Mentally interpolate the actual value (3 minutes in this case).

Table 1 corrected time = 2054 + 3 minutes = 2057.

Either option (arithmetic or Table 1 correction) will work…it's just a matter of preference.

Step 4: Due to the moons proximity to the earth, its motions in the sky are complicated. In order to account for longitude, it is necessary to use Table 2 in the Nautical Almanac, which involves completing the above procedure a total of two times (once for the day in question, and once for the following day (western hemisphere) or preceding day (eastern hemisphere)).

The nearest bracketing latitudes for 3 August are:
45° N: 2128
42.5° = unknown value
40° N: 2124

Differences for 3 August:
40° N to 42.5° = 2.5°
40° N to 45° N = 4 minutes

$$\frac{x}{4\,minutes} = \frac{2.5°}{5°}$$

$$\frac{x}{4\,minutes} = 0.5$$

$$x = (0.5)\,(4)$$

$x = 2$ minutes (later)

Corrections for 3 August:
Latitude corrected time = 2124 (base) + 2 minutes = 2126
Option 2: Table 1 correction = 2124 (base) + approx. 2 min = 2126

Step 5: Using the information for the two consecutive dates, use Table 2 in the Nautical Almanac (re-created in it's entirety here) determine longitude correction.

Longitude: 070° W.
Nearest tabular longitude: 070°
Difference in moonset times between consecutive dates:
(3 Aug) – (4 Aug) = Difference
2126 – 2057 = 29 minutes
Using Table 2 (longitude of 70° and time difference of 29m), the correction is approximately <u>6 minutes</u>.

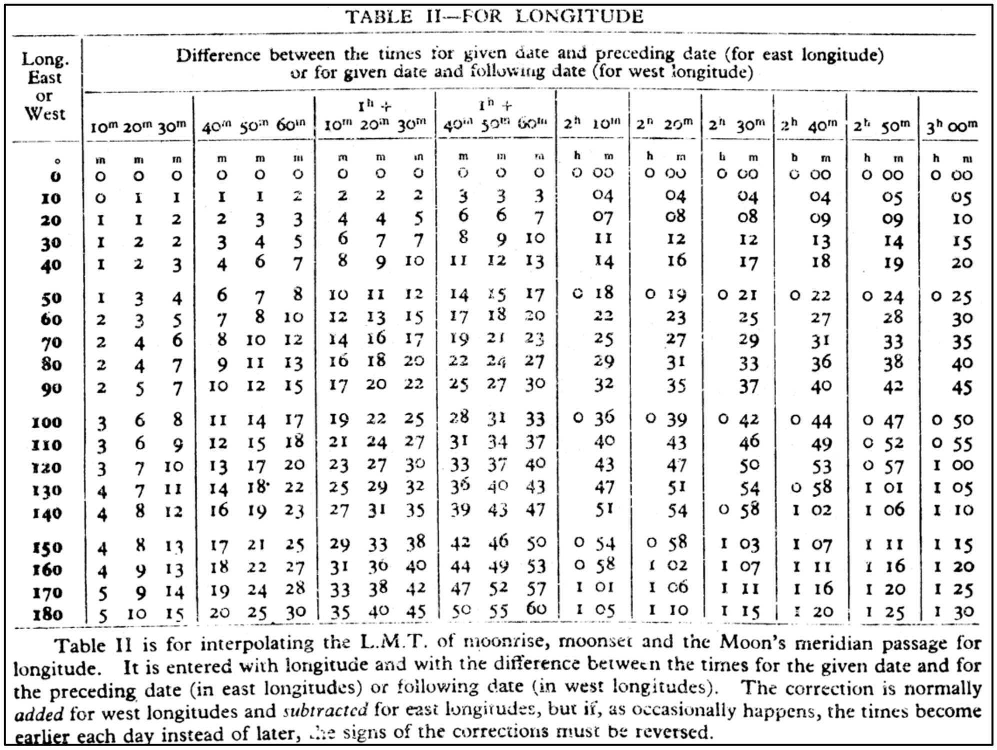


TABLE II—FOR LONGITUDE

Long. East or West	Difference between the times for given date and preceding date (for east longitude) or for given date and following date (for west longitude)																	
							1^h +			1^h +								
	10^m	20^m	30^m	40^m	50^m	60^m	10^m	20^m	30^m	40^m	50^m	60^m	$2^h\ 10^m$	$2^h\ 20^m$	$2^h\ 30^m$	$2^h\ 40^m$	$2^h\ 50^m$	$3^h\ 00^m$
°	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m	h m	h m
0	0	0	0	0	0	0	0	0	0	0	0	0	0 00	0 00	0 00	0 00	0 00	0 00
10	0	1	1	1	1	2	2	2	2	3	3	3	04	04	04	04	05	05
20	1	1	2	2	3	3	4	4	5	6	6	7	07	08	08	09	09	10
30	1	2	2	3	4	5	6	7	7	8	9	10	11	12	12	13	14	15
40	1	2	3	4	6	7	8	9	10	11	12	13	14	16	17	18	19	20
50	1	3	4	6	7	8	10	11	12	14	15	17	0 18	0 19	0 21	0 22	0 24	0 25
60	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30
70	2	4	6	8	10	12	14	16	17	19	21	23	25	27	29	31	33	35
80	2	4	7	9	11	13	16	18	20	22	24	27	29	31	33	36	38	40
90	2	5	7	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45
100	3	6	8	11	14	17	19	22	25	28	31	33	0 36	0 39	0 42	0 44	0 47	0 50
110	3	6	9	12	15	18	21	24	27	31	34	37	40	43	46	49	0 52	0 55
120	3	7	10	13	17	20	23	27	30	33	37	40	43	47	50	53	0 57	1 00
130	4	7	11	14	18	22	25	29	32	36	40	43	47	51	54	0 58	1 01	1 05
140	4	8	12	16	19	23	27	31	35	39	43	47	51	54	0 58	1 02	1 06	1 10
150	4	8	13	17	21	25	29	33	38	42	46	50	0 54	0 58	1 03	1 07	1 11	1 15
160	4	9	13	18	22	27	31	36	40	44	49	53	0 58	1 02	1 07	1 11	1 16	1 20
170	5	9	14	19	24	28	33	38	42	47	52	57	1 01	1 06	1 11	1 16	1 20	1 25
180	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20	1 25	1 30

Table II is for interpolating the L.M.T. of moonrise, moonset and the Moon's meridian passage for longitude. It is entered with longitude and with the difference between the times for the given date and for the preceding date (in east longitudes) or following date (in west longitudes). The correction is normally *added* for west longitudes and *subtracted* for east longitudes, but if, as occasionally happens, the times become earlier each day instead of later, the signs of the corrections must be reversed.

Step 6: Apply the Table 2 correction to the latitude-corrected time for the original date (2 August) to determine time of moonset. Corrections are typically added in the western hemisphere and subtracted in the eastern hemisphere, however there are occasional reversals, per the directions at the bottom of Table 2.

2057 + 6 minutes = **2103**

<u>Problem 5-2</u>. The following question illustrates the process of calculating moonrise.

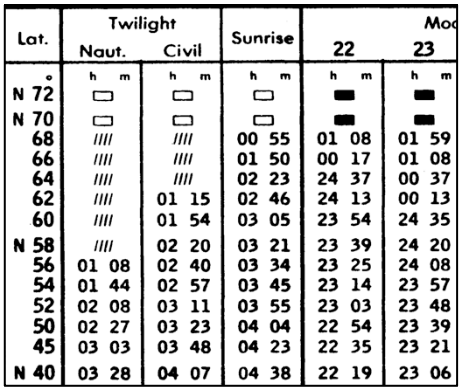
Your ship is in drydock, but you wish to practice your celestial navigation. The ship's position is latitude 43° 12.7' N and longitude 069° 33.2' W. The ship is not moving. The date is 22 May and you are observing (+4) zone time. What is the zone time of moonrise?

Answer: Approximately 22:38:18 zone time.

Step 1: Locate the tabular values in the Nautical Almanac.

The nearest bracketing latitudes are:
45° N: 2235
40° N: 2219

Note the tabular interval is 5°.



Lat.	Twilight		Sunrise	Mo	
	Naut.	Civil		22	23
°	h m	h m	h m	h m	h m
N 72	▭	▭	▭	■	■
N 70	▭	▭	▭	■	■
68	////	////	00 55	01 08	01 59
66	////	////	01 50	00 17	01 08
64	////	////	02 23	24 37	00 37
62	////	01 15	02 46	24 13	00 13
60	////	01 54	03 05	23 54	24 35
N 58	////	02 20	03 21	23 39	24 20
56	01 08	02 40	03 34	23 25	24 08
54	01 44	02 57	03 45	23 14	23 57
52	02 08	03 11	03 55	23 03	23 48
50	02 27	03 23	04 04	22 54	23 39
45	03 03	03 48	04 23	22 35	23 21
N 40	03 28	04 07	04 38	22 19	23 06

Step 2: Convert local latitude to decimal notation and identify the difference from the nearest bracketing latitudes.

45° N: 2235
43° 12.7' N = 43.212° = unknown value
40° N: 2219

Differences:
40° N to 43.212° = 3.212°
40° N to 45° N = 16 minutes

Step 3: Complete the latitude correction (using mental interpolation or Table 1 in the Nautical Almanac).

$$\frac{x}{16\,minutes} = \frac{3.212°}{5°}$$
$$\frac{x}{16\,minutes} = 0.6424$$
$$x = (0.6424)\,(16)$$
$$x = 10.278 \text{ minutes (later)}$$

Latitude corrected time = 2219 (base) + 10.3 minutes = 22:29:18

Table 1 correction = 2219 (base) + approximately 11 min = 22:30

Step 4: Complete the same calculation for the following day (note – use preceding day in eastern hemisphere problems).

The nearest bracketing latitudes for 23 May are:

45° N: 2321
43.212° = unknown value
40° N: 2306

Differences for 23 May:
40° N to 43.212° = 3.212°
40° N to 45° N = 15 minutes

$$\frac{x}{15\ minutes} = \frac{3.212°}{5°}$$
$$\frac{x}{15\ minutes} = 0.6424$$
$$x = (0.6424)\ (15)$$
$x = 9.636$ minutes (later)

Corrections for 23 May:
Latitude corrected time = 2306 (base) + 9.6 minutes = 23:15:36
Table 1 correction = (base) + 10 min = 23:16

Step 5: Use Table 2 in the Nautical Almanac to determine longitude correction.

Longitude: 069° 33.2
Nearest tabular longitude: 070°
Difference between consecutive dates: 23:15:36 – 22:29:18 = 00:46:18.
Tabular correction based on above information: approximately 9 min (added per directions in Table 2).

Step 6: Apply the Table 2 correction to the latitude-corrected time for the original date (22 May) to determine time of moonrise.

22:29:18 + 00:09:00 = **22:38:18**

In summary, the steps to calculate moonrise or moonset manually are:

Step 1: Locate bracketing values for your latitude from the Nautical Almanac.

Step 2: Identify the difference from the bracketing values to your latitude.

Step 3: Correct the sunrise/sunset values for latitude, either using mental interpolation or Table 1 in the Nautical Almanac.

Step 4: Determine the difference in longitude from your DR position to the standard meridian being observed by your ship's clocks.

Step 5: Convert the difference obtained in step 4 to time using the Conversion of Arc to Time table in the Nautical Almanac.

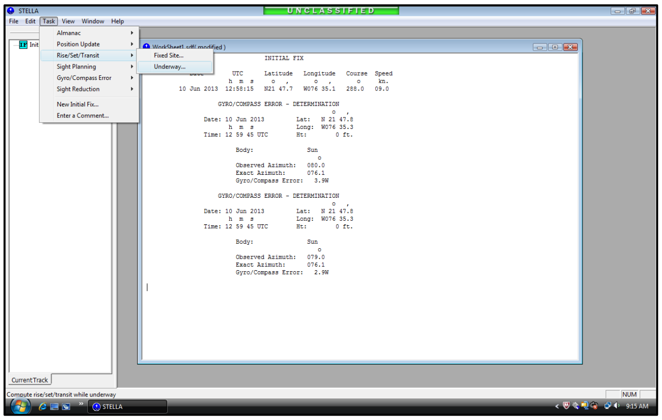
Step 6: Correct the value from step 3 for longitude.

Step 7: Perform the same calculation for the following day (west longitude) or preceding day (east longitude) and utilize Table 2 in the Nautical Almanac to determine your answer.

STELLA Calculations of Moonrise and Moonset

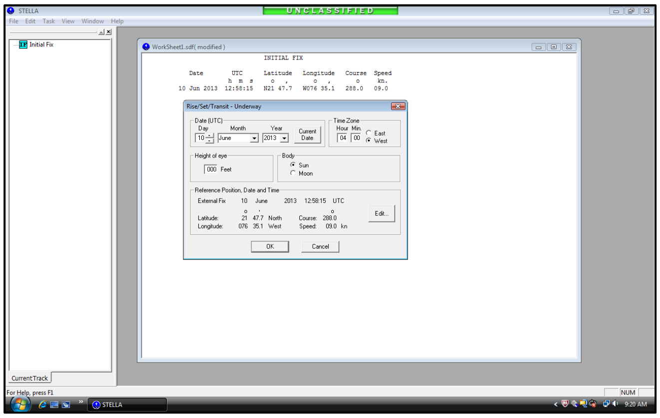
To determine the time of rise, set, or transit for any body using the STELLA program, first establish a DR position (Initial Fix). Then follow:

Step 1:
Task > Rise/Set/Transit >Underway



```
                      INITIAL FIX

                 UTC      Latitude   Longitude   Course  Speed
                h  m  s     o  ,        o  ,        o      kn.
   10 Jun 2013  12:58:15  N21 47.7   W076 35.1   288.0   09.0

          GYRO/COMPASS ERROR - DETERMINATION
                                       o  ,
       Date: 10 Jun 2013        Lat:   N 21 47.8
             h  m  s            Long:  W076 35.3
       Time: 12 59 45 UTC       Ht:         0 ft.

              Body:                Sun
                                     o
              Observed Azimuth:    080.0
              Exact Azimuth:       076.1
              Gyro/Compass Error:    3.9W

          GYRO/COMPASS ERROR - DETERMINATION
                                       o  ,
       Date: 10 Jun 2013        Lat:   N 21 47.8
             h  m  s            Long:  W076 35.3
       Time: 12 59 45 UTC       Ht:         0 ft.

              Body:                Sun
                                     o
              Observed Azimuth:    079.0
              Exact Azimuth:       076.1
              Gyro/Compass Error:    2.9W
```

Step 2:
Enter data in all appropriate fields.



```
                      INITIAL FIX

   Date          UTC      Latitude   Longitude   Course  Speed
                h  m  s     o  ,        o  ,        o      kn.
   10 Jun 2013  12:58:15  N21 47.7   W076 35.1   288.0   09.0
```

Date (UTC): Day 10, Month June, Year 2013

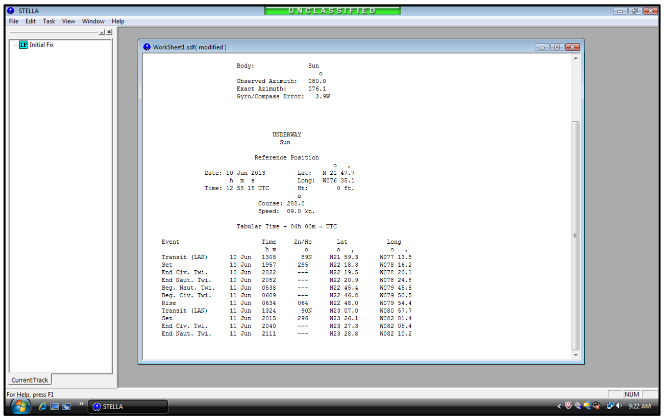
Time Zone: Hour 04, Min. 00 ○ East ● West

Height of eye: 000 Feet

Body: ● Sun ○ Moon

Reference Position, Date and Time:
External Fix 10 June 2013 12:58:15 UTC
Latitude: 21° 47.7' North Course: 288.0°
Longitude: 076 35.1 West Speed: 09.0 kn

Step 3:
Retrieve appropriate data.



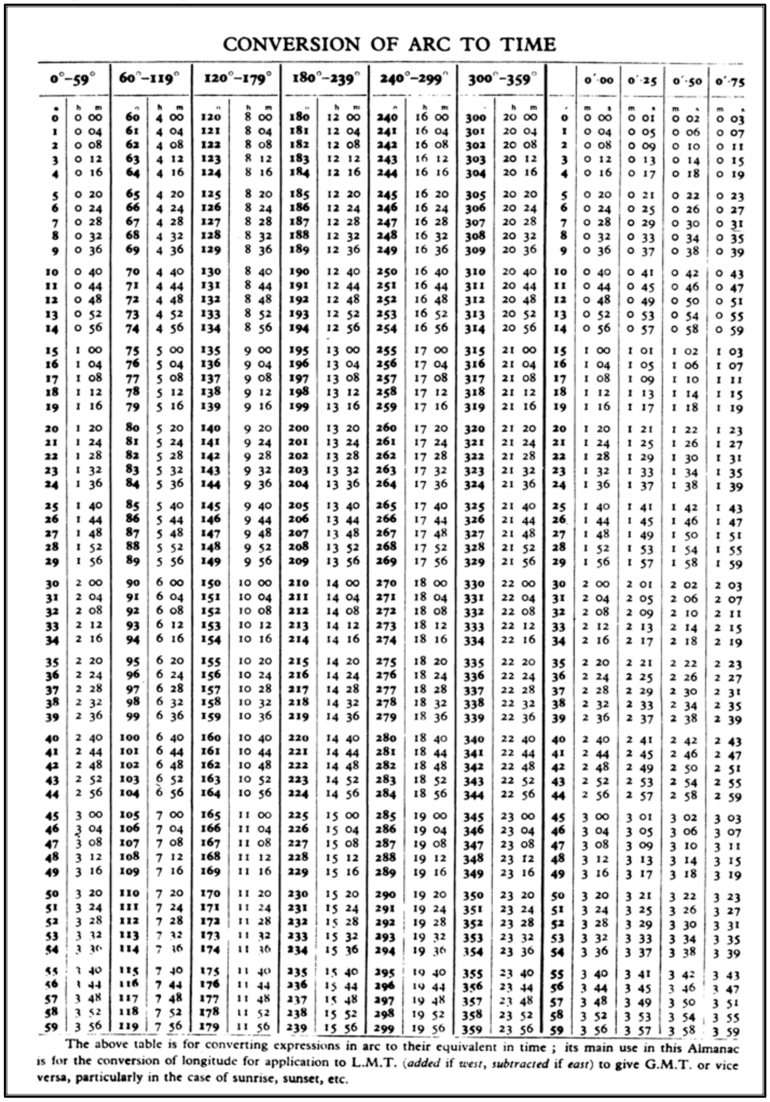
```
              Body:                Sun
                                     o
              Observed Azimuth:    080.0
              Exact Azimuth:       076.1
              Gyro/Compass Error:    3.9W


                        UNDERWAY
                          Sun

                   Reference Position
                                       o  ,
       Date: 10 Jun 2013        Lat:   N 21 47.7
             h  m  s            Long:  W076 35.1
       Time: 12 58 15 UTC       Ht:         0 ft.
                                o
                   Course: 288.0
                   Speed:  09.0 kn.

              Tabular Time + 04h 00m = UTC

Event                        Time    Zn/Hc     Lat        Long
                              h m      o      o  ,        o  ,
Transit (LAN)     10 Jun   1308     89N    N21 59.3    W077 13.5
Set               10 Jun   1957    295     N22 18.3    W078 16.2
End Civ. Twi.     10 Jun   2022    ---     N22 19.5    W078 20.1
End Naut. Twi.    10 Jun   2052    ---     N22 20.9    W078 24.8
Beg. Naut. Twi.   11 Jun   0538    ---     N22 45.4    W079 45.8
Beg. Civ. Twi.    11 Jun   0609    ---     N22 46.8    W079 50.5
Rise              11 Jun   0634    064     N22 48.0    W079 54.4
Transit (LAN)     11 Jun   1324     90N    N23 07.0    W080 57.7
Set               11 Jun   2015    296     N23 26.1    W082 01.4
End Civ. Twi.     11 Jun   2040    ---     N23 27.3    W082 05.4
End Naut. Twi.    11 Jun   2111    ---     N23 28.8    W082 10.2
```

Advanced Theory and Other Matters for Moonrise and Moonset

Even Bowditch states that exact times of moonrise and moonset are seldom required, so striving for an accuracy of 5-10 minutes is generally sufficient. However, more precise calculations are possible.

The explanations provided in this text are for stationary ships. In order to be precise on a moving ship, the time of moonrise and moonset must be calculated not for the position the ship is in at the time of calculation, but for the position the ship will be in at the time of phenomenon…this means doing two calculations for maximum precision.

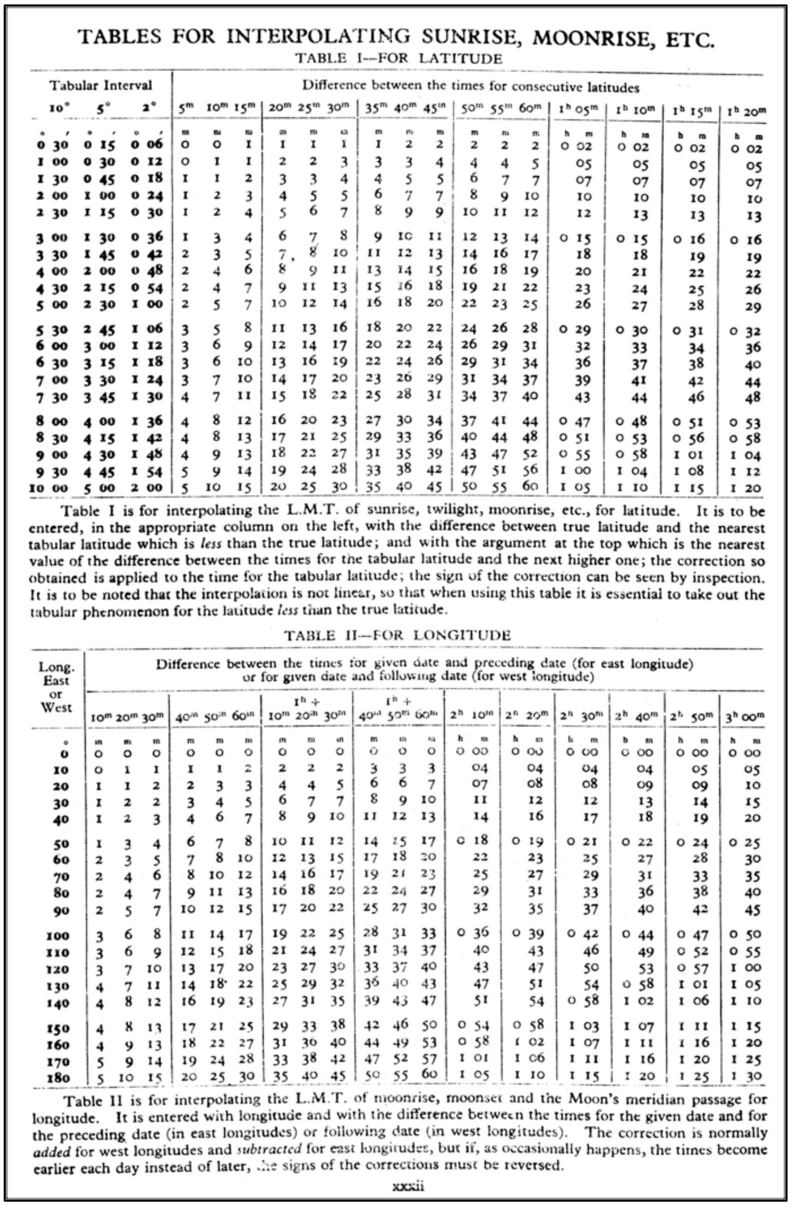
For more detailed explanations of time of phenomenon problems, including problems for moving ships and second-estimate problems, refer to Part 9 of "*The Cutterman's Guide to Navigation Problems*" which is available at www.practicalnavigator.org.



CONVERSION OF ARC TO TIME

0°–59°		60°–119°		120°–179°		180°–239°		240°–299°		300°–359°			0′·00	0′·25	0′·50	0′·75
°	h m	°	h m	°	h m	°	h m	°	h m	°	h m	′	m s	m s	m s	m s
0	0 00	60	4 00	120	8 00	180	12 00	240	16 00	300	20 00	0	0 00	0 01	0 02	0 03
1	0 04	61	4 04	121	8 04	181	12 04	241	16 04	301	20 04	1	0 04	0 05	0 06	0 07
2	0 08	62	4 08	122	8 08	182	12 08	242	16 08	302	20 08	2	0 08	0 09	0 10	0 11
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12	3	0 12	0 13	0 14	0 15
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16	4	0 16	0 17	0 18	0 19
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20	5	0 20	0 21	0 22	0 23
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24	6	0 24	0 25	0 26	0 27
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28	7	0 28	0 29	0 30	0 31
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32	8	0 32	0 33	0 34	0 35
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36	9	0 36	0 37	0 38	0 39
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40	10	0 40	0 41	0 42	0 43
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44	11	0 44	0 45	0 46	0 47
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48	12	0 48	0 49	0 50	0 51
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52	13	0 52	0 53	0 54	0 55
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56	14	0 56	0 57	0 58	0 59
15	1 00	75	5 00	135	9 00	195	13 00	255	17 00	315	21 00	15	1 00	1 01	1 02	1 03
16	1 04	76	5 04	136	9 04	196	13 04	256	17 04	316	21 04	16	1 04	1 05	1 06	1 07
17	1 08	77	5 08	137	9 08	197	13 08	257	17 08	317	21 08	17	1 08	1 09	1 10	1 11
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12	18	1 12	1 13	1 14	1 15
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16	19	1 16	1 17	1 18	1 19
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20	20	1 20	1 21	1 22	1 23
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24	21	1 24	1 25	1 26	1 27
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28	22	1 28	1 29	1 30	1 31
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32	23	1 32	1 33	1 34	1 35
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36	24	1 36	1 37	1 38	1 39
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40	25	1 40	1 41	1 42	1 43
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44	26	1 44	1 45	1 46	1 47
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48	27	1 48	1 49	1 50	1 51
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52	28	1 52	1 53	1 54	1 55
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56	29	1 56	1 57	1 58	1 59
30	2 00	90	6 00	150	10 00	210	14 00	270	18 00	330	22 00	30	2 00	2 01	2 02	2 03
31	2 04	91	6 04	151	10 04	211	14 04	271	18 04	331	22 04	31	2 04	2 05	2 06	2 07
32	2 08	92	6 08	152	10 08	212	14 08	272	18 08	332	22 08	32	2 08	2 09	2 10	2 11
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12	2 13	2 14	2 15
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16	2 17	2 18	2 19
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20	2 21	2 22	2 23
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24	2 25	2 26	2 27
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28	2 29	2 30	2 31
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32	2 33	2 34	2 35
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36	2 37	2 38	2 39
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40	2 41	2 42	2 43
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44	2 45	2 46	2 47
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48	2 49	2 50	2 51
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52	2 53	2 54	2 55
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56	2 57	2 58	2 59
45	3 00	105	7 00	165	11 00	225	15 00	285	19 00	345	23 00	45	3 00	3 01	3 02	3 03
46	3 04	106	7 04	166	11 04	226	15 04	286	19 04	346	23 04	46	3 04	3 05	3 06	3 07
47	3 08	107	7 08	167	11 08	227	15 08	287	19 08	347	23 08	47	3 08	3 09	3 10	3 11
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12	3 13	3 14	3 15
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16	3 17	3 18	3 19
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20	3 21	3 22	3 23
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24	3 25	3 26	3 27
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28	3 29	3 30	3 31
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32	3 33	3 34	3 35
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36	3 37	3 38	3 39
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40	3 41	3 42	3 43
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44	3 45	3 46	3 47
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48	3 49	3 50	3 51
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52	3 53	3 54	3 55
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56	3 57	3 58	3 59

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to L.M.T. (*added* if *west*, *subtracted* if *east*) to give G.M.T. or vice versa, particularly in the case of sunrise, sunset, etc.



TABLES FOR INTERPOLATING SUNRISE, MOONRISE, ETC.

TABLE I—FOR LATITUDE

Tabular Interval			Difference between the times for consecutive latitudes															
10°	5°	2°	5m	10m	15m	20m	25m	30m	35m	40m	45m	50m	55m	60m	1h 05m	1h 10m	1h 15m	1h 20m
° ′	° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m
0 30	0 15	0 06	0	0	1	1	1	1	1	2	2	2	2	2	0 02	0 02	0 02	0 02
1 00	0 30	0 12	0	1	1	2	2	3	3	3	4	4	4	5	05	05	05	05
1 30	0 45	0 18	1	1	2	3	3	4	4	5	5	6	7	7	07	07	07	07
2 00	1 00	0 24	1	2	3	4	5	5	6	7	7	8	9	10	10	10	10	10
2 30	1 15	0 30	1	2	4	5	6	7	8	9	9	10	11	12	12	13	13	13
3 00	1 30	0 36	1	3	4	6	7	8	9	10	11	12	13	14	0 15	0 15	0 16	0 16
3 30	1 45	0 42	2	3	5	7	8	10	11	12	13	14	16	17	18	18	19	19
4 00	2 00	0 48	2	4	6	8	9	11	13	14	15	16	18	19	20	21	22	22
4 30	2 15	0 54	2	4	7	9	11	13	15	16	18	19	21	22	23	24	25	26
5 00	2 30	1 00	2	5	7	10	12	14	16	18	20	22	23	25	26	27	28	29
5 30	2 45	1 06	3	5	8	11	13	16	18	20	22	24	26	28	0 29	0 30	0 31	0 32
6 00	3 00	1 12	3	6	9	12	14	17	20	22	24	26	29	31	32	33	34	36
6 30	3 15	1 18	3	6	10	13	16	19	22	24	26	29	31	34	36	37	38	40
7 00	3 30	1 24	3	7	10	14	17	20	23	26	29	31	34	37	39	41	42	44
7 30	3 45	1 30	4	7	11	15	18	22	25	28	31	34	37	40	43	44	46	48
8 00	4 00	1 36	4	8	12	16	20	23	27	30	34	37	41	44	0 47	0 48	0 51	0 53
8 30	4 15	1 42	4	8	13	17	21	25	29	33	36	40	44	48	0 51	0 53	0 56	0 58
9 00	4 30	1 48	4	9	13	18	22	27	31	35	39	43	47	52	0 55	0 58	1 01	1 04
9 30	4 45	1 54	5	9	14	19	24	28	33	38	42	47	51	56	1 00	1 04	1 08	1 12
10 00	5 00	2 00	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20

Table I is for interpolating the L.M.T. of sunrise, twilight, moonrise, etc., for latitude. It is to be entered, in the appropriate column on the left, with the difference between true latitude and the nearest tabular latitude which is *less* than the true latitude; and with the argument at the top which is the nearest value of the difference between the times for the tabular latitude and the next higher one; the correction so obtained is applied to the time for the tabular latitude; the sign of the correction can be seen by inspection. It is to be noted that the interpolation is not linear, so that when using this table it is essential to take out the tabular phenomenon for the latitude *less* than the true latitude.

TABLE II—FOR LONGITUDE

Long. East or West	Difference between the times for given date and preceding date (for east longitude) or for given date and following date (for west longitude)																	
							1h +			1h +								
	10m	20m	30m	40m	50m	60m	10m	20m	30m	40m	50m	60m	2h 10m	2h 20m	2h 30m	2h 40m	2h 50m	3h 00m
°	m	m	m	m	m	m	m	m	m	m	m	m	h m	h m	h m	h m	h m	h m
0	0	0	0	0	0	0	0	0	0	0	0	0	0 00	0 00	0 00	0 00	0 00	0 00
10	0	1	1	1	1	2	2	2	2	3	3	3	04	04	04	04	05	05
20	1	1	2	2	3	3	4	4	5	6	6	7	07	08	08	09	09	10
30	1	2	2	3	4	5	6	7	7	8	9	10	11	12	12	13	14	15
40	1	2	3	4	6	7	8	9	10	11	12	13	14	16	17	18	19	20
50	1	3	4	6	7	8	10	11	12	14	15	17	0 18	0 19	0 21	0 22	0 24	0 25
60	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30
70	2	4	6	8	10	12	14	16	17	19	21	23	25	27	29	31	33	35
80	2	4	7	9	11	13	16	18	20	22	24	27	29	31	33	36	38	40
90	2	5	7	10	12	15	17	20	22	25	27	30	32	35	37	40	42	45
100	3	6	8	11	14	17	19	22	25	28	31	33	0 36	0 39	0 42	0 44	0 47	0 50
110	3	6	9	12	15	18	21	24	27	31	34	37	40	43	46	49	0 52	0 55
120	3	7	10	13	17	20	23	27	30	33	37	40	43	47	50	53	0 57	1 00
130	4	7	11	14	18	22	25	29	32	36	40	43	47	51	54	0 58	1 01	1 05
140	4	8	12	16	19	23	27	31	35	39	43	47	51	54	0 58	1 02	1 06	1 10
150	4	8	13	17	21	25	29	33	38	42	46	50	0 54	0 58	1 03	1 07	1 11	1 15
160	4	9	13	18	22	27	31	36	40	44	49	53	0 58	1 02	1 07	1 11	1 16	1 20
170	5	9	14	19	24	28	33	38	42	47	52	57	1 01	1 06	1 11	1 16	1 20	1 25
180	5	10	15	20	25	30	35	40	45	50	55	60	1 05	1 10	1 15	1 20	1 25	1 30

Table II is for interpolating the L.M.T. of moonrise, moonset and the Moon's meridian passage for longitude. It is entered with longitude and with the difference between the times for the given date and for the preceding date (in east longitudes) or following date (in west longitudes). The correction is normally *added* for west longitudes and *subtracted* for east longitudes, but if, as occasionally happens, the times become earlier each day instead of later, the signs of the corrections must be reversed.

Part 3: Basic Celestial Problems

In which we solve gyro error by amplitude problems, local apparent noon latitude problems, and latitude by Polaris problems, enabling completion of three tasks in the Coast Guard Navigation Standards.

Chapter 6: Determine Gyro Error by Amplitude of the Sun

The Basic Idea

Imagine watching the sunset from your favorite beachside location. If the date happened to be approximately March or September 22nd, the vernal and autumnal **equinoxes**, then the sun would be setting exactly west – 270° true. At any other time of year, it sets at a different bearing, and that difference from true west (or east for sunrise) is called "**amplitude**."

In the northern hemisphere, in summer, the sun sets north of west (and rises north of east), while in the northern hemisphere, in winter, the sun sets south of west (and rises south of east). Table 22 in Bowditch will enable you to calculate exactly how big this "amplitude" is. Once you know what the bearing to sunset (or sunrise) *should* be, you can compare it to what you observe, and determine your gyro compass error.

Manual Calculations

The process of calculating the desired amplitude uses Table 22 in Bowditch. The inputs necessary to use the table are the ship's **latitude** and the **declination** of the sun (to the nearest half degree). You can find the declination of the sun in the Nautical Almanac's daily pages.

The observation utilizes the standard **telescopic alidade**, and the measurement of the sun should be taken when the sun is 2/3 of it's own diameter above the visible horizon (in other words, there should be a gap below the sun of about 2/3 of it's width).

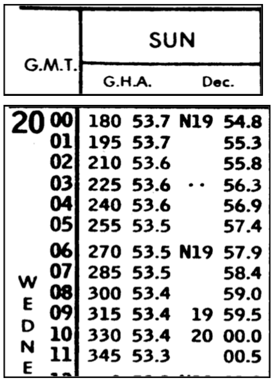
<u>Problem 6-1</u>. The following question illustrates how to solve basic amplitude problems involving the sun on the **celestial horizon**.

It is 20 May and you are departing Hampton Roads aboard CGC TAMPA for patrol. You have taken an observation of the rising sun when its lower limb is approximately 2/3 of a sun's diameter above the visible horizon (therefore the sun's center is on the celestial horizon). The time of observation is 1000 UTC. Your latitude is 36° N.

- a) *What is the amplitude of the sun for this date?*
- b) *What true bearing should the sunrise be observed?*
- c) *If you actually observe the sun rising at 068° T, what is the gyro error?*

Answers:
a) E 25° N
b) 065° T
c) 3° W

Step 1: Determine the declination of the sun for the time of observation using the Nautical Almanac.
The declination at 1000 UTC is N 20° 00’.



G.M.T.		SUN G.H.A.	SUN Dec.
20	00	180 53.7	N19 54.8
	01	195 53.7	55.3
	02	210 53.6	55.8
	03	225 53.6	·· 56.3
	04	240 53.6	56.9
	05	255 53.5	57.4
	06	270 53.5	N19 57.9
W	07	285 53.5	58.4
E	08	300 53.4	59.0
D	09	315 53.4	19 59.5
N	10	330 53.4	20 00.0
E	11	345 53.3	00.5

Step 2: Determine the ship’s latitude at the time of observation.
Latitude – 36° N (given)

Step 3: Enter Table 22 in Bowditch with declination and latitude to determine the amplitude.
Declination: 20°
Latitude: 36°

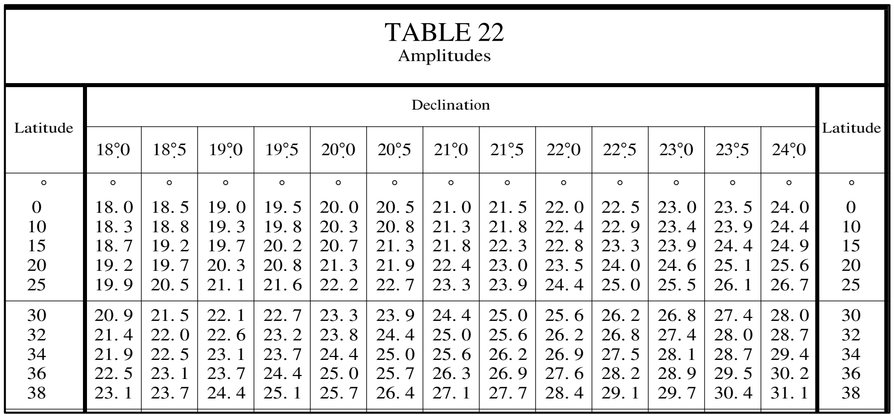


TABLE 22
Amplitudes

Latitude	Declination 18°0	18°5	19°0	19°5	20°0	20°5	21°0	21°5	22°0	22°5	23°0	23°5	24°0	Latitude
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	18. 0	18. 5	19. 0	19. 5	20. 0	20. 5	21. 0	21. 5	22. 0	22. 5	23. 0	23. 5	24. 0	0
10	18. 3	18. 8	19. 3	19. 8	20. 3	20. 8	21. 3	21. 8	22. 4	22. 9	23. 4	23. 9	24. 4	10
15	18. 7	19. 2	19. 7	20. 2	20. 7	21. 3	21. 8	22. 3	22. 8	23. 3	23. 9	24. 4	24. 9	15
20	19. 2	19. 7	20. 3	20. 8	21. 3	21. 9	22. 4	23. 0	23. 5	24. 0	24. 6	25. 1	25. 6	20
25	19. 9	20. 5	21. 1	21. 6	22. 2	22. 7	23. 3	23. 9	24. 4	25. 0	25. 5	26. 1	26. 7	25
30	20. 9	21. 5	22. 1	22. 7	23. 3	23. 9	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	30
32	21. 4	22. 0	22. 6	23. 2	23. 8	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	28. 7	32
34	21. 9	22. 5	23. 1	23. 7	24. 4	25. 0	25. 6	26. 2	26. 9	27. 5	28. 1	28. 7	29. 4	34
36	22. 5	23. 1	23. 7	24. 4	25. 0	25. 7	26. 3	26. 9	27. 6	28. 2	28. 9	29. 5	30. 2	36
38	23. 1	23. 7	24. 4	25. 1	25. 7	26. 4	27. 1	27. 7	28. 4	29. 1	29. 7	30. 4	31. 1	38

Step 4: Answer required questions.

a) **Amplitude = E 25° N, or 25° north of east.**
b) Standard sunrise is 090° T. In the northern hemisphere in spring and summer, the sun rises north of east. Therefore the calculated sunrise is 090° - 25° = **065° T**
c) If the sun is observed rising at 068° T, while the calculated sunrise is 065° T, the gyro error is 068° - 065° = 3°. To determine the direction of error, use the mnemonic “Gyro Best, Error West, Gyro Least, Error East.” In this case, the gyro is higher (“best”) than the observation, so the error is **3° W.**

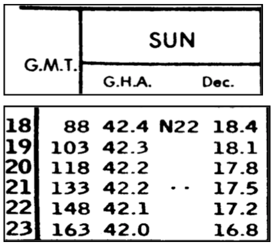
<u>Problem 6-2</u>. The following question illustrates how to solve basic amplitude problems involving the sun, including necessary **interpolation** of figures.

It is 9 July and you are aboard CGC STRATTON, departing for a D17 patrol. You have taken an observation of the setting sun when its lower limb is approximately 2/3 of a *sun's diameter above the horizon (in other words the sun's center is on the celestial horizon). The time of observation is 2100 UTC. Your latitude is 33° N.*

- *a) What is the amplitude of the sun?*
- *b) What true bearing should the sunrise be observed?*
- *c) If you actually observe the sun setting at 300° T, what is the gyro error?*

Answers:
a) W 27° N
b) 297° T
c) 3° W

Step 1: Determine the declination of the sun for the time of observation using the Nautical Almanac.
The declination at 2100 UTC is N 22° 17.5'.



G.M.T.	SUN G.H.A.	SUN Dec.
18	88 42.4	N22 18.4
19	103 42.3	18.1
20	118 42.2	17.8
21	133 42.2	· · 17.5
22	148 42.1	17.2
23	163 42.0	16.8

Step 2: Determine the ship's latitude at the time of observation.
Latitude – 33° N (given)

Step 3: Enter Table 22 in Bowditch with declination (in tenths notation) and latitude to determine the amplitude.
Declination: 22° 17.5' = 22.3°
Latitude: 33°

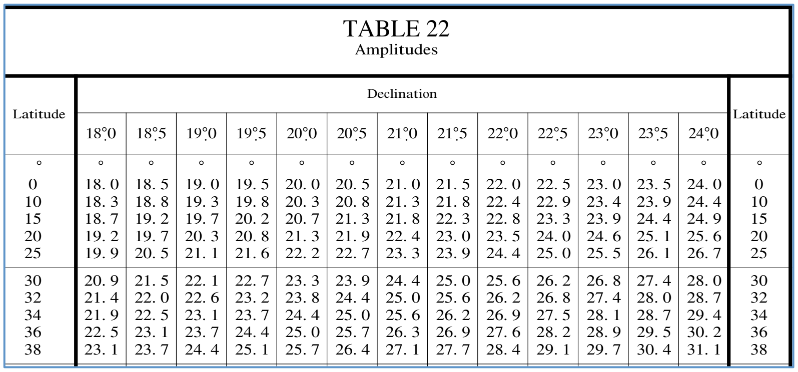
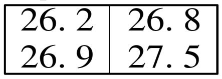


TABLE 22
Amplitudes

Latitude	Declination 18°0	18°5	19°0	19°5	20°0	20°5	21°0	21°5	22°0	22°5	23°0	23°5	24°0	Latitude
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	18. 0	18. 5	19. 0	19. 5	20. 0	20. 5	21. 0	21. 5	22. 0	22. 5	23. 0	23. 5	24. 0	0
10	18. 3	18. 8	19. 3	19. 8	20. 3	20. 8	21. 3	21. 8	22. 4	22. 9	23. 4	23. 9	24. 4	10
15	18. 7	19. 2	19. 7	20. 2	20. 7	21. 3	21. 8	22. 3	22. 8	23. 3	23. 9	24. 4	24. 9	15
20	19. 2	19. 7	20. 3	20. 8	21. 3	21. 9	22. 4	23. 0	23. 5	24. 0	24. 6	25. 1	25. 6	20
25	19. 9	20. 5	21. 1	21. 6	22. 2	22. 7	23. 3	23. 9	24. 4	25. 0	25. 5	26. 1	26. 7	25
30	20. 9	21. 5	22. 1	22. 7	23. 3	23. 9	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	30
32	21. 4	22. 0	22. 6	23. 2	23. 8	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	28. 7	32
34	21. 9	22. 5	23. 1	23. 7	24. 4	25. 0	25. 6	26. 2	26. 9	27. 5	28. 1	28. 7	29. 4	34
36	22. 5	23. 1	23. 7	24. 4	25. 0	25. 7	26. 3	26. 9	27. 6	28. 2	28. 9	29. 5	30. 2	36
38	23. 1	23. 7	24. 4	25. 1	25. 7	26. 4	27. 1	27. 7	28. 4	29. 1	29. 7	30. 4	31. 1	38

a) Since the entering values are not whole numbers of declination or latitude, interpolation is required. Locate the bracketing values.



26. 2	26. 8
26. 9	27. 5

	Declination 22.0°	**Declination 22.3°**	Declination 22.5°
Latitude 32°	26.2°		26.8°
Latitude 33°		**Unknown value**	
Latitude 34°	26.9°		27.5°

b) Interpolate the bracketing values four ways to the nearest tenth.

	Declination 22.0°	Declination 22.3°	Declination 22.5°
Latitude 32°	26.2°	**26.6°**	26.8°
Latitude 33°	**26.6°**	Unknown value	**27.2°**
Latitude 34°	26.9°	**27.3°**	27.5°

c) Solve the interpolation for the desired value.

	Declination 22.0°	Declination 22.3°	Declination 22.5°
Latitude 32°	26.2°	26.6°	26.8°
Latitude 33°	26.6°	**27.0°**	27.2°
Latitude 34°	26.9°	27.3°	27.5°

Step 4: Answer required questions.

a) **Amplitude = W 27° N**

b) Standard sunset is 270° T. In the northern hemisphere in spring and summer, the sun sets north of west. Therefore the calculated sunrise is 270° + 27° = **297° T**

c) If the sun is observed setting at 300° T, while the calculated sunset is 297° T, the gyro error is 300° - 297° = 3.0°. To determine the direction of error, use the mnemonic "Gyro Best, Error West, Gyro Least, Error East." In this case, the gyro is higher (best) than the observation, so the error is **3° W.**

In summary, the steps to calculate Gyro Error by Amplitude manually are:

Step 1: Determine the declination of the sun using the Nautical Almanac (interpolate if necessary).

Step 2: Determine the ship's latitude at the time of observation.

Step 3: Utilize Table 22 in Bowditch to determine the Amplitude of the Sun (interpolate if necessary).

Step 4: Determine the calculated bearing to sunrise or sunset, and compare it to the measured value to determine Gyro Compass Error using the following aid:

G-E-T or (Gyro Best, Error West! Gyro Least, Error East!)

STELLA Calculations of Gyro Error by Amplitude

This is not a task that can be completed in STELLA. However, you can easily calculate gyro error by azimuth at any time of day in STELLA. For that process, see chapter 10.

Advanced Theory

The observation of the sun should take place when the sun is on the celestial horizon. This occurs when the sun is 2/3 of it's own diameter above the **visible horizon**.

However, if you take the measurement when the sun's center is on the visible horizon (e.g. when the sun is halfway risen or set), then you need to apply a correction, which can be found in Table 23 in Bowditch.

To simplify the process, try to time measurements for the first case – when the sun is 2/3 of it's own diameter above the horizon.

Also note that *any* body can be utilized for an amplitude measurement, such as a planet, star, or the moon. The process is the same.

Chapter 7: Observe Local Apparent Noon (LAN) and Determine Latitude

The Basic Idea

At **local apparent noon (LAN)**, the sun is due south or due north of the ship's position, and it is at its highest point in the sky for the day. At this time, the complex geometry of celestial navigation is reduced to a special, simple situation.

If the sun's **altitude** is observed with a sextant at the time of local apparent noon, the ship's latitude can be determined quickly by hand.

Manual Calculations

To determine the time of local apparent noon (LAN), one can either wait outside, constantly observing the sun's altitude, until it reaches its highest point for the day, or one can pre-calculate the time of LAN using a similar process to determining the time of sunrise or sunset, which is covered in chapter 4 (instead of using sunrise and sunset values from the Nautical Almanac, use the "Time of Meridian Passage," located on the same daily pages in the almanac).

Either way, when the sun reaches its highest point in the sky for the day, a sextant measurement is taken, and the reading is corrected for the three "standard" corrections discussed in chapter 3 (index error, height of eye, and main correction).

Once the sun is observed, the sun's **zenith distance** is determined. Zenith distance is equal to 90° minus the sun's altitude. For instance if the altitude was measured to be 30°, then the zenith distance is (90° - 30°), or 60°.

The second input for latitude by local apparent noon is sun's **declination.** The declination of the sun is the latitude of the spot on the earth directly beneath the sun, and can be retrieved from the daily pages of the Nautical Almanac. Strictly speaking, interpolation is necessary for the exact time. However, for beginners it is safe to round the declination to the nearest hourly figure, or mentally estimate it.

After determining the sun's zenith distance and locating the sun's declination from the Nautical Almanac, there are four situations to determine the formula for latitude:

> *Situation One:* If the ship is in the same hemisphere as the sun but has a higher latitude (for example, Boston in summer):
> Latitude = Zenith Distance + Declination.
>
> *Situation Two:* If the ship is in the same hemisphere as the sun but has a lower latitude than the body (for example, Hawaii in summer):
> Latitude = Declination – Zenith Distance.

<u>Situation Three</u>: If the ship is in the opposite hemisphere from the sun (for example, anywhere in North America in winter):

Latitude = Zenith Distance - Declination.

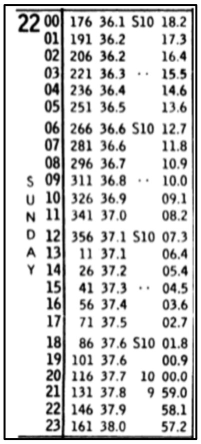
<u>Situation Four</u>: If the ship is directly beneath the sun (for example, at certain times of summer in the Caribbean Sea or Tropical Eastern Pacific Ocean:

Latitude = Declination.

<u>Problem 7-1.</u> The following question illustrates how to solve basic latitude by local apparent noon problems:

While on patrol aboard CGC THETIS, on 22 February local apparent noon (LAN) occurs at 1447 GMT, at which time a meridian altitude of the Sun's lower limb is observed. After all three standard sextant corrections, the observed altitude (Ho) for this sight is 73° 33.3'. The ship's DR latitude is 29° 45' N. What is the calculated latitude at LAN?

Answer: 26° 31.4' S.



22	00	176	36.1	S10	18.2
	01	191	36.2		17.3
	02	206	36.2		16.4
	03	221	36.3	··	15.5
	04	236	36.4		14.6
	05	251	36.5		13.6
	06	266	36.6	S10	12.7
	07	281	36.6		11.8
	08	296	36.7		10.9
S	09	311	36.8	··	10.0
U	10	326	36.9		09.1
N	11	341	37.0		08.2
D	12	356	37.1	S10	07.3
A	13	11	37.1		06.4
Y	14	26	37.2		05.4
	15	41	37.3	··	04.5
	16	56	37.4		03.6
	17	71	37.5		02.7
	18	86	37.6	S10	01.8
	19	101	37.6		00.9
	20	116	37.7	10	00.0
	21	131	37.8	9	59.0
	22	146	37.9		58.1
	23	161	38.0		57.2

Step 1: Determine the declination of the sun for the GMT time of sight.
At 1447 GMT:
Declination (1400): S 10° 05.4' (decreasing)
We are 47 minutes into the hour, or about 3/4ths of the way from 1400 to 1500 GMT. Therefore, we can easily estimate that the declination should be
<u>S 10° 04.7'</u>

Step 2: Determine the observed altitude of the sun.
The three standard sextant corrections are completed for you in this problem, so the observed altitude (ho)
is given as <u>73° 33.3'</u>

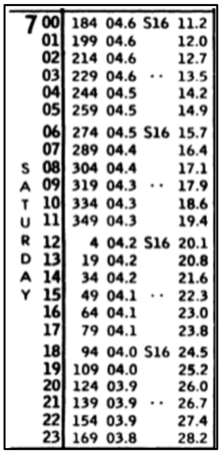
Step 3: Determine the zenith distance of the sight.
ZD = 90° - observed altitude.
ZD = 90° - 73° 33.3' = <u>16° 26.7'</u>

Step 4: Determine the latitude.

Since the observer is in the same hemisphere as the sun, but further away from the equator (as evidenced by the DR latitude), the formula is:
Latitude = Zenith Distance + Declination
Latitude = 16° 26.7' + 10° 04.7' = **26° 31.4' S**

Problem 7-2. The following question illustrates how to solve basic latitude by local apparent noon problems, including standard sextant corrections for height of eye, index error, and main correction. The figures are tricky – pay attention!

While on an Eastern Pacific patrol aboard CGC STEADFAST, on 7 November your morning fix gives you a position of latitude 27° 36.0' N, longitude 163° 19.0' W. Local apparent noon (LAN) occurs at 2238 GMT, at which time a meridian altitude of the Sun's lower limb is observed. The sextant altitude (Hs) for this sight is 45° 25.7'. Height of eye is 17 feet above sea level, and index error is 2.0' on the arc. What is the calculated latitude at LAN?



7	00	184	04.6	S16	11.2
	01	199	04.6		12.0
	02	214	04.6		12.7
	03	229	04.6	··	13.5
	04	244	04.5		14.2
	05	259	04.5		14.9
	06	274	04.5	S16	15.7
	07	289	04.4		16.4
S	08	304	04.4		17.1
A	09	319	04.3	··	17.9
T	10	334	04.3		18.6
U	11	349	04.3		19.4
R	12	4	04.2	S16	20.1
D	13	19	04.2		20.8
A	14	34	04.2		21.6
Y	15	49	04.1	··	22.3
	16	64	04.1		23.0
	17	79	04.1		23.8
	18	94	04.0	S16	24.5
	19	109	04.0		25.2
	20	124	03.9		26.0
	21	139	03.9	··	26.7
	22	154	03.9		27.4
	23	169	03.8		28.2

Answer: 27° 57.2' N

Step 1: Determine the declination of the sun for the GMT time of sight.
At 2238 GMT:
Declination (2200): S 16° 27.4' (increasing)
Estimating declination for our time of 2238 (about 2/3 of the way from 2200 to 2300), we come up with S 16° 27.8'

Step 2: Determine the observed altitude of the sun by making three **standard sextant corrections** (utilize the reprint of the Altitude Correction Tables from the Nautical Almanac on the following page).

The sextant altitude is given as: 45° 25.7'

The height of eye is given as 17 feet above sea level.
Looking in the tables at the front of the Nautical Almanac (reprinted on the following page), the dip correction is -4.0'.

The index error is given as 2.0' on the arc.
Therefore the index correction is -2.0'.

Since the sextant altitude was 45° 25.7', we need to subtract both corrections (-4.0' and -2.0'), and we determine the apparent altitude (Ha) to be 45° 25.7' – 4.0' – 2.0' = 45° 19.7'

Using the tables at the front of the Nautical Almanac (reprinted on the following page) apparent altitude correction for this figure is +15.3'

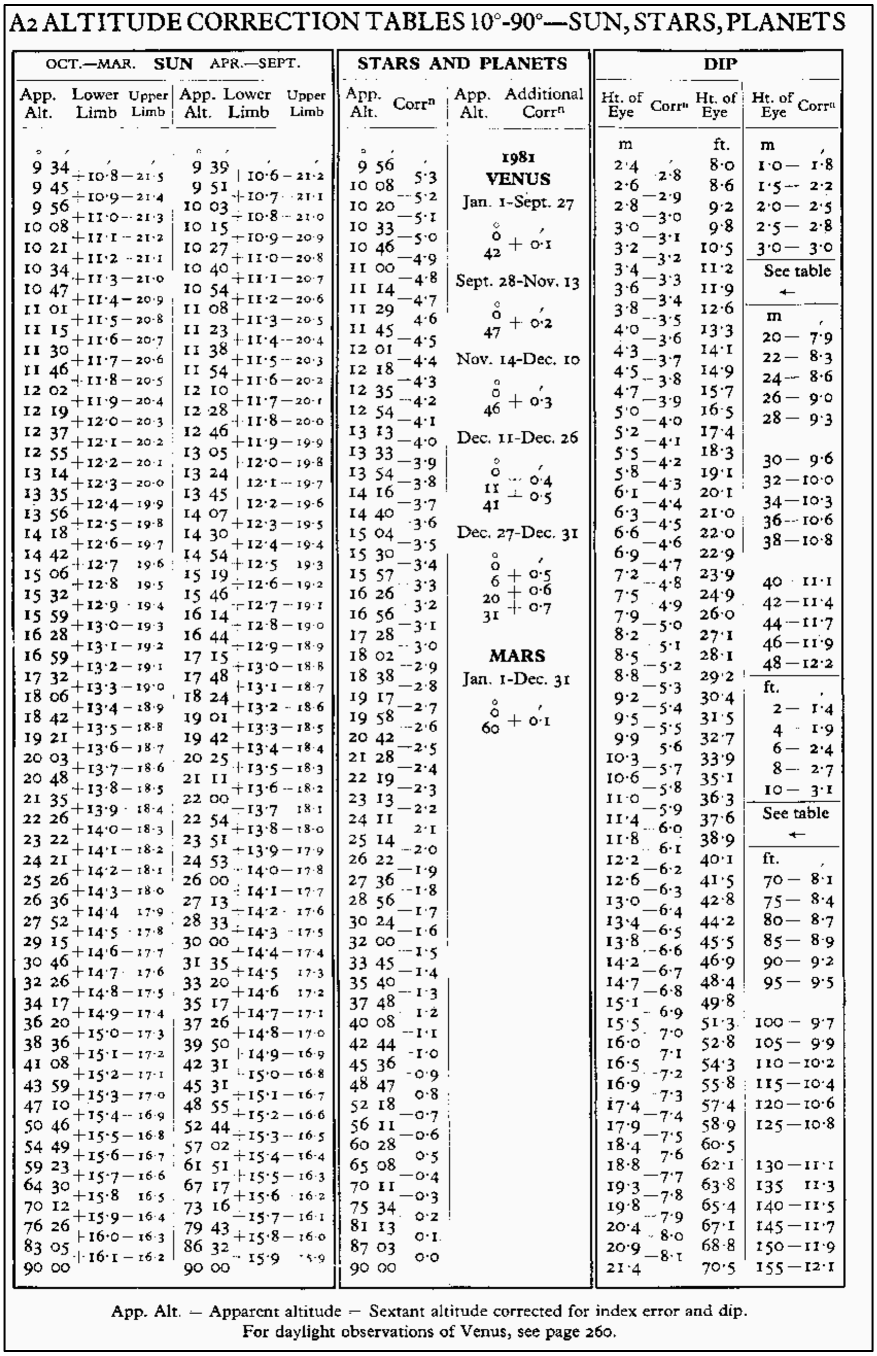
Therefore the observed altitude (Ho) of the sun is
45° 19.7' + 15.3' = 45° 35.0'

Step 3: Determine the zenith distance of the sight.

ZD = 90° - observed altitude.
ZD = 90° - 45° 35.0’ = 44° 25.0’

Step 4: Determine the latitude.

Since the observer is in the opposite hemisphere as the sun (as evidenced by the DR latitude), the formula is:
Latitude = Zenith Distance - Declination
Latitude = 44° 25.0’ - 16° 27.8’ = **27° 57.2’ N**



A2 ALTITUDE CORRECTION TABLES 10°-90°—SUN, STARS, PLANETS

OCT.—MAR. SUN			APR.—SEPT. SUN			STARS AND PLANETS		DIP		
App. Alt.	Lower Limb	Upper Limb	App. Alt.	Lower Limb	Upper Limb	App. Alt.	Corrn	Ht. of Eye	Corrn	Ht. of Eye
° ′	′	′	° ′	′	′	° ′	′	m	′	ft.
9 34			9 39			9 56		2·4		8·0
	+10·8	−21·5		+10·6	−21·2		−5·3		−2·8	
9 45			9 51			10 08		2·6		8·6
	+10·9	−21·4		+10·7	−21·1		−5·2		−2·9	
9 56			10 03			10 20		2·8		9·2
	+11·0	−21·3		+10·8	−21·0		−5·1		−3·0	
10 08			10 15			10 33		3·0		9·8
	+11·1	−21·2		+10·9	−20·9		−5·0		−3·1	
10 21			10 27			10 46		3·2		10·5
	+11·2	−21·1		+11·0	−20·8		−4·9		−3·2	
10 34			10 40			11 00		3·4		11·2
	+11·3	−21·0		+11·1	−20·7		−4·8		−3·3	
10 47			10 54			11 14		3·6		11·9
	+11·4	−20·9		+11·2	−20·6		−4·7		−3·4	
11 01			11 08			11 29		3·8		12·6
	+11·5	−20·8		+11·3	−20·5		−4·6		−3·5	
11 15			11 23			11 45		4·0		13·3
	+11·6	−20·7		+11·4	−20·4		−4·5		−3·6	
11 30			11 38			12 01		4·3		14·1
	+11·7	−20·6		+11·5	−20·3		−4·4		−3·7	
11 46			11 54			12 18		4·5		14·9
	+11·8	−20·5		+11·6	−20·2		−4·3		−3·8	
12 02			12 10			12 35		4·7		15·7
	+11·9	−20·4		+11·7	−20·1		−4·2		−3·9	
12 19			12 28			12 54		5·0		16·5
	+12·0	−20·3		+11·8	−20·0		−4·1		−4·0	
12 37			12 46			13 13		5·2		17·4
	+12·1	−20·2		+11·9	−19·9		−4·0		−4·1	
12 55			13 05			13 33		5·5		18·3
	+12·2	−20·1		+12·0	−19·8		−3·9		−4·2	
13 14			13 24			13 54		5·8		19·1
	+12·3	−20·0		+12·1	−19·7		−3·8		−4·3	
13 35			13 45			14 16		6·1		20·1
	+12·4	−19·9		+12·2	−19·6		−3·7		−4·4	
13 56			14 07			14 40		6·3		21·0
	+12·5	−19·8		+12·3	−19·5		−3·6		−4·5	
14 18			14 30			15 04		6·6		22·0
	+12·6	−19·7		+12·4	−19·4		−3·5		−4·6	
14 42			14 54			15 30		6·9		22·9
	+12·7	−19·6		+12·5	−19·3		−3·4		−4·7	
15 06			15 19			15 57		7·2		23·9
	+12·8	−19·5		+12·6	−19·2		−3·3		−4·8	
15 32			15 46			16 26		7·5		24·9
	+12·9	−19·4		+12·7	−19·1		−3·2		−4·9	
15 59			16 14			16 56		7·9		26·0
	+13·0	−19·3		+12·8	−19·0		−3·1		−5·0	
16 28			16 44			17 28		8·2		27·1
	+13·1	−19·2		+12·9	−18·9		−3·0		−5·1	
16 59			17 15			18 02		8·5		28·1
	+13·2	−19·1		+13·0	−18·8		−2·9		−5·2	
17 32			17 48			18 38		8·8		29·2
	+13·3	−19·0		+13·1	−18·7		−2·8		−5·3	
18 06			18 24			19 17		9·2		30·4
	+13·4	−18·9		+13·2	−18·6		−2·7		−5·4	
18 42			19 01			19 58		9·5		31·5
	+13·5	−18·8		+13·3	−18·5		−2·6		−5·5	
19 21			19 42			20 42		9·9		32·7
	+13·6	−18·7		+13·4	−18·4		−2·5		−5·6	
20 03			20 25			21 28		10·3		33·9
	+13·7	−18·6		+13·5	−18·3		−2·4		−5·7	
20 48			21 11			22 19		10·6		35·1
	+13·8	−18·5		+13·6	−18·2		−2·3		−5·8	
21 35			22 00			23 13		11·0		36·3
	+13·9	−18·4		+13·7	−18·1		−2·2		−5·9	
22 26			22 54			24 11		11·4		37·6
	+14·0	−18·3		+13·8	−18·0		−2·1		−6·0	
23 22			23 51			25 14		11·8		38·9
	+14·1	−18·2		+13·9	−17·9		−2·0		−6·1	
24 21			24 53			26 22		12·2		40·1
	+14·2	−18·1		+14·0	−17·8		−1·9		−6·2	
25 26			26 00			27 36		12·6		41·5
	+14·3	−18·0		+14·1	−17·7		−1·8		−6·3	
26 36			27 13			28 56		13·0		42·8
	+14·4	−17·9		+14·2	−17·6		−1·7		−6·4	
27 52			28 33			30 24		13·4		44·2
	+14·5	−17·8		+14·3	−17·5		−1·6		−6·5	
29 15			30 00			32 00		13·8		45·5
	+14·6	−17·7		+14·4	−17·4		−1·5		−6·6	
30 46			31 35			33 45		14·2		46·9
	+14·7	−17·6		+14·5	−17·3		−1·4		−6·7	
32 26			33 20			35 40		14·7		48·4
	+14·8	−17·5		+14·6	−17·2		−1·3		−6·8	
34 17			35 17			37 48		15·1		49·8
	+14·9	−17·4		+14·7	−17·1		−1·2		−6·9	
36 20			37 26			40 08		15·5		51·3
	+15·0	−17·3		+14·8	−17·0		−1·1		−7·0	
38 36			39 50			42 44		16·0		52·8
	+15·1	−17·2		+14·9	−16·9		−1·0		−7·1	
41 08			42 31			45 36		16·5		54·3
	+15·2	−17·1		+15·0	−16·8		−0·9		−7·2	
43 59			45 31			48 47		16·9		55·8
	+15·3	−17·0		+15·1	−16·7		−0·8		−7·3	
47 10			48 55			52 18		17·4		57·4
	+15·4	−16·9		+15·2	−16·6		−0·7		−7·4	
50 46			52 44			56 11		17·9		58·9
	+15·5	−16·8		+15·3	−16·5		−0·6		−7·5	
54 49			57 02			60 28		18·4		60·5
	+15·6	−16·7		+15·4	−16·4		−0·5		−7·6	
59 23			61 51			65 08		18·8		62·1
	+15·7	−16·6		+15·5	−16·3		−0·4		−7·7	
64 30			67 17			70 11		19·3		63·8
	+15·8	−16·5		+15·6	−16·2		−0·3		−7·8	
70 12			73 16			75 34		19·8		65·4
	+15·9	−16·4		+15·7	−16·1		−0·2		−7·9	
76 26			79 43			81 13		20·4		67·1
	+16·0	−16·3		+15·8	−16·0		−0·1		−8·0	
83 05			86 32			87 03		20·9		68·8
	+16·1	−16·2		+15·9	−15·9		0·0		−8·1	
90 00			90 00			90 00		21·4		70·5

App. Alt.	Additional Corrn
1981 VENUS	
Jan. 1-Sept. 27	
0	
	+0·1
42	
Sept. 28-Nov. 13	
0	
	+0·2
47	
Nov. 14-Dec. 10	
0	
	+0·3
46	
Dec. 11-Dec. 26	
0	
	+0·4
11	
	+0·5
41	
Dec. 27-Dec. 31	
0	
	+0·5
6	
	+0·6
20	
	+0·7
31	
MARS	
Jan. 1-Dec. 31	
0	
	+0·1
60	

DIP Ht. of Eye	Corrn
m	′
1·0	−1·8
1·5	−2·2
2·0	−2·5
2·5	−2·8
3·0	−3·0
See table ←	
m	′
20	−7·9
22	−8·3
24	−8·6
26	−9·0
28	−9·3
30	−9·6
32	−10·0
34	−10·3
36	−10·6
38	−10·8
40	−11·1
42	−11·4
44	−11·7
46	−11·9
48	−12·2
ft.	′
2	−1·4
4	−1·9
6	−2·4
8	−2·7
10	−3·1
See table ←	
ft.	′
70	−8·1
75	−8·4
80	−8·7
85	−8·9
90	−9·2
95	−9·5
100	−9·7
105	−9·9
110	−10·2
115	−10·4
120	−10·6
125	−10·8
130	−11·1
135	−11·3
140	−11·5
145	−11·7
150	−11·9
155	−12·1

App. Alt. — Apparent altitude — Sextant altitude corrected for index error and dip.
For daylight observations of Venus, see page 260.

In summary, the steps to calculate latitude at local apparent noon are:

Step 1: Measure the sun's altitude at the time of meridian passage (when the sun is highest in the sky, either due south or due north of you).

Step 2: Determine declination of the sun for the time of observation.

Step 3: Determine the observed altitude of the sun, by making all three standard sextant corrections.

Step 4: Determine the zenith distance of the sight by subtracting the observed altitude from 90°.

Step 5: Determine latitude by using one of the four situations:

If ship is in same hemisphere as sun, but higher latitude: Latitude = Zenith Distance + Declination If the ship is in same hemisphere as sun, but lower latitude: Latitude = Declination – Zenith Distance	If the ship is in the opposite hemisphere as the sun: Latitude = Zenith Distance - Body's Declination. If the ship is directly beneath the sun: Latitude = Body's Declination

STELLA Calculations of Latitude by Local Apparent Noon

This is not a task that can be completed in STELLA. However, you can determine a line of position from the sun at the time of local apparent noon to determine latitude indirectly. Lines of position from the sun are covered in chapter 11.

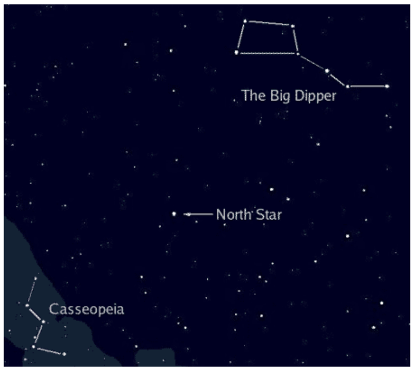
Advanced Theory

Latitude is determined at local apparent noon using the sun most frequently, but it can also be determined using any celestial body. For more on these problems, which are called "Meridian Passage" problems, see part 11 of *The Cutterman's Guide to Navigation Problems*, available at www.practicalnavigator.org.

Chapter 8: Compute Latitude by Polaris

The Basic Idea

Since **Polaris**, or the North Star, sits practically right over the Earth's northern pole, it appears to remain stationary in the night sky, almost like a lighthouse in the heavens. All other stars rotate about Polaris over the course of the night. As a fixed point, it has historically been - and remains - an extremely important navigational star.



The altitude of Polaris above the horizon is almost exactly equal to the latitude of the observer. However, nothing is perfect, and Polaris varies ever so slightly from true north over the course of Earth's orbit and rotation, necessitating a few minor corrections.

Polaris can be found by tracing a line from the leading edge of Ursa Major (the Big Dipper), or from the pointer star Eta-Cassiopeia in that constellation.

Manual Calculations

The Polaris Tables near the back of the Nautical Almanac facilitate quick solutions to latitude by Polaris. Instructions are provided at the bottom of the page, but in order to use the table successfully, you must enter the table with the current month, DR latitude, as well as the **Local Hour Angle (LHA)** of **Aries**.

Aries is a constellation, and, used here, it refers to the "first point of Aries," which is a mathematical point in the sky that represents the location of the Sun over the Earth during the spring equinox. None of this theory is necessary, however, since all that is required is to look up the Aries figures in the Nautical Almanac and perform one addition or subtraction calculation.

Local Hour Angle comes from **Greenwich Hour Angle (GHA)**, and refers to the difference between the observer's longitude and the longitude of the body. GHA can be retrieved from the Nautical Almanac, and LHA is given by:

LHA = GHA – Ship Longitude (western hemisphere)
LHA = GHA + Ship Longitude (eastern hemisphere)

Once the sextant reading has been corrected and all table inputs have been retrieved (current month, DR latitude, and LHA of Aries), the Polaris Table produces 3 figures (a0, a1, and a2), and the ship's true latitude is given by:

Latitude = Observed altitude – 1° + a0 + a1 + a2

Problem 8-1. The following question illustrates how to solve latitude by Polaris problems.

You are aboard CGC ALEX HALEY en route California for drydock. On 15 March at 0445 GMT, you take a sextant observation of Polaris. Your DR position is latitude 29° 10' N, longitude 154° 30' W. Your sextant reads 29° 53.5'. Your height of eye is 24 feet and the index error is 1.3' off the arc. Determine the latitude by Polaris.

Answer: 29° 21.3' N

Step 1: Determine the observed altitude of the body using the correction tables in the Nautical Almanac (reproduced at the end of this chapter).

The sextant altitude is given as: 29° 53.5'

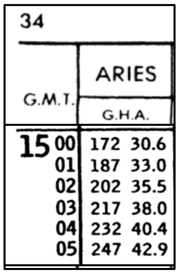
The height of eye is given as 24 feet above sea level.
Looking in the tables at the front of the Nautical Almanac (reprinted on the following page), the dip correction is - 4.8'.

The index error is given as 1.3' off the arc.
Therefore the index correction is + 1.3'.

Since the sextant altitude was 29° 53.5', we need to add or subtract the corrections, and we determine the apparent altitude (Ha) to be 29° 53.5'– 4.8' + 1.3' = 29° 50.0'

Using the star and planet correction tables at the front of the Nautical Almanac (reprinted at the end of this chapter) the apparent altitude correction for this figure is -1.7'.

Therefore the observed altitude (Ho) of the sun is 29° 50.0'– 1.7' = 29° 48.3'



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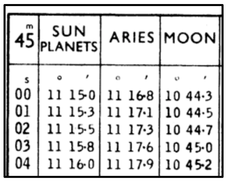
G.M.T.	ARIES G.H.A.
15 00	172 30.6
01	187 33.0
02	202 35.5
03	217 38.0
04	232 40.4
05	247 42.9

Step 2: Determine the GHA of Aries for the time of sight.

From the Nautical Almanac:
GHA (Aries), whole hours (for 0400): 232° 40.4'

Since there are 45 remaining minutes to account for, we use the increments and corrections tables in the back of the Nautical Almanac to determine the increment of 45 minutes:
GHA (Aries), increment: 11° 16.8'



45 m	SUN PLANETS	ARIES	MOON
s	° '	° '	° '
00	11 15·0	11 16·8	10 44·3
01	11 15·3	11 17·1	10 44·5
02	11 15·5	11 17·3	10 44·7
03	11 15·8	11 17·6	10 45·0
04	11 16·0	11 17·9	10 45·2

Therefore, the total GHA of Aries is:
GHA (Aries): 232° 40.4' + 11° 16.8' = 243° 57.2'

Step 3: Determine the LHA of Aries.

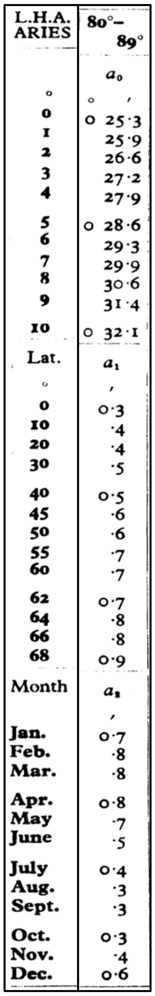
Since the ship is in the western hemisphere, LHA is equal to GHA minus ship's longitude.

GHA (Aries): 243° 57.2'
DR Longitude: 154° 30 W
LHA (Aries) = 243° 57.2' – 154° 30' W = <u>89° 27.2'</u>

Step 4: Enter the Polaris Tables with LHA (Aries), DR Latitude, and Month to determine the a0, a1, and a2 correction factors.
a0 (LHA correction): 0° 31.7'
a1 (Latitude correction): 0.5'
a2 (Month correction): 0.8'

Step 5: Calculate latitude using the Polaris Formula, provided at the bottom of the Polaris Tables.
Latitude = Observed altitude – 1° + a0 + a1 + a2

Lat = 29° 48.3' – 1° + 31.7' + 0.5' + 0.8' = **29° 21.3' N**



L.H.A. ARIES	80°– 89°
	a_0
°	° '
0	0 25·3
1	25·9
2	26·6
3	27·2
4	27·9
5	0 28·6
6	29·3
7	29·9
8	30·6
9	31·4
10	0 32·1
Lat.	a_1
°	'
0	0·3
10	·4
20	·4
30	·5
40	0·5
45	·6
50	·6
55	·7
60	·7
62	0·7
64	·8
66	·8
68	0·9
Month	a_2
	'
Jan.	0·7
Feb.	·8
Mar.	·8
Apr.	0·8
May	·7
June	·5
July	0·4
Aug.	·3
Sept.	·3
Oct.	0·3
Nov.	·4
Dec.	0·6

STELLA Calculations of Latitude by Polaris

Any observation of Polaris always yields a line of latitude. So observing Polaris as if it were any other object meets the requirement of the Coast Guard Navigation Standards. For the steps in completing a STELLA sight reduction of any body (including Polaris), see chapter 11.

<u>In summary, the steps to calculate Latitude by Polaris manually are:</u>

Step 1: Observe Polaris and determine the apparent altitude by correcting the sextant reading for 3 standard corrections.

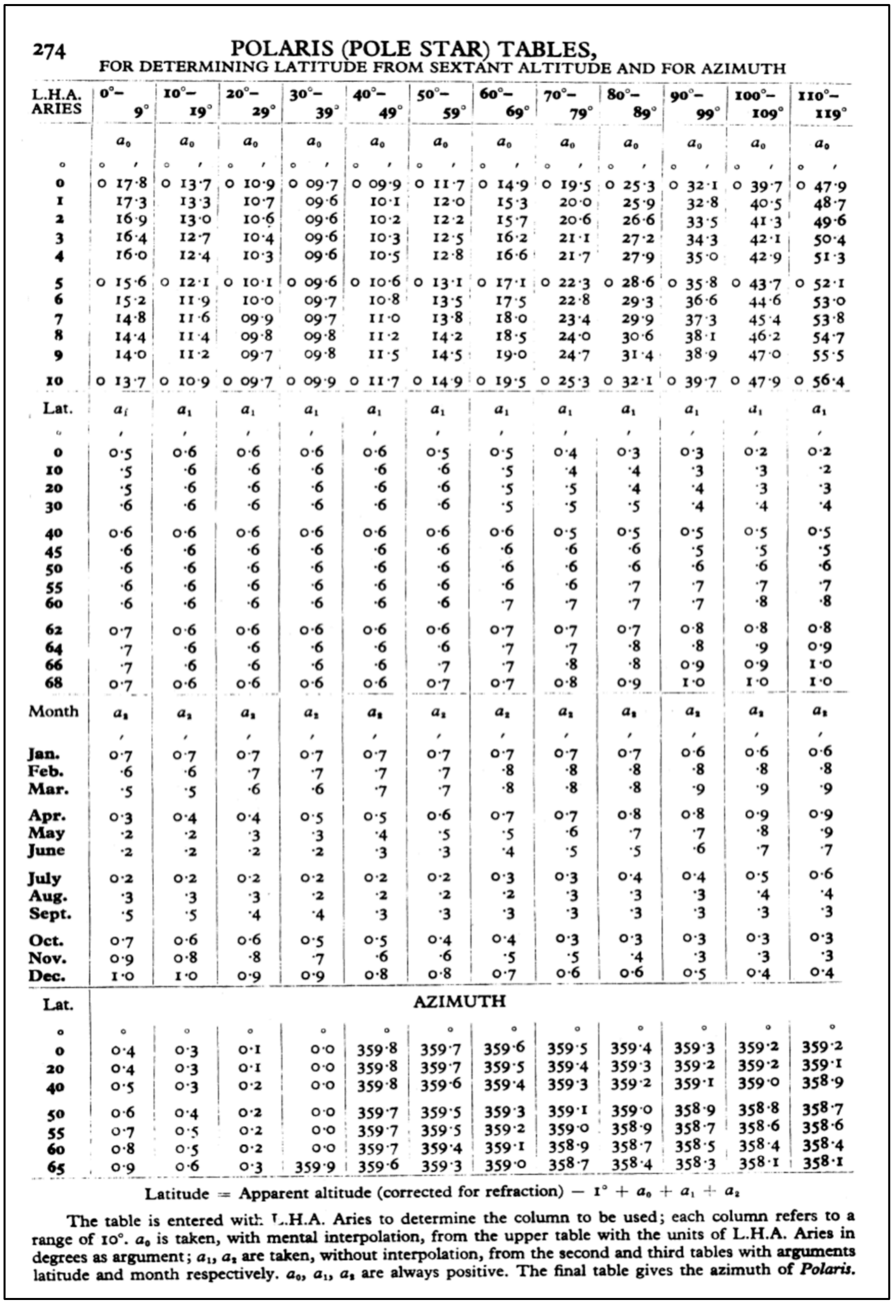
Step 2: Determine the GHA of Aries for the time of the sight.

Step 3: Determine the LHA of Polaris (LHA = GHA – (Long W) or (+Long E))

Step 4: Enter Polaris Tables and compute Latitude.

Advanced Theory

In emergency navigation techniques, latitude can be found by Polaris without the preceding corrections, with enough accuracy to determine course to steer or nearest land.



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POLARIS (POLE STAR) TABLES,
FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE AND FOR AZIMUTH

L.H.A. ARIES	0°–9°	10°–19°	20°–29°	30°–39°	40°–49°	50°–59°	60°–69°	70°–79°	80°–89°	90°–99°	100°–109°	110°–119°
	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 17·8	0 13·7	0 10·9	0 09·7	0 09·9	0 11·7	0 14·9	0 19·5	0 25·3	0 32·1	0 39·7	0 47·9
1	17·3	13·3	10·7	09·6	10·1	12·0	15·3	20·0	25·9	32·8	40·5	48·7
2	16·9	13·0	10·6	09·6	10·2	12·2	15·7	20·6	26·6	33·5	41·3	49·6
3	16·4	12·7	10·4	09·6	10·3	12·5	16·2	21·1	27·2	34·3	42·1	50·4
4	16·0	12·4	10·3	09·6	10·5	12·8	16·6	21·7	27·9	35·0	42·9	51·3
5	0 15·6	0 12·1	0 10·1	0 09·6	0 10·6	0 13·1	0 17·1	0 22·3	0 28·6	0 35·8	0 43·7	0 52·1
6	15·2	11·9	10·0	09·7	10·8	13·5	17·5	22·8	29·3	36·6	44·6	53·0
7	14·8	11·6	09·9	09·7	11·0	13·8	18·0	23·4	29·9	37·3	45·4	53·8
8	14·4	11·4	09·8	09·8	11·2	14·2	18·5	24·0	30·6	38·1	46·2	54·7
9	14·0	11·2	09·7	09·8	11·5	14·5	19·0	24·7	31·4	38·9	47·0	55·5
10	0 13·7	0 10·9	0 09·7	0 09·9	0 11·7	0 14·9	0 19·5	0 25·3	0 32·1	0 39·7	0 47·9	0 56·4
Lat.	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1
°	′	′	′	′	′	′	′	′	′	′	′	′
0	0·5	0·6	0·6	0·6	0·6	0·5	0·5	0·4	0·3	0·3	0·2	0·2
10	·5	·6	·6	·6	·6	·6	·5	·4	·4	·3	·3	·2
20	·5	·6	·6	·6	·6	·6	·5	·5	·4	·4	·3	·3
30	·6	·6	·6	·6	·6	·6	·5	·5	·5	·4	·4	·4
40	0·6	0·6	0·6	0·6	0·6	0·6	0·6	0·5	0·5	0·5	0·5	0·5
45	·6	·6	·6	·6	·6	·6	·6	·6	·6	·5	·5	·5
50	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6
55	·6	·6	·6	·6	·6	·6	·6	·6	·7	·7	·7	·7
60	·6	·6	·6	·6	·6	·6	·7	·7	·7	·7	·8	·8
62	0·7	0·6	0·6	0·6	0·6	0·6	0·7	0·7	0·7	0·8	0·8	0·8
64	·7	·6	·6	·6	·6	·6	·7	·7	·8	·8	·9	0·9
66	·7	·6	·6	·6	·6	·7	·7	·8	·8	0·9	0·9	1·0
68	0·7	0·6	0·6	0·6	0·6	0·7	0·7	0·8	0·9	1·0	1·0	1·0
Month	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2
	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·6	0·6	0·6
Feb.	·6	·6	·7	·7	·7	·7	·8	·8	·8	·8	·8	·8
Mar.	·5	·5	·6	·6	·7	·7	·8	·8	·8	·9	·9	·9
Apr.	0·3	0·4	0·4	0·5	0·5	0·6	0·7	0·7	0·8	0·8	0·9	0·9
May	·2	·2	·3	·3	·4	·5	·5	·6	·7	·7	·8	·9
June	·2	·2	·2	·2	·3	·3	·4	·5	·5	·6	·7	·7
July	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·6
Aug.	·3	·3	·3	·2	·2	·2	·2	·3	·3	·3	·4	·4
Sept.	·5	·5	·4	·4	·3	·3	·3	·3	·3	·3	·3	·3
Oct.	0·7	0·6	0·6	0·5	0·5	0·4	0·4	0·3	0·3	0·3	0·3	0·3
Nov.	0·9	0·8	·8	·7	·6	·6	·5	·5	·4	·3	·3	·3
Dec.	1·0	1·0	0·9	0·9	0·8	0·8	0·7	0·6	0·6	0·5	0·4	0·4
Lat.	AZIMUTH											
°	°	°	°	°	°	°	°	°	°	°	°	°
0	0·4	0·3	0·1	0·0	359·8	359·7	359·6	359·5	359·4	359·3	359·2	359·2
20	0·4	0·3	0·1	0·0	359·8	359·7	359·5	359·4	359·3	359·2	359·2	359·1
40	0·5	0·3	0·2	0·0	359·8	359·6	359·4	359·3	359·2	359·1	359·0	358·9
50	0·6	0·4	0·2	0·0	359·7	359·5	359·3	359·1	359·0	358·9	358·8	358·7
55	0·7	0·5	0·2	0·0	359·7	359·5	359·2	359·0	358·9	358·7	358·6	358·6
60	0·8	0·5	0·2	0·0	359·7	359·4	359·1	358·9	358·7	358·5	358·4	358·4
65	0·9	0·6	0·3	359·9	359·6	359·3	359·0	358·7	358·4	358·3	358·1	358·1

Latitude = Apparent altitude (corrected for refraction) $- 1° + a_0 + a_1 + a_2$

The table is entered with L.H.A. Aries to determine the column to be used; each column refers to a range of 10°. a_0 is taken, with mental interpolation, from the upper table with the units of L.H.A. Aries in degrees as argument; a_1, a_2 are taken, without interpolation, from the second and third tables with arguments latitude and month respectively. a_0, a_1, a_2 are always positive. The final table gives the azimuth of *Polaris.*

A2 ALTITUDE CORRECTION TABLES 10°-90°—SUN, STARS, PLANETS

OCT.—MAR. SUN APR.—SEPT.

App. Alt.	Lower Limb	Upper Limb	App. Alt.	Lower Limb	Upper Limb
° ′	′	′	° ′	′	′
9 34			9 39		
	+10·8	−21·5		+10·6	−21·2
9 45			9 51		
	+10·9	−21·4		+10·7	−21·1
9 56			10 03		
	+11·0	−21·3		+10·8	−21·0
10 08			10 15		
	+11·1	−21·2		+10·9	−20·9
10 21			10 27		
	+11·2	−21·1		+11·0	−20·8
10 34			10 40		
	+11·3	−21·0		+11·1	−20·7
10 47			10 54		
	+11·4	−20·9		+11·2	−20·6
11 01			11 08		
	+11·5	−20·8		+11·3	−20·5
11 15			11 23		
	+11·6	−20·7		+11·4	−20·4
11 30			11 38		
	+11·7	−20·6		+11·5	−20·3
11 46			11 54		
	+11·8	−20·5		+11·6	−20·2
12 02			12 10		
	+11·9	−20·4		+11·7	−20·1
12 19			12 28		
	+12·0	−20·3		+11·8	−20·0
12 37			12 46		
	+12·1	−20·2		+11·9	−19·9
12 55			13 05		
	+12·2	−20·1		+12·0	−19·8
13 14			13 24		
	+12·3	−20·0		+12·1	−19·7
13 35			13 45		
	+12·4	−19·9		+12·2	−19·6
13 56			14 07		
	+12·5	−19·8		+12·3	−19·5
14 18			14 30		
	+12·6	−19·7		+12·4	−19·4
14 42			14 54		
	+12·7	−19·6		+12·5	−19·3
15 06			15 19		
	+12·8	−19·5		+12·6	−19·2
15 32			15 46		
	+12·9	−19·4		+12·7	−19·1
15 59			16 14		
	+13·0	−19·3		+12·8	−19·0
16 28			16 44		
	+13·1	−19·2		+12·9	−18·9
16 59			17 15		
	+13·2	−19·1		+13·0	−18·8
17 32			17 48		
	+13·3	−19·0		+13·1	−18·7
18 06			18 24		
	+13·4	−18·9		+13·2	−18·6
18 42			19 01		
	+13·5	−18·8		+13·3	−18·5
19 21			19 42		
	+13·6	−18·7		+13·4	−18·4
20 03			20 25		
	+13·7	−18·6		+13·5	−18·3
20 48			21 11		
	+13·8	−18·5		+13·6	−18·2
21 35			22 00		
	+13·9	−18·4		+13·7	−18·1
22 26			22 54		
	+14·0	−18·3		+13·8	−18·0
23 22			23 51		
	+14·1	−18·2		+13·9	−17·9
24 21			24 53		
	+14·2	−18·1		+14·0	−17·8
25 26			26 00		
	+14·3	−18·0		+14·1	−17·7
26 36			27 13		
	+14·4	−17·9		+14·2	−17·6
27 52			28 33		
	+14·5	−17·8		+14·3	−17·5
29 15			30 00		
	+14·6	−17·7		+14·4	−17·4
30 46			31 35		
	+14·7	−17·6		+14·5	−17·3
32 26			33 20		
	+14·8	−17·5		+14·6	−17·2
34 17			35 17		
	+14·9	−17·4		+14·7	−17·1
36 20			37 26		
	+15·0	−17·3		+14·8	−17·0
38 36			39 50		
	+15·1	−17·2		+14·9	−16·9
41 08			42 31		
	+15·2	−17·1		+15·0	−16·8
43 59			45 31		
	+15·3	−17·0		+15·1	−16·7
47 10			48 55		
	+15·4	−16·9		+15·2	−16·6
50 46			52 44		
	+15·5	−16·8		+15·3	−16·5
54 49			57 02		
	+15·6	−16·7		+15·4	−16·4
59 23			61 51		
	+15·7	−16·6		+15·5	−16·3
64 30			67 17		
	+15·8	−16·5		+15·6	−16·2
70 12			73 16		
	+15·9	−16·4		+15·7	−16·1
76 26			79 43		
	+16·0	−16·3		+15·8	−16·0
83 05			86 32		
	+16·1	−16·2		+15·9	−15·9
90 00			90 00		

STARS AND PLANETS

App. Alt.	Corrn
° ′	′
9 56	
	−5·3
10 08	
	−5·2
10 20	
	−5·1
10 33	
	−5·0
10 46	
	−4·9
11 00	
	−4·8
11 14	
	−4·7
11 29	
	−4·6
11 45	
	−4·5
12 01	
	−4·4
12 18	
	−4·3
12 35	
	−4·2
12 54	
	−4·1
13 13	
	−4·0
13 33	
	−3·9
13 54	
	−3·8
14 16	
	−3·7
14 40	
	−3·6
15 04	
	−3·5
15 30	
	−3·4
15 57	
	−3·3
16 26	
	−3·2
16 56	
	−3·1
17 28	
	−3·0
18 02	
	−2·9
18 38	
	−2·8
19 17	
	−2·7
19 58	
	−2·6
20 42	
	−2·5
21 28	
	−2·4
22 19	
	−2·3
23 13	
	−2·2
24 11	
	−2·1
25 14	
	−2·0
26 22	
	−1·9
27 36	
	−1·8
28 56	
	−1·7
30 24	
	−1·6
32 00	
	−1·5
33 45	
	−1·4
35 40	
	−1·3
37 48	
	−1·2
40 08	
	−1·1
42 44	
	−1·0
45 36	
	−0·9
48 47	
	−0·8
52 18	
	−0·7
56 11	
	−0·6
60 28	
	−0·5
65 08	
	−0·4
70 11	
	−0·3
75 34	
	−0·2
81 13	
	−0·1
87 03	
	0·0
90 00	

App. Alt.	Additional Corrn
1981	
VENUS	
Jan. 1-Sept. 27	
°	′
0	
	+0·1
42	
Sept. 28-Nov. 13	
°	′
0	
	+0·2
47	
Nov. 14-Dec. 10	
°	′
0	
	+0·3
46	
Dec. 11-Dec. 26	
°	′
0	
	+0·4
11	
	+0·5
41	
Dec. 27-Dec. 31	
°	′
0	
	+0·5
6	
	+0·6
20	
	+0·7
31	
MARS	
Jan. 1-Dec. 31	
°	′
0	
	+0·1
60	

DIP

Ht. of Eye	Corrn	Ht. of Eye
m	′	ft.
2·4		8·0
	−2·8	
2·6		8·6
	−2·9	
2·8		9·2
	−3·0	
3·0		9·8
	−3·1	
3·2		10·5
	−3·2	
3·4		11·2
	−3·3	
3·6		11·9
	−3·4	
3·8		12·6
	−3·5	
4·0		13·3
	−3·6	
4·3		14·1
	−3·7	
4·5		14·9
	−3·8	
4·7		15·7
	−3·9	
5·0		16·5
	−4·0	
5·2		17·4
	−4·1	
5·5		18·3
	−4·2	
5·8		19·1
	−4·3	
6·1		20·1
	−4·4	
6·3		21·0
	−4·5	
6·6		22·0
	−4·6	
6·9		22·9
	−4·7	
7·2		23·9
	−4·8	
7·5		24·9
	−4·9	
7·9		26·0
	−5·0	
8·2		27·1
	−5·1	
8·5		28·1
	−5·2	
8·8		29·2
	−5·3	
9·2		30·4
	−5·4	
9·5		31·5
	−5·5	
9·9		32·7
	−5·6	
10·3		33·9
	−5·7	
10·6		35·1
	−5·8	
11·0		36·3
	−5·9	
11·4		37·6
	−6·0	
11·8		38·9
	−6·1	
12·2		40·1
	−6·2	
12·6		41·5
	−6·3	
13·0		42·8
	−6·4	
13·4		44·2
	−6·5	
13·8		45·5
	−6·6	
14·2		46·9
	−6·7	
14·7		48·4
	−6·8	
15·1		49·8
	−6·9	
15·5		51·3
	−7·0	
16·0		52·8
	−7·1	
16·5		54·3
	−7·2	
16·9		55·8
	−7·3	
17·4		57·4
	−7·4	
17·9		58·9
	−7·5	
18·4		60·5
	−7·6	
18·8		62·1
	−7·7	
19·3		63·8
	−7·8	
19·8		65·4
	−7·9	
20·4		67·1
	−8·0	
20·9		68·8
	−8·1	
21·4		70·5

Ht. of Eye	Corrn
m	′
1·0	−1·8
1·5	−2·2
2·0	−2·5
2·5	−2·8
3·0	−3·0
See table ←	
m	′
20	−7·9
22	−8·3
24	−8·6
26	−9·0
28	−9·3
30	−9·6
32	−10·0
34	−10·3
36	−10·6
38	−10·8
40	−11·1
42	−11·4
44	−11·7
46	−11·9
48	−12·2
ft.	′
2	−1·4
4	−1·9
6	−2·4
8	−2·7
10	−3·1
See table ←	
ft.	′
70	−8·1
75	−8·4
80	−8·7
85	−8·9
90	−9·2
95	−9·5
100	−9·7
105	−9·9
110	−10·2
115	−10·4
120	−10·6
125	−10·8
130	−11·1
135	−11·3
140	−11·5
145	−11·7
150	−11·9
155	−12·1

App. Alt. = Apparent altitude = Sextant altitude corrected for index error and dip.
For daylight observations of Venus, see page 260.

Part 4: Advanced Azimuth Problems

In which we solve gyro error by Polaris problems and gyro error by azimuth of the sun problems, enabling completion of two tasks in the Coast Guard Navigation Standards.

Chapter 9: Determine Gyro Error by Polaris

The Basic Idea

As discussed in chapter 8 (Latitude by Polaris), the star Polaris sits practically right over the Earth's north pole. However, nothing is perfect, and Polaris varies ever so slightly from true north over the course of Earth's orbit and rotation.

But with just a few small corrections, the calculated bearing (or **azimuth**), to Polaris can be determined. Then, a measured value can be compared to the calculated figure to determine gyro compass error.

Using a standard **azimuth circle** (see chapter 3), measure the bearing to Polaris. Then, for the time of observation, complete a Polaris calculation, exactly as if you would were you calculating latitude by Polaris (chapter 8). But instead of completing the latitude calculation formula, simply retrieve the azimuth value and compare to the measured value to obtain gyro compass error.

Manual Calculations

Using a standard **azimuth circle** (see chapter 3), measure the bearing to Polaris. Then, for the time of observation, complete a Polaris calculation, exactly as if you would were you calculating latitude by Polaris (chapter 8). But instead of completing the latitude calculation formula, simply retrieve the azimuth value and compare to the measured value to obtain gyro compass error.

Problem 9-1. The following question illustrates how to solve compass problems involving Polaris.

While on an international arctic exercise aboard CGC WILLOW, on 6 February your 0120 GMT position is latitude 52° 28' N, longitude 23° 48' W. You observe Polaris bearing 000.2° pgc. At the time of observation, the helmsman noted that she was heading 224° per gyro compass. What is the gyro compass error by Polaris?

Answer: 1.5° W.

Step 1: Determine the GHA of Aries for the time of sight.

From the Nautical Almanac:
GHA (Aries), whole hours (for 0100): 151° 04.9'

Since there are 20 remaining minutes to account for, we use the increments and corrections tables in the back of the Nautical Almanac to determine the increment of 20 minutes:
GHA (Aries), increment: 5° 00.8'

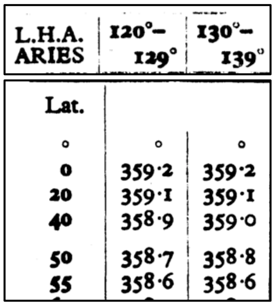
Therefore, the total GHA of Aries is:
GHA (Aries): 151° 04.9’+ 5° 00.8’= 156° 05.7’

Step 2: Determine the LHA of Aries.

Since the ship is in the western hemisphere, LHA is equal to GHA minus ship’s longitude.

GHA (Aries): 156° 05.7’
DR Longitude: 23° 48’ W
LHA (Aries) = 156° 05.7’ – 23° 48’ W = 132° 17.7’

Step 3: Enter the Polaris Tables with LHA (Aries), DR Latitude, and Month to determine the azimuth to Polaris (the full Polaris Tables are located at the end of this chapter).
Azimuth (interpolated) = 358.7°



L.H.A. ARIES	120°– 129°	130°– 139°
Lat.		
°	°	°
0	359·2	359·2
20	359·1	359·1
40	358·9	359·0
50	358·7	358·8
55	358·6	358·6

Step 4: Determine the gyro compass error (using the acronym G-E-T).

G (Gyro): 000.2° pgc
E (Error): TBD
T (True): 358.7° per Polaris azimuth tables

Gyro error = 1.5° W

In summary, the steps to calculate Gyro Error by Polaris manually are:

Step 1: Determine the GHA of Aries for the time of the sight.

Step 2: Determine the LHA of Polaris (LHA = GHA – (Long W) or (+Long E))

Step 3: Enter Polaris Tables and retrieve calculated azimuth.

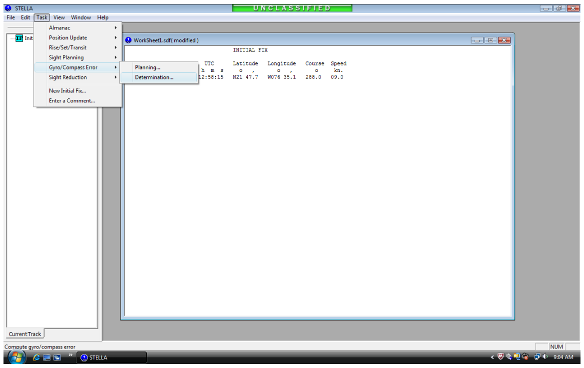
Step 4: Compare the calculated azimuth to the measured value to determine Gyro Compass Error using the following aid:

G-E-T or “Gyro Best, Error West. Gyro Least, Error East”

STELLA Calculations of Gyro Error by Polaris

To determine the gyro compass error for any body using the STELLA program, first establish a DR position (Initial Fix). Then follow:

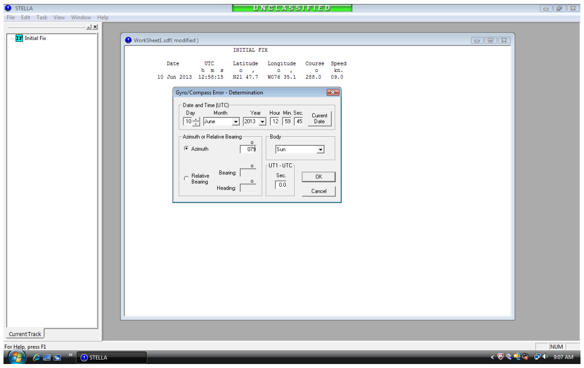
Step 1: Task>Gyro/Compass Error>Determination



```
                 INITIAL FIX

   UTC      Latitude   Longitude   Course  Speed
  h  m  s     o  ,       o  ,        o      kn.
 12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

Step 2: Populate all fields as necessary.



```
                       INITIAL FIX

    Date       UTC      Latitude   Longitude   Course  Speed
              h  m  s     o  ,       o  ,        o      kn.
10 Jun 2013  12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

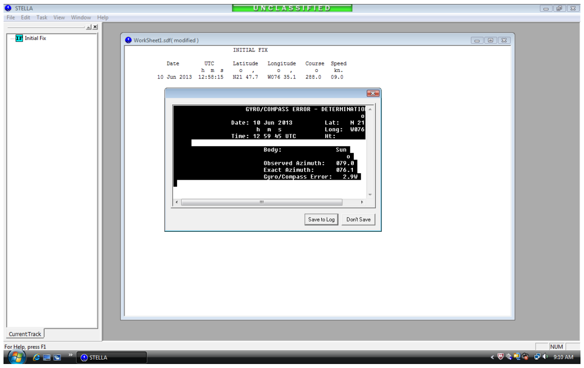
Date and Time (UTC): Day 10, Month June, Year 2013, Hour 12, Min. 59, Sec. 45

Azimuth or Relative Bearing: ● Azimuth 079°; ○ Relative Bearing (Bearing: °, Heading: °)

Body: Sun

UT1 - UTC: Sec. 0.0

Step 3: Retrieve the gyro compass error from STELLA and note it in the ship’s navigational worksheet or log.



```
                       INITIAL FIX

    Date       UTC      Latitude   Longitude   Course  Speed
              h  m  s     o  ,       o  ,        o      kn.
10 Jun 2013  12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

```
                 GYRO/COMPASS ERROR - DETERMINATIO
                                                 o
          Date: 10 Jun 2013        Lat:   N 21
                 h  m  s           Long:  W076
          Time: 12 59 45 UTC       Ht:

                      Body:                 Sun
                                              o
                      Observed Azimuth:   079.0
                      Exact Azimuth:      076.1
                      Gyro/Compass Error:   2.9W
```

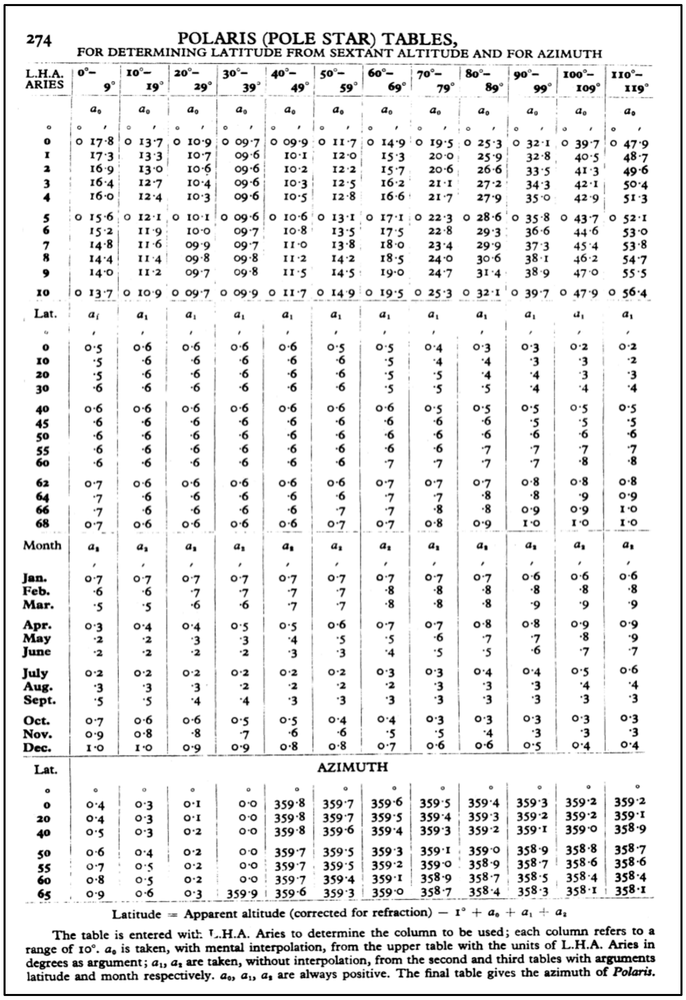
Advanced Theory for Gyro Compass Error by Polaris

Magnetic compass deviation can also be calculated using Polaris (or any other body).

For instance in the example provided in this chapter, assume the helmsmen noted her magnetic heading as 244° per steering compass and the charted variation was 20° W. After determining the gyro error as described above, the magnetic deviation can be determined with an additional step using the acronym CDMVT (Can Dead Men Vote Twice) or TVMDC (True Vampires Make Dull Companions). For more on compass calculations, see *The Cutterman's Guide to Navigation Problems*, part 6.

Determine the deviation (using a standard compass problem format).

Gyro: 224° pgc (Given)
Error: 1.5° W (Determine in step 5)
True Course: 222.5° (Calculated)
Variation: 20° W (Given)
Magnetic Course: 242.5° (Calculated)
Deviation: 1.5° W (Calculated)
Compass Course: 244° per steering compass (Given)



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POLARIS (POLE STAR) TABLES,
FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE AND FOR AZIMUTH

L.H.A. ARIES	0°– 9°	10°– 19°	20°– 29°	30°– 39°	40°– 49°	50°– 59°	60°– 69°	70°– 79°	80°– 89°	90°– 99°	100°– 109°	110°– 119°
	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0	a_0
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 17·8	0 13·7	0 10·9	0 09·7	0 09·9	0 11·7	0 14·9	0 19·5	0 25·3	0 32·1	0 39·7	0 47·9
1	17·3	13·3	10·7	09·6	10·1	12·0	15·3	20·0	25·9	32·8	40·5	48·7
2	16·9	13·0	10·6	09·6	10·2	12·2	15·7	20·6	26·6	33·5	41·3	49·6
3	16·4	12·7	10·4	09·6	10·3	12·5	16·2	21·1	27·2	34·3	42·1	50·4
4	16·0	12·4	10·3	09·6	10·5	12·8	16·6	21·7	27·9	35·0	42·9	51·3
5	0 15·6	0 12·1	0 10·1	0 09·6	0 10·6	0 13·1	0 17·1	0 22·3	0 28·6	0 35·8	0 43·7	0 52·1
6	15·2	11·9	10·0	09·7	10·8	13·5	17·5	22·8	29·3	36·6	44·6	53·0
7	14·8	11·6	09·9	09·7	11·0	13·8	18·0	23·4	29·9	37·3	45·4	53·8
8	14·4	11·4	09·8	09·8	11·2	14·2	18·5	24·0	30·6	38·1	46·2	54·7
9	14·0	11·2	09·7	09·8	11·5	14·5	19·0	24·7	31·4	38·9	47·0	55·5
10	0 13·7	0 10·9	0 09·7	0 09·9	0 11·7	0 14·9	0 19·5	0 25·3	0 32·1	0 39·7	0 47·9	0 56·4
Lat.	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1	a_1
°	′	′	′	′	′	′	′	′	′	′	′	′
0	0·5	0·6	0·6	0·6	0·6	0·5	0·5	0·4	0·3	0·3	0·2	0·2
10	·5	·6	·6	·6	·6	·6	·5	·4	·4	·3	·3	·2
20	·5	·6	·6	·6	·6	·6	·5	·5	·4	·4	·3	·3
30	·6	·6	·6	·6	·6	·6	·5	·5	·5	·4	·4	·4
40	0·6	0·6	0·6	0·6	0·6	0·6	0·6	0·5	0·5	0·5	0·5	0·5
45	·6	·6	·6	·6	·6	·6	·6	·6	·6	·5	·5	·5
50	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6	·6
55	·6	·6	·6	·6	·6	·6	·6	·6	·7	·7	·7	·7
60	·6	·6	·6	·6	·6	·6	·7	·7	·7	·7	·8	·8
62	0·7	0·6	0·6	0·6	0·6	0·6	0·7	0·7	0·7	0·8	0·8	0·8
64	·7	·6	·6	·6	·6	·6	·7	·7	·8	·8	·9	0·9
66	·7	·6	·6	·6	·6	·7	·7	·8	·8	0·9	0·9	1·0
68	0·7	0·6	0·6	0·6	0·6	0·7	0·7	0·8	0·9	1·0	1·0	1·0
Month	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2	a_2
	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·7	0·6	0·6	0·6
Feb.	·6	·6	·7	·7	·7	·7	·8	·8	·8	·8	·8	·8
Mar.	·5	·5	·6	·6	·7	·7	·8	·8	·8	·9	·9	·9
Apr.	0·3	0·4	0·4	0·5	0·5	0·6	0·7	0·7	0·8	0·8	0·9	0·9
May	·2	·2	·3	·3	·4	·5	·5	·6	·7	·7	·8	·9
June	·2	·2	·2	·2	·3	·3	·4	·5	·5	·6	·7	·7
July	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·6
Aug.	·3	·3	·3	·2	·2	·2	·2	·3	·3	·3	·4	·4
Sept.	·5	·5	·4	·4	·3	·3	·3	·3	·3	·3	·3	·3
Oct.	0·7	0·6	0·6	0·5	0·5	0·4	0·4	0·3	0·3	0·3	0·3	0·3
Nov.	0·9	0·8	·8	·7	·6	·6	·5	·5	·4	·3	·3	·3
Dec.	1·0	1·0	0·9	0·9	0·8	0·8	0·7	0·6	0·6	0·5	0·4	0·4
Lat.	AZIMUTH											
°	°	°	°	°	°	°	°	°	°	°	°	°
0	0·4	0·3	0·1	0·0	359·8	359·7	359·6	359·5	359·4	359·3	359·2	359·2
20	0·4	0·3	0·1	0·0	359·8	359·7	359·5	359·4	359·3	359·2	359·2	359·1
40	0·5	0·3	0·2	0·0	359·8	359·6	359·4	359·3	359·2	359·1	359·0	358·9
50	0·6	0·4	0·2	0·0	359·7	359·5	359·3	359·1	359·0	358·9	358·8	358·7
55	0·7	0·5	0·2	0·0	359·7	359·5	359·2	359·0	358·9	358·7	358·6	358·6
60	0·8	0·5	0·2	0·0	359·7	359·4	359·1	358·9	358·7	358·5	358·4	358·4
65	0·9	0·6	0·3	359·9	359·6	359·3	359·0	358·7	358·4	358·3	358·1	358·1

Latitude = Apparent altitude (corrected for refraction) $- 1° + a_0 + a_1 + a_2$

The table is entered with L.H.A. Aries to determine the column to be used; each column refers to a range of 10°. a_0 is taken, with mental interpolation, from the upper table with the units of L.H.A. Aries in degrees as argument; a_1, a_2 are taken, without interpolation, from the second and third tables with arguments latitude and month respectively. a_0, a_1, a_2 are always positive. The final table gives the azimuth of *Polaris*.

Chapter 10: Determine Gyro Error by Azimuth of the Sun

The Basic Idea

In order to calculate gyro error by azimuth of the sun, or any other celestial body, you must calculate the **azimuth** (bearing) to the object at a specific time, and then compare the observed azimuth to on observed azimuth, obtained by using an **azimuth circle** to measure the bearing of the sun.

In order to calculate an azimuth for a moving object, you must know your exact position, and the exact **geographic position** of the celestial body (recall that geographic position is the latitude and longitude on the earth directly beneath the celestial body, and is defined as **declination** (latitude), and **Greenwich Hour Angle** (longitude)).

You must then determine the **local hour angle** from your position to the body's position, recalling that local hour angle is the Greenwich Hour Angle minus longitude (in the western hemisphere). Your goal is to determine exact values for latitude, declination, and local hour angle, using these values as entering arguments to retrieve the calculated azimuth from the sight reduction tables (HO229).

Finally, a comparison of the calculated azimuth to the measured azimuth yields compass error.

Manual Calculations

Before completing an actual example problem, lets look at a hypothetical case with easy numbers for calculation.

If your position was 30°N and 60°W, and the Sun's geographic position was Declination 20°S and GHA 100° degrees, then you would obtain the following arguments, which you would use to enter the sight reduction tables (HO229): Latitude 30°N, Declination 20°S, and LHA 40° (100° - 60°).

After obtaining these entering arguments, you retrieve the azimuth from the sight reduction tables. In this case, the azimuth angle (Z) is 137.4°. However, there is one last trick – in order to make the sight reduction tables smaller, the tables are only computed for certain figures. Not a huge problem, there is just a conversion factor on the top and bottom inside margins of the tables, which allow you to convert the tabular azimuth angle (Z) into your actual computed azimuth (bearing). It's not something that needs to be memorized - just glance at the tables each time you do these problems.

Reading the conversion table, you note that if the LHA is less than 180° (which it is in our case), we must convert azimuth angle (Z) to Zn as: Zn = 360° - Z. So our actual azimuth (bearing) to the sun is 222.6°. The last step is to compare this calculated figure to an observed bearing to the sun (obtained by using an **azimuth circle**)

However, the values for latitude, declination, and LHA are seldom whole numbers. Therefore, you must **interpolate** for actual values three times, and use the interpolated figures to determine the actual azimuth. The best way to do this is to set up a table to organize your work, like this one.

Base Argument	Argument Increment (I)	Base Azimuth	Next Azimuth	Azimuth Difference (D)	Correction (I x D)/60
Lat					
Dec					
LHA					
Total					

The ultimate goal of the table is to determine the actual computed azimuth for your unique situation. The interpolation is best organized in a table, and helps keep track of all the moving parts of the math. The table columns should be:

Base Argument – this is the whole number of degrees, declination, and LHA that you have computed. For example if your latitude is 41° 30'N, the Base Argument would be 41°N.

Argument Increment (I) – this is the remainder of degrees, declination and LHA arguments left over after removing the base argument. For example if your latitude is 41° 30'N, the Argument Increment (I) would be 30'.

Base Azimuth – this is the value retrieved from the sight reduction tables (HO229) for the base arguments. For example if your latitude is 41° 30'N, you would look in HO229 for a latitude of 41°, and record the azimuth angle (Z) value here.

Next Azimuth – this is the value retrieved from the sight reduction tables (HO229) for the *next whole base argument*. For example, if your latitude is 41° 30'N, you would look in HO229 for a latitude of 42°, and record the azimuth angle (Z) value here.

Azimuth Difference (D) – the difference between the Base Azimuth and the Next Azimuth.

Correction (IxD)/60 – this is a math calculation, and is the Argument Increment times Azimuth Difference, all divided by 60. This enables you to calculate the incremental values for latitude, declination, and LHA fairly easily, without having to mentally interpolate each value.

As you can see, the way the table works is to determine bracketing values for each category, and then it provides a math solution to determine the actual azimuth.

Once the correction has been determined for latitude, declination, and LHA, the total correction is applied to the base azimuth, and you have obtained the exact azimuth for your exact values of latitude, declination, and LHA. This can be compared to the observed azimuth to a body to determine gyro compass error.

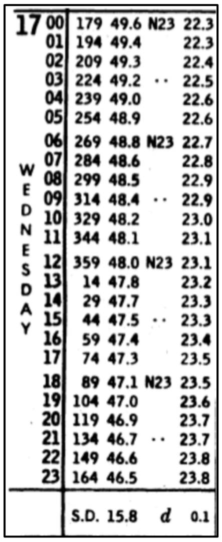
For example, if your latitude was 30° 15’N, the declination of the sun was 10° 30’N, and the computed LHA was 315° 45’, the table would look like this, worked left to right

Base Argument	Argument Increment (I)	Base Azimuth	Next Azimuth	Azimuth Difference (D)	Correction (I x D)/60
Lat 30°	15’	105.9°	106.8°	+0.9°	+0.225°
Dec 10°	30’	105.9°	104.7°	-1.2°	-0.6°
LHA 315°	45’	105.9°	106.6°	+0.7°	+0.525°
Total		105.9°			+0.15°

Once the total correction is obtained (+0.15°), this is applied to the base azimuth to determine the true azimuth and rounded to the nearest tenth of a degree (105.9° + 0.15° = 106.1°). This is then compared with the observed value to determine gyro error.

Problem 10-1. The following question illustrates how to solve azimuth problems involving the Sun.

You are aboard CGC JOSHUA JAMES, and are conducting operations with the US Navy. On 17 June, your 08:13:48 GMT GPS position is latitude 25° 27.0’ N, longitude 47° 16.0’ W. At that time, you observe the Sun bearing 079.9° per gyro compass. What is the gyro compass error?

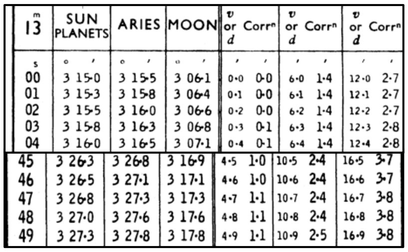


17	00	179 49.6	N23 22.3
	01	194 49.4	22.3
	02	209 49.3	22.4
	03	224 49.2	·· 22.5
	04	239 49.0	22.6
	05	254 48.9	22.6
	06	269 48.8	N23 22.7
W E D N E S D A Y	07	284 48.6	22.8
	08	299 48.5	22.9
	09	314 48.4	·· 22.9
	10	329 48.2	23.0
	11	344 48.1	23.1
	12	359 48.0	N23 23.1
	13	14 47.8	23.2
	14	29 47.7	23.3
	15	44 47.5	·· 23.3
	16	59 47.4	23.4
	17	74 47.3	23.5
	18	89 47.1	N23 23.5
	19	104 47.0	23.6
	20	119 46.9	23.7
	21	134 46.7	·· 23.7
	22	149 46.6	23.8
	23	164 46.5	23.8
		S.D. 15.8	*d* 0.1

Answer: 1.0° W

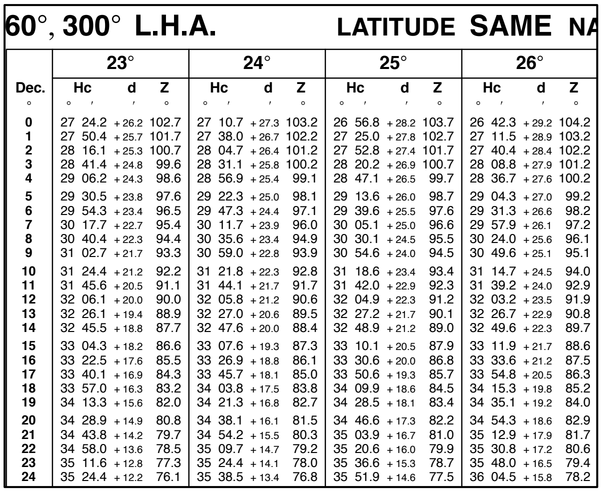
Step 1: Determine the declination of the Sun (to review exact declination calculations, refer to appendix 2).
Declination (hours): N 23° 23.1’ (d number 0.1’)
Declination (increment): 0
Declination (total): N 23° 23.1’

Step 2: Determine the GHA of the Sun (to review exact GHA calculations, refer to appendix 2).
GHA (hours): 344° 48.1’
GHA (increment): 3° 27.0’
GHA (total): 348° 15.1’



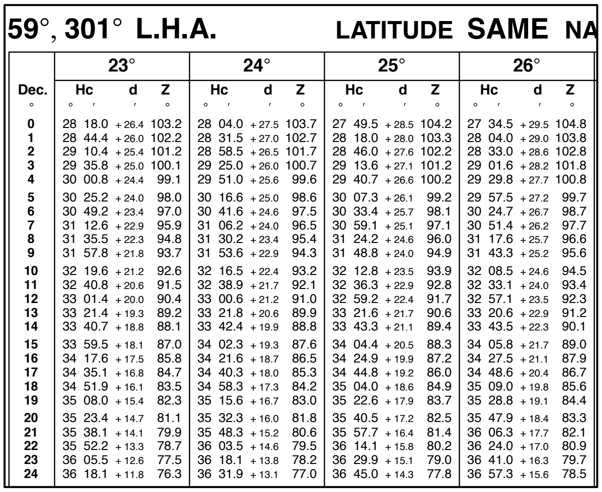
13ᵐ	SUN PLANETS	ARIES	MOON	*v* or *d*	Corrⁿ	*v* or *d*	Corrⁿ	*v* or *d*	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	3 15·0	3 15·5	3 06·1	0·0	0·0	6·0	1·4	12·0	2·7
01	3 15·3	3 15·8	3 06·4	0·1	0·0	6·1	1·4	12·1	2·7
02	3 15·5	3 16·0	3 06·6	0·2	0·0	6·2	1·4	12·2	2·7
03	3 15·8	3 16·3	3 06·8	0·3	0·1	6·3	1·4	12·3	2·8
04	3 16·0	3 16·5	3 07·1	0·4	0·1	6·4	1·4	12·4	2·8
45	3 26·3	3 26·8	3 16·9	4·5	1·0	10·5	2·4	16·5	3·7
46	3 26·5	3 27·1	3 17·1	4·6	1·0	10·6	2·4	16·6	3·7
47	3 26·8	3 27·3	3 17·3	4·7	1·1	10·7	2·4	16·7	3·8
48	3 27·0	3 27·6	3 17·6	4·8	1·1	10·8	2·4	16·8	3·8
49	3 27·3	3 27·8	3 17·8	4·9	1·1	10·9	2·5	16·9	3·8

Step 3: Determine the LHA of the Sun.
GHA (Sun): 348° 15.1’
DR Longitude: 47° 16.0’ W (subtract west, add east)
LHA (Sun): 348° 15.1’ – 47° 16.0’ W = 300° 59.1’



60°, 300° L.H.A. LATITUDE SAME NA

Dec.	23°			24°			25°			26°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
0	27 24.2	+26.2	102.7	27 10.7	+27.3	103.2	26 56.8	+28.2	103.7	26 42.3	+29.2	104.2
1	27 50.4	+25.7	101.7	27 38.0	+26.7	102.2	27 25.0	+27.8	102.7	27 11.5	+28.9	103.2
2	28 16.1	+25.3	100.7	28 04.7	+26.4	101.2	27 52.8	+27.4	101.7	27 40.4	+28.4	102.2
3	28 41.4	+24.8	99.6	28 31.1	+25.8	100.2	28 20.2	+26.9	100.7	28 08.8	+27.9	101.2
4	29 06.2	+24.3	98.6	28 56.9	+25.4	99.1	28 47.1	+26.5	99.7	28 36.7	+27.6	100.2
5	29 30.5	+23.8	97.6	29 22.3	+25.0	98.1	29 13.6	+26.0	98.7	29 04.3	+27.0	99.2
6	29 54.3	+23.4	96.5	29 47.3	+24.4	97.1	29 39.6	+25.5	97.6	29 31.3	+26.6	98.2
7	30 17.7	+22.7	95.4	30 11.7	+23.9	96.0	30 05.1	+25.0	96.6	29 57.9	+26.1	97.2
8	30 40.4	+22.3	94.4	30 35.6	+23.4	94.9	30 30.1	+24.5	95.5	30 24.0	+25.6	96.1
9	31 02.7	+21.7	93.3	30 59.0	+22.8	93.9	30 54.6	+24.0	94.5	30 49.6	+25.1	95.1
10	31 24.4	+21.2	92.2	31 21.8	+22.3	92.8	31 18.6	+23.4	93.4	31 14.7	+24.5	94.0
11	31 45.6	+20.5	91.1	31 44.1	+21.7	91.7	31 42.0	+22.9	92.3	31 39.2	+24.0	92.9
12	32 06.1	+20.0	90.0	32 05.8	+21.2	90.6	32 04.9	+22.3	91.2	32 03.2	+23.5	91.9
13	32 26.1	+19.4	88.9	32 27.0	+20.6	89.5	32 27.2	+21.7	90.1	32 26.7	+22.9	90.8
14	32 45.5	+18.8	87.7	32 47.6	+20.0	88.4	32 48.9	+21.2	89.0	32 49.6	+22.3	89.7
15	33 04.3	+18.2	86.6	33 07.6	+19.3	87.3	33 10.1	+20.5	87.9	33 11.9	+21.7	88.6
16	33 22.5	+17.6	85.5	33 26.9	+18.8	86.1	33 30.6	+20.0	86.8	33 33.6	+21.2	87.5
17	33 40.1	+16.9	84.3	33 45.7	+18.1	85.0	33 50.6	+19.3	85.7	33 54.8	+20.5	86.3
18	33 57.0	+16.3	83.2	34 03.8	+17.5	83.8	34 09.9	+18.6	84.5	34 15.3	+19.8	85.2
19	34 13.3	+15.6	82.0	34 21.3	+16.8	82.7	34 28.5	+18.1	83.4	34 35.1	+19.2	84.0
20	34 28.9	+14.9	80.8	34 38.1	+16.1	81.5	34 46.6	+17.3	82.2	34 54.3	+18.6	82.9
21	34 43.8	+14.2	79.7	34 54.2	+15.5	80.3	35 03.9	+16.7	81.0	35 12.9	+17.9	81.7
22	34 58.0	+13.6	78.5	35 09.7	+14.7	79.2	35 20.6	+16.0	79.9	35 30.8	+17.2	80.6
23	35 11.6	+12.8	77.3	35 24.4	+14.1	78.0	35 36.6	+15.3	78.7	35 48.0	+16.5	79.4
24	35 24.4	+12.2	76.1	35 38.5	+13.4	76.8	35 51.9	+14.6	77.5	36 04.5	+15.8	78.2



59°, 301° L.H.A. LATITUDE SAME NA

Dec.	23°			24°			25°			26°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
0	28 18.0	+26.4	103.2	28 04.0	+27.5	103.7	27 49.5	+28.5	104.2	27 34.5	+29.5	104.8
1	28 44.4	+26.0	102.2	28 31.5	+27.0	102.7	28 18.0	+28.0	103.3	28 04.0	+29.0	103.8
2	29 10.4	+25.4	101.2	28 58.5	+26.5	101.7	28 46.0	+27.6	102.2	28 33.0	+28.6	102.8
3	29 35.8	+25.0	100.1	29 25.0	+26.0	100.7	29 13.6	+27.1	101.2	29 01.6	+28.2	101.8
4	30 00.8	+24.4	99.1	29 51.0	+25.6	99.6	29 40.7	+26.6	100.2	29 29.8	+27.7	100.8
5	30 25.2	+24.0	98.0	30 16.6	+25.0	98.6	30 07.3	+26.1	99.2	29 57.5	+27.2	99.7
6	30 49.2	+23.4	97.0	30 41.6	+24.6	97.5	30 33.4	+25.7	98.1	30 24.7	+26.7	98.7
7	31 12.6	+22.9	95.9	31 06.2	+24.0	96.5	30 59.1	+25.1	97.1	30 51.4	+26.2	97.7
8	31 35.5	+22.3	94.8	31 30.2	+23.4	95.4	31 24.2	+24.6	96.0	31 17.6	+25.7	96.6
9	31 57.8	+21.8	93.7	31 53.6	+22.9	94.3	31 48.8	+24.0	94.9	31 43.3	+25.2	95.6
10	32 19.6	+21.2	92.6	32 16.5	+22.4	93.2	32 12.8	+23.5	93.9	32 08.5	+24.6	94.5
11	32 40.8	+20.6	91.5	32 38.9	+21.7	92.1	32 36.3	+22.9	92.8	32 33.1	+24.0	93.4
12	33 01.4	+20.0	90.4	33 00.6	+21.2	91.0	32 59.2	+22.4	91.7	32 57.1	+23.5	92.3
13	33 21.4	+19.3	89.2	33 21.8	+20.6	89.9	33 21.6	+21.7	90.6	33 20.6	+22.9	91.2
14	33 40.7	+18.8	88.1	33 42.4	+19.9	88.8	33 43.3	+21.1	89.4	33 43.5	+22.3	90.1
15	33 59.5	+18.1	87.0	34 02.3	+19.3	87.6	34 04.4	+20.5	88.3	34 05.8	+21.7	89.0
16	34 17.6	+17.5	85.8	34 21.6	+18.7	86.5	34 24.9	+19.9	87.2	34 27.5	+21.1	87.9
17	34 35.1	+16.8	84.7	34 40.3	+18.0	85.3	34 44.8	+19.2	86.0	34 48.6	+20.4	86.7
18	34 51.9	+16.1	83.5	34 58.3	+17.3	84.2	35 04.0	+18.6	84.9	35 09.0	+19.8	85.6
19	35 08.0	+15.4	82.3	35 15.6	+16.7	83.0	35 22.6	+17.9	83.7	35 28.8	+19.1	84.4
20	35 23.4	+14.7	81.1	35 32.3	+16.0	81.8	35 40.5	+17.2	82.5	35 47.9	+18.4	83.3
21	35 38.1	+14.1	79.9	35 48.3	+15.2	80.6	35 57.7	+16.4	81.4	36 06.3	+17.7	82.1
22	35 52.2	+13.3	78.7	36 03.5	+14.6	79.5	36 14.1	+15.8	80.2	36 24.0	+17.0	80.9
23	36 05.5	+12.6	77.5	36 18.1	+13.8	78.2	36 29.9	+15.1	79.0	36 41.0	+16.3	79.7
24	36 18.1	+11.8	76.3	36 31.9	+13.1	77.0	36 45.0	+14.3	77.8	36 57.3	+15.6	78.5

Step 4: Enter HO229 with whole values of latitude, declination (on the "same" pages in this case) and LHA.

Step 5: Utilize an azimuth interpolation table. By increasing the value of each argument by 1 whole increment, triple interpolate for the exact values of each for the desired time/location. Illustrated here is the sequential completion of the table:

	Base Value	Base Z	Next incremental Z	Difference in Z	**Increment**	Correction *(Diff Z x Increment) / 60*
Latitude – N	**25°**				**27.0’**	
Declination - N	**23°**				**23.1’**	
LHA	**300°**				**59.1’**	

	Base Value	**Base Z**	Next incremental Z	Difference in Z	Increment	Correction *(Diff Z x Increment) / 60*
Latitude	25°	**78.7°**			27.0’	
Declination	23°	**78.7°**			23.1’	
LHA	300°	**78.7°**			59.1’	

	Base Value	Base Z	**Next incremental Z**	**Difference in Z**	Increment	Correction *(Diff Z x Increment) / 60*
Latitude	25°	78.7°	**79.4°**	**0.7°**	27.0’	
Declination	23°	78.7°	**77.5°**	**-1.2°**	23.1’	
LHA	300°	78.7°	**79.0°**	**0.3°**	59.1’	

	Base Value	Base Z	Next incremental Z	Difference in Z	Increment	**Correction** ***(Diff Z x Increment) / 60***
Latitude	25°	78.7°	79.4°	0.7°	27.0’	**+0.32°**
Declination	23°	78.7°	77.5°	-1.2°	23.1’	**-0.46°**
LHA	300°	78.7°	79.0°	0.3°	59.1’	**+0.30°**

Total correction = 0.32° - 0.46° + 0.30° = +0.2°

Step 6: Apply the correction to the base values to determine true azimuth.
Base azimuth: 078.7°
Correction: +0.2°
Corrected azimuth: 078.7° + 0.2° = 078.9°
Note - Check azimuth rules: if LHA greater than 180°, then zn = z (no correction is required in this case).

Step 7: Answer the required questions.

Observed azimuth to the sun (per gyro compass): 079.9° True
Calculated azimuth to the sun: 078.9°

Utilize the acronym "Gyro Best, Error West. Gyro Least, Error East" to determine the gyro error.

Gyro is larger (best) in this case, so the error is **1.0° W.**

In summary, the steps to calculate Gyro Error by Azimuth manually are:

Step 1: Determine the declination of the sun using the Nautical Almanac (interpolate if necessary).

Step 2: Determine the GHA of the Sun for the time of sight.

Step 2: Determine the LHA of the Sun for the time of sight.

Step 3: Enter the Sight Reduction Tables (HO229) with Latitude, Declination, and LHA.

Step 4: After correcting the azimuth figure if necessary (using the conversion table at the top and bottom of each page), utilize a triple interpolation table method to determine the final azimuth.

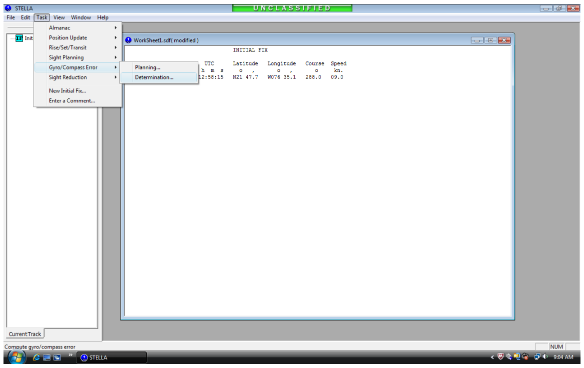
Step 5: Compare the calculated azimuth to the observed azimuth to determine gyro compass error utilizing the acronym:

G-E-T or "Gyro Best, Error West. Gyro Least, Error East"

STELLA Calculations

To determine the gyro compass error for any body using the STELLA program, first establish a DR position (Initial Fix). Then follow:

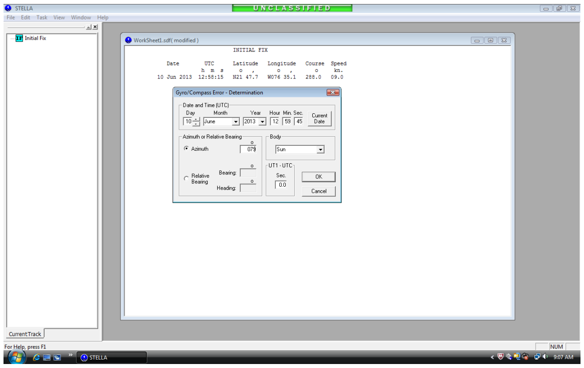
Step 1: Task>Gyro/Compass Error>Determination



```
                    INITIAL FIX

          UTC      Latitude   Longitude   Course  Speed
         h  m  s     o  ,        o  ,        o     kn.
        12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

Step 2: Populate all fields as necessary.



```
                         INITIAL FIX

   Date         UTC      Latitude   Longitude   Course  Speed
              h  m  s     o  ,        o  ,        o     kn.
10 Jun 2013  12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

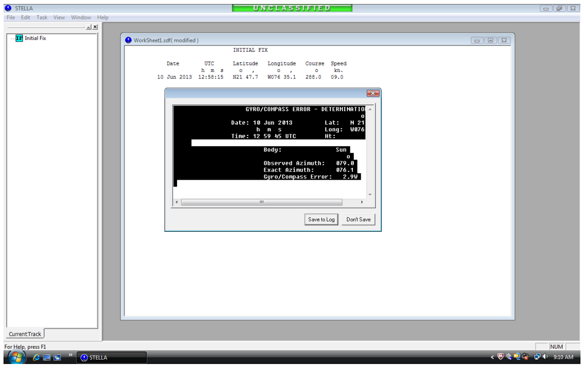
Date and Time (UTC): Day 10, Month June, Year 2013, Hour 12, Min. 59, Sec. 45

Azimuth or Relative Bearing: ● Azimuth 079°; ○ Relative Bearing, Bearing: °, Heading: °

Body: Sun

UT1 - UTC Sec.: 0.0

Step 3: Retrieve the gyro compass error from STELLA and note it in the ship's navigational worksheet or log.



```
                         INITIAL FIX

   Date         UTC      Latitude   Longitude   Course  Speed
              h  m  s     o  ,        o  ,        o     kn.
10 Jun 2013  12:58:15   N21 47.7   W076 35.1   288.0   09.0
```

```
                 GYRO/COMPASS ERROR - DETERMINATIO
                                                  o
            Date: 10 Jun 2013        Lat:   N 21
                   h  m  s           Long:  W076
            Time: 12 59 45 UTC       Ht:

                     Body:                Sun
                                            o
                     Observed Azimuth:   079.0
                     Exact Azimuth:      076.1
                     Gyro/Compass Error:   2.9W
```

Advanced Theory

Azimuth calculations are often the most complicated manual calculations the navigator must complete. However, much of the intimidation factor comes from the triple interpolation factor. With practice, this will seem like second nature.

It is possible to directly calculate the azimuth angle to the sun at any time, without using the Sight Reduction Tables (HO229). An intermediate calculation is required to determine Hc (the bodies calculated altitude). The formulae are:

$\sin Hc = \sin(L)\sin(d) + \cos(L)\cos(d)\cos(LHA)$ Equation (1)

$\cos A = (\sin(d) - \sin(L)\sin(Hc)) / \cos(L)\cos(Hc)$ Equation (2)

Where the variables (all in decimal notation) are:
Hc is computed height
L is latitude
d is declination
LHA is LHA

To solve for the azimuth angle, take $\cos^{-1}$ of the right side of equation 2.

Azimuths can be calculated for any body in the sky; the process is the same.

Part 5: Advanced Celestial Problems

In which we solve celestial sight reduction problems, by solving for lines of position of the sun or other celestial bodies, and using them to determine our position, enabling completion of two tasks in the Coast Guard Navigation Standards.

Chapter 11: Obtain a Line of Position from the Sun

The Basic Idea

At sea, you can use the height of the sun above the horizon to calculate a line of position, much as you would use a lighthouse or other navigation aid. By measuring how high the sun is above the horizon, then comparing the measurement to a calculated height, you can obtain a line of position from the sun.

Manual Calculations

The sun is the most frequently sighted object for daily navigation. Typically, the lower limb of the sun is brought to the horizon to take an altitude measurement, however the upper limb can be used, just with different corrections.

After measuring the **altitude** of the sun and making the three **standard sextant corrections**, you must determine the exact **declination** and **Greenwich Hour Angle** of the sun. These values can be obtained from the Nautical Almanac, and must be **interpolated** for the exact time of measurement, using mental interpolation or the conversion of arc to time pages in the Nautical Almanac.

Once the declination and GHA have been determined, an assumed latitude and longitude must be chosen. The assumed latitude is the nearest whole degree of latitude to your DR position. The assumed longitude is a nearby longitude which, when added (in the eastern hemisphere), or subtracted (in the western hemisphere) to the GHA, results in a whole number of **local hour angle (LHA).** This is important because it enables you to utilize HO229 without needing to interpolate. For example, if the GHA of the sun was 135° 30', and your DR longitude was 30° 15' W, you would assume a longitude of 30° 30' W, and then subtract this from the GHA to obtain an LHA of 105° (a whole number).

After determining whole numbers of latitude, declination, and LHA, you retrieve a **computed height** (Hc) and **azimuth** (Z) from the appropriate pages of HO229. After a few corrections, this computed height is compared to the observed height and an altitude difference is determined.

If the observed height is higher than the computed height, then the ship is closer to the celestial object than the assumed position. In this case, you would plot the assumed position, draw a line in the direction of the azimuth (Z), and measure off the difference between the computed and observed heights. A perpendicular line at this point is equal to a line of position.

If the observed height is lower than the computed height, then the ship is further away from the celestial object than the assumed position. In this case, you would plot the assumed position, draw a line in the opposite direction of the azimuth (Z), and measure off the difference between the computed and observed heights. A perpendicular line at this point is equal to a line of position. A memory aid is “C-G-A” – or “computed greater away.”

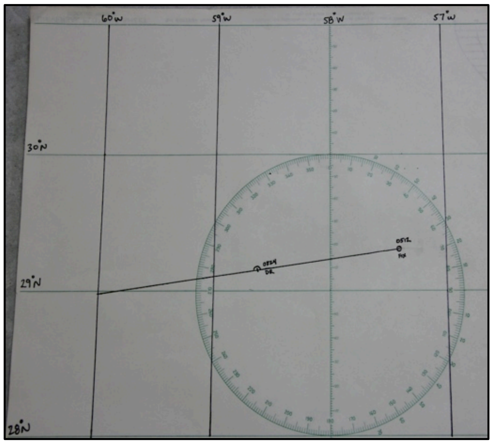
Problem 11-1. The following question illustrates how to solve celestial sight reduction problems involving the Sun.

You are aboard CGC HARRIET LANE, returning from a high seas SAR case southeast of Bermuda. On 15 August, your 0512 zone time position was latitude 29° 18’ N, longitude 57° 24’ W. Your vessel was steaming on course 262° T at 20 knots. An observation of the Sun’s lower limb was made at 0824 zone time. The chronometer read 00h 22m 24s and was slow 01m 34s. The observed altitude (ho) was 38° 16.7’. LAN occurred at 1204 zone time and the observed altitude (ho) was 74° 58.0’. What was the longitude of your 1204 zone time running fix?

Answer: 59° 59’ W

Step 1: Determine the GMT of the morning Sun sight.
Chronometer time: 00h 22m 24s
Chronometer error: 01m 34s slow
Correct chronometer time: 00h 22m 24s + 01m 34s = 00h 23m 58s
Ship time of sight: 0824 ZT
DR longitude: 57° 24’ W corresponds to (+4 ZD)
GMT of sight: <u>12:23:58 GMT, 15 August</u>

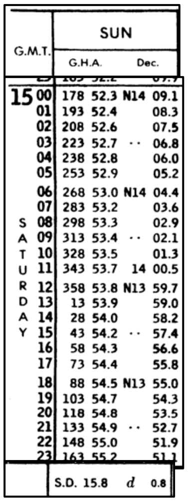
Step 2: Advance the original fix location to the morning Sun sight. Note this solution uses a plotting sheet, but the position may also be advanced by mid-latitude sailing (see Part 5 or Part 9).
Original fix time: 0512 ZT or 0912 GMT
Original fix position: 29° 18’ N, 57° 24’ W.
Morning observation time: 0824 ZT or 1224 GMT
Course and speed: 262° T at 20 knots
Time underway: 0824 ZT – 0512 ZT = 3 hours, 12 minutes, or 3.2 hours
Distance travelled: 3.2 hours for 20 knots = 64.0 miles covered
Morning DR position (original fix advanced 64 miles in direction 262°):
<u>29° 09’ N, 58° 37’ W</u>



Step 3: Determine the observed altitude of the morning Sun sight.
ho: 38° 16.7’ (Given)

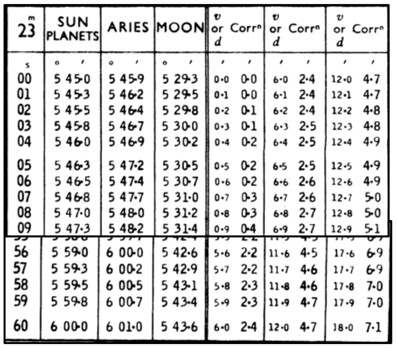
Step 4: Determine the declination of the Sun for the morning Sun sight.
Declination (hours): N 13° 59.7’ (d number 0.8)
Declination (increments): + 0.3’
Declination (total): N 14° 00.0’

Step 5: Determine the GHA of the Sun for the morning Sun sight.
GHA (hours): 358° 53.8’
GHA (increments): 5° 59.5’
GHA (total): 364° 53.3’ (-360°) = 4° 53.3’



	G.M.T.	SUN G.H.A.	SUN Dec.
15	00	178 52.3	N14 09.1
	01	193 52.4	08.3
	02	208 52.6	07.5
	03	223 52.7	·· 06.8
	04	238 52.8	06.0
	05	253 52.9	05.2
	06	268 53.0	N14 04.4
	07	283 53.2	03.6
S	08	298 53.3	02.9
A	09	313 53.4	·· 02.1
T	10	328 53.5	01.3
U	11	343 53.7	14 00.5
R	12	358 53.8	N13 59.7
D	13	13 53.9	59.0
A	14	28 54.0	58.2
Y	15	43 54.2	·· 57.4
	16	58 54.3	56.6
	17	73 54.4	55.8
	18	88 54.5	N13 55.0
	19	103 54.7	54.3
	20	118 54.8	53.5
	21	133 54.9	·· 52.7
	22	148 55.0	51.9
	23	163 55.2	51.1
		S.D. 15.8	*d* 0.8

Step 6: Determine the assumed position of the ship.
DR latitude: 29° 09’ N
Assumed latitude: 29° N
DR longitude: 58° 37’ W
Assumed longitude (to ensure whole number of LHA): 58° 53.3’ W

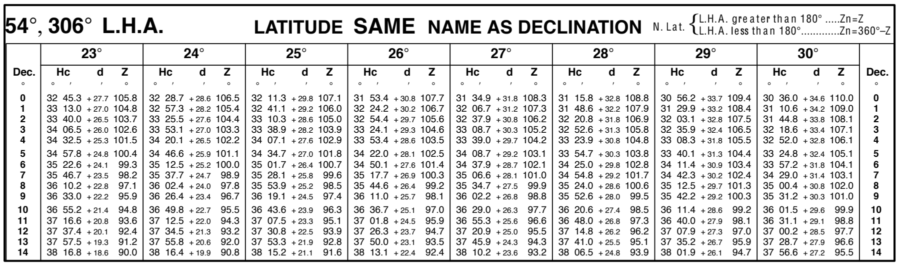


23m	SUN PLANETS	ARIES	MOON	*v* or *d*	Corrⁿ	*v* or *d*	Corrⁿ	*v* or *d*	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 45·0	5 45·9	5 29·3	0·0	0·0	6·0	2·4	12·0	4·7
01	5 45·3	5 46·2	5 29·5	0·1	0·0	6·1	2·4	12·1	4·7
02	5 45·5	5 46·4	5 29·8	0·2	0·1	6·2	2·4	12·2	4·8
03	5 45·8	5 46·7	5 30·0	0·3	0·1	6·3	2·5	12·3	4·8
04	5 46·0	5 46·9	5 30·2	0·4	0·2	6·4	2·5	12·4	4·9
05	5 46·3	5 47·2	5 30·5	0·5	0·2	6·5	2·5	12·5	4·9
06	5 46·5	5 47·4	5 30·7	0·6	0·2	6·6	2·6	12·6	4·9
07	5 46·8	5 47·7	5 31·0	0·7	0·3	6·7	2·6	12·7	5·0
08	5 47·0	5 48·0	5 31·2	0·8	0·3	6·8	2·7	12·8	5·0
09	5 47·3	5 48·2	5 31·4	0·9	0·4	6·9	2·7	12·9	5·1
56	5 59·0	6 00·0	5 42·6	5·6	2·2	11·6	4·5	17·6	6·9
57	5 59·3	6 00·2	5 42·9	5·7	2·2	11·7	4·6	17·7	6·9
58	5 59·5	6 00·5	5 43·1	5·8	2·3	11·8	4·6	17·8	7·0
59	5 59·8	6 00·7	5 43·4	5·9	2·3	11·9	4·7	17·9	7·0
60	6 00·0	6 01·0	5 43·6	6·0	2·4	12·0	4·7	18·0	7·1

Step 7: Determine the LHA of the Sun for the morning Sun sight.
GHA (Sun): 4° 53.3’ W
Assumed longitude: 58° 53.3’ W
LHA 4° 53.3’ (+360°) – 58° 53.3’ W = 306° (subtract west, add east)

Step 8: Entering publication HO229 with assumed latitude, declination, and LHA, retrieve the computed altitude (hc), altitude difference (d), and azimuth (z) for the assumed position.
Assumed latitude: 29° N
Declination: N 14° (no increments in this problem)
LHA: 306° (Same Pages)

HO 229 values:
Computed altitude (hc): 38° 01.9’
Altitude difference (d): +26.1’
Azimuth (z): 94.7° T



54°, 306° L.H.A. LATITUDE SAME NAME AS DECLINATION N. Lat. {L.H.A. greater than 180° .....Zn=Z; L.H.A. less than 180°............Zn=360°–Z}

	23°			24°			25°			26°			27°			28°			29°			30°			
Dec.	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	32 45.3	+27.7	105.8	32 28.7	+28.6	106.5	32 11.3	+29.8	107.1	31 53.4	+30.8	107.7	31 34.9	+31.8	108.3	31 15.8	+32.8	108.8	30 56.2	+33.7	109.4	30 36.0	+34.6	110.0	0
1	33 13.0	+27.0	104.8	32 57.3	+28.2	105.4	32 41.1	+29.2	106.0	32 24.2	+30.2	106.7	32 06.7	+31.2	107.3	31 48.6	+32.2	107.9	31 29.9	+33.2	108.4	31 10.6	+34.2	109.0	1
2	33 40.0	+26.5	103.7	33 25.5	+27.6	104.4	33 10.3	+28.6	105.0	32 54.4	+29.7	105.6	32 37.9	+30.8	106.2	32 20.8	+31.8	106.9	32 03.1	+32.8	107.5	31 44.8	+33.8	108.1	2
3	34 06.5	+26.0	102.6	33 53.1	+27.0	103.3	33 38.9	+28.2	103.9	33 24.1	+29.3	104.6	33 08.7	+30.3	105.2	32 52.6	+31.3	105.8	32 35.9	+32.4	106.5	32 18.6	+33.4	107.1	3
4	34 32.5	+25.3	101.5	34 20.1	+26.5	102.2	34 07.1	+27.6	102.9	33 53.4	+28.6	103.5	33 39.0	+29.7	104.2	33 23.9	+30.8	104.8	33 08.3	+31.8	105.5	32 52.0	+32.8	106.1	4
5	34 57.8	+24.8	100.4	34 46.6	+25.9	101.1	34 34.7	+27.0	101.8	34 22.0	+28.1	102.5	34 08.7	+29.2	103.1	33 54.7	+30.3	103.8	33 40.1	+31.3	104.4	33 24.8	+32.4	105.1	5
6	35 22.6	+24.1	99.3	35 12.5	+25.2	100.0	35 01.7	+26.4	100.7	34 50.1	+27.6	101.4	34 37.9	+28.7	102.1	34 25.0	+29.8	102.8	34 11.4	+30.9	103.4	33 57.2	+31.8	104.1	6
7	35 46.7	+23.5	98.2	35 37.7	+24.7	98.9	35 28.1	+25.8	99.6	35 17.7	+26.9	100.3	35 06.6	+28.1	101.0	34 54.8	+29.2	101.7	34 42.3	+30.2	102.4	34 29.0	+31.4	103.1	7
8	36 10.2	+22.8	97.1	36 02.4	+24.0	97.8	35 53.9	+25.2	98.5	35 44.6	+26.4	99.2	35 34.7	+27.5	99.9	35 24.0	+28.6	100.6	35 12.5	+29.7	101.3	35 00.4	+30.8	102.0	8
9	36 33.0	+22.2	95.9	36 26.4	+23.4	96.7	36 19.1	+24.5	97.4	36 11.0	+25.7	98.1	36 02.2	+26.8	98.8	35 52.6	+28.0	99.5	35 42.2	+29.2	100.3	35 31.2	+30.3	101.0	9
10	36 55.2	+21.4	94.8	36 49.8	+22.7	95.5	36 43.6	+23.9	96.3	36 36.7	+25.1	97.0	36 29.0	+26.3	97.7	36 20.6	+27.4	98.5	36 11.4	+28.6	99.2	36 01.5	+29.6	99.9	10
11	37 16.6	+20.8	93.6	37 12.5	+22.0	94.3	37 07.5	+23.3	95.1	37 01.8	+24.5	95.9	36 55.3	+25.6	96.6	36 48.0	+26.8	97.3	36 40.0	+27.9	98.1	36 31.1	+29.1	98.8	11
12	37 37.4	+20.1	92.4	37 34.5	+21.3	93.2	37 30.8	+22.5	93.9	37 26.3	+23.7	94.7	37 20.9	+25.0	95.5	37 14.8	+26.2	96.2	37 07.9	+27.3	97.0	37 00.2	+28.5	97.7	12
13	37 57.5	+19.3	91.2	37 55.8	+20.6	92.0	37 53.3	+21.9	92.8	37 50.0	+23.1	93.5	37 45.9	+24.3	94.3	37 41.0	+25.5	95.1	37 35.2	+26.7	95.9	37 28.7	+27.9	96.6	13
14	38 16.8	+18.6	90.0	38 16.4	+19.9	90.8	38 15.2	+21.1	91.6	38 13.1	+22.4	92.4	38 10.2	+23.6	93.2	38 06.5	+24.8	93.9	38 01.9	+26.1	94.7	37 56.6	+27.2	95.5	14

Step 9: Determine the azimuth correction for the sight. In this problem there are no corrections required, but the step is shown for training purposes.

By increasing the value of each argument by 1 whole increment, triple interpolate for the exact values of azimuth (for detailed instructions see Part 14).

	Base Value	Base Z	Next incremental Z	Difference in Z	Increment	Correction *(Diff Z x Increment) / 60*
Latitude – N	29°	94.7°	-	-	00.0’	0
Declination – N	14°	94.7°	-	-	00.0’	0
LHA	306°	94.7°	-	-	00.0’	0

Total correction = 0.0°

Step 10: Apply the correction to the base values to determine true azimuth.
Base azimuth: 94.7°
Correction: 0.0°
Corrected azimuth: 94.7°
Note - Check azimuth rules: if LHA greater than 180°, then zn = z.
Corrected azimuth: 94.7°

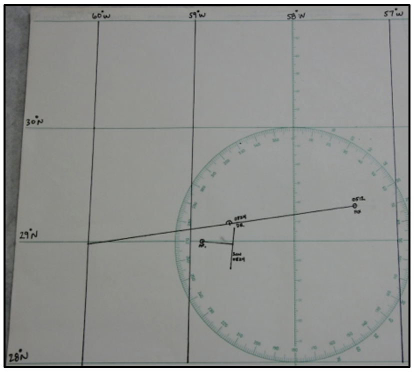
Step 11: Determine the computed altitude. In this problem the altitude difference correction is not necessary, but is shown for training purposes.
Tabular computed altitude (hc): 38° 01.9’
Altitude difference (d): +26.1’
Declination: N 14° 00.0’
Declination increments: 00.0’

Altitude difference correction:
Tens: 00.0’
Units/decimals: 0.0’
Total correction: 00.0’

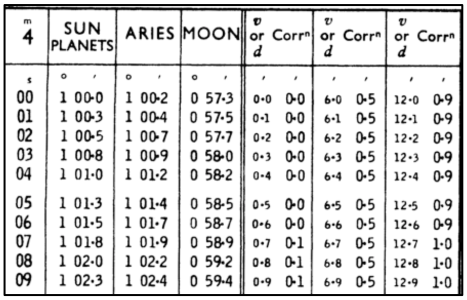
Tabular hc: 38° 01.9’
Alt correction: 00.0’
hc: 38° 01.9’

Step 12: Determine the intercept (a).
Observed altitude: 38° 16.7’
Computed altitude: 38° 01.9’
Intercept (a): 38° 16.7’ – 38° 01.9’ = 14.8’
If observed altitude is greater, intercept is towards.

Step 13: Plot the morning Sun sight.
Assumed position: 29° N, 58° 53.3’ W
Azimuth: 094.7’
Intercept: 14.8’ towards



Step 14: Calculated the latitude at meridian passage (see Part 11).
Time of meridian passage sight: 1204 zone time or 1604 GMT
Observed altitude: 74° 58.0’
Zenith Distance: 90° 00.0 – 74° 58.0’ = <u>15° 02.0’</u>
Declination (Sun – hours): 13° 56.6’ N (d number = 0.8)
Declination (Sun – increments): +0.1’
Declination (Sun – total): <u>13° 56.7’</u>
Latitude at meridian passage = zenith distance + declination =
15° 02.0’ N + 13° 56.7’ N = <u>28° 58.7’ N</u>

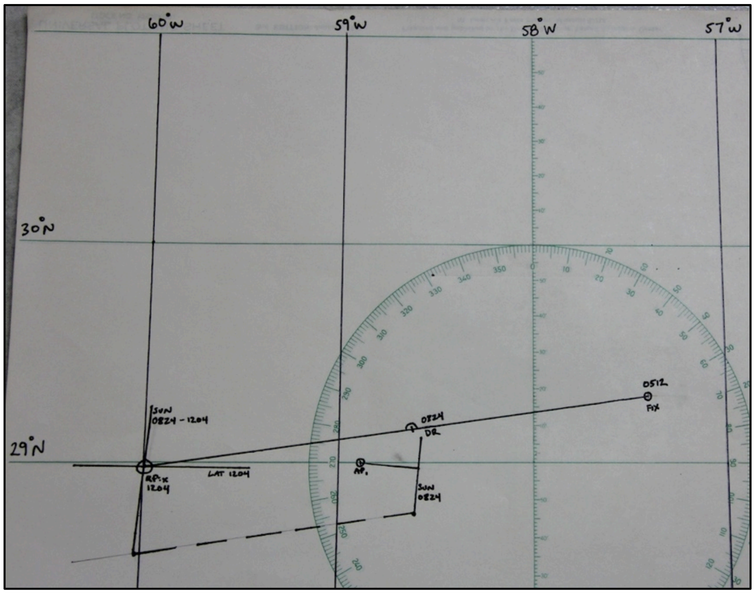


m 4	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	1 00·0	1 00·2	0 57·3	0·0	0·0	6·0	0·5	12·0	0·9
01	1 00·3	1 00·4	0 57·5	0·1	0·0	6·1	0·5	12·1	0·9
02	1 00·5	1 00·7	0 57·7	0·2	0·0	6·2	0·5	12·2	0·9
03	1 00·8	1 00·9	0 58·0	0·3	0·0	6·3	0·5	12·3	0·9
04	1 01·0	1 01·2	0 58·2	0·4	0·0	6·4	0·5	12·4	0·9
05	1 01·3	1 01·4	0 58·5	0·5	0·0	6·5	0·5	12·5	0·9
06	1 01·5	1 01·7	0 58·7	0·6	0·0	6·6	0·5	12·6	0·9
07	1 01·8	1 01·9	0 58·9	0·7	0·1	6·7	0·5	12·7	1·0
08	1 02·0	1 02·2	0 59·2	0·8	0·1	6·8	0·5	12·8	1·0
09	1 02·3	1 02·4	0 59·4	0·9	0·1	6·9	0·5	12·9	1·0

Step 15: Plot the meridian passage latitude.
Latitude: 28° 58.7’ N

Step 16: Advance the morning Sun sight (0824 zone time) to the meridian passage latitude to determine the running fix.
0824 zone time to 1204 zone time = 3 hours 40 minutes = 3.67 hours
3.67 hours at 20 knots = 73.34 miles covered (course 262° T)

Step 17: Answer the required question.
Longitude = **59° 59’ W**



In summary, the steps to determine an LOP from the Sun:

Step 1: Measure the altitude of the body using a sextant and make 3 standard sextant corrections.

Step 2: Determine the Geographic Position (GHA and Declination) of the body.

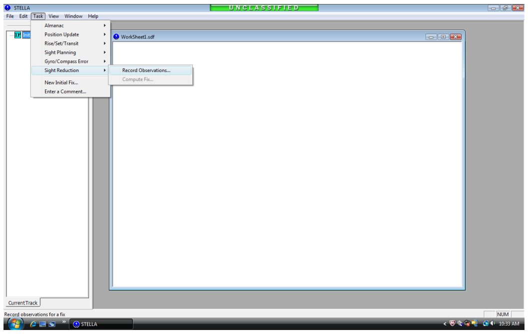
Step 3: Determine the entering arguments for HO229 by obtaining whole numbers of Latitude, Declination, and LHA (LHA is obtained by subtracting (western hemisphere) or adding (eastern hemisphere) the assumed longitude from the GHA of the sun.

Step 4: Retrieve the computed height and azimuth from HO229, and correct each for increments of declination.

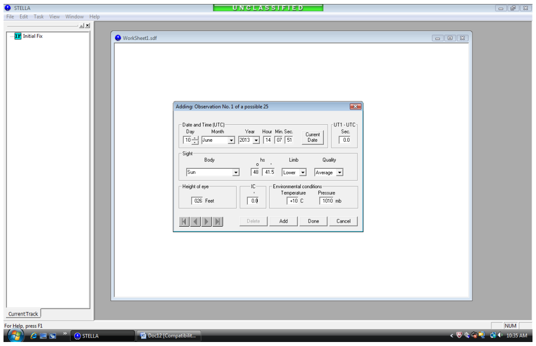
Step 5: Plot the line of position.

STELLA Calculations

Step 1: Task>Sight Reduction>Record Observations.



Step 2: Enter appropriate data.



Adding: Observation No. 1 of a possible 25

Date and Time (UTC): Day 10, Month June, Year 2013, Hour 14, Min. 07, Sec. 51

UT1 - UTC Sec. 0.0

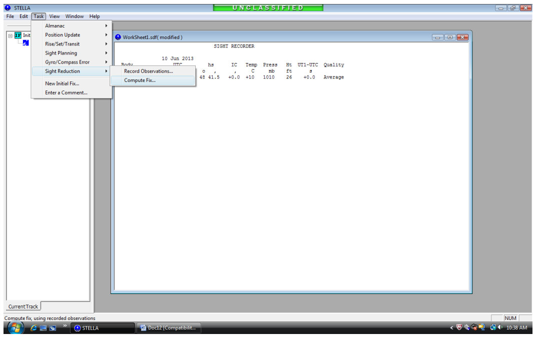
Sight: Body Sun, hs 48° 41.5', Limb Lower, Quality Average

Height of eye: 026 Feet

IC ': 0.0

Environmental conditions: Temperature +10 C, Pressure 1010 mb

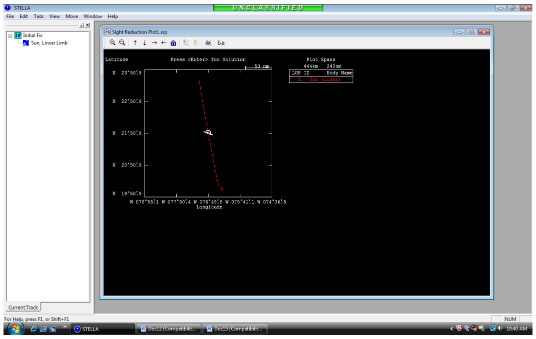
Step 3: Task>Sight Reduction> Compute Fix.



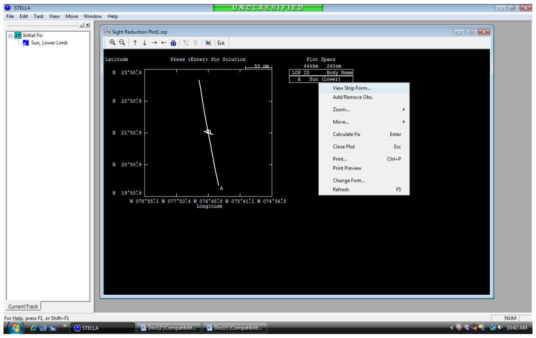
```
                    SIGHT RECORDER

           10 Jun 2013
Body             UTC        hs     IC   Temp  Press  Ht  UT1-UTC  Quality
                            o  ,    ,     C    mb    ft     s
                           48 41.5 +0.0  +10   1010  26    +0.0   Average
```

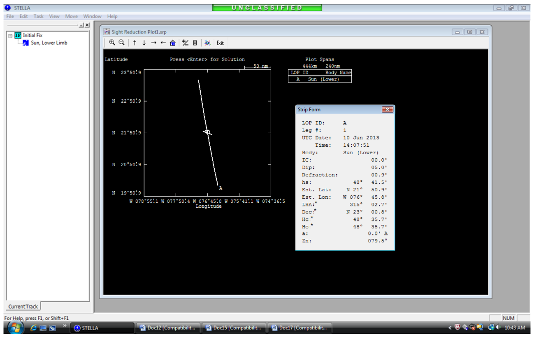
Step 4: Observe LOP and hit "Enter"



Step 5: Right click and "View Strip Form"



Step 6: Record observation data in ship's navigation log.



```
LOP ID:       A
Leg #:        1
UTC Date:     10 Jun 2013
    Time:     14:07:51
Body:         Sun (Lower)
IC:                      00.0'
Dip:                     05.0'
Refraction:              00.9'
hs:                48°   41.5'
Est. Lat:        N 21°   50.9'
Est. Lon:       W 076°   45.8'
LHA:*             315°   02.7'
Dec:*            N 23°   00.8'
Hc:*               48°   35.7'
Ho:*               48°   35.7'
a:                      0.0' A
Zn:                     079.5°
```

Advanced Theory

It is possible to directly calculate the computed height and azimuth angle to the sun at any time, without using the Sight Reduction Tables (HO229). The formulae are:

$$\sin Hc = \sin (L) \sin (d) + \cos (L) \cos (d) \cos (LHA) \qquad \text{Equation (1)}$$

$$\cos A = (\sin (d) - \sin (L) \sin (Hc)) / \cos (L) \cos (Hc) \qquad \text{Equation (2)}$$

Where the variables (all in decimal notation) are:
Hc is computed height
L is latitude
d is declination
LHA is LHA

Chapter 12: Obtain the Ship's Position by Sight Reduction

The Basic Idea

Fixing the ship's position by sight reduction simply means to complete 3 or more simultaneous sight reductions, plotting each to (hopefully) render a fix. For moderate ship speeds, sights with 1-2 minutes of each other will suffice for a simultaneous fix.

Manual Calculations

The process for reducing celestial bodies depends on which type of body is observed. Using the standard sun sight reduction featured in chapter 11, sight reductions of stars, planets, and the moon require only small modifications. They are presented in the following pages, each with an example problem to aid comprehension.

However, in general, the steps are the same as for a sight reduction of the sun.

In summary, the steps to determine an LOP from any body:

Step 1: Measure the altitude of the body using a sextant and make 3 standard sextant corrections.

Step 2: Determine the Geographic Position (GHA and Declination) of the body.
For stars: GHA = GHA (Aries) + SHA
For planets: ensure v corrections are completed when necessary
For the Moon: ensure v and HP corrections are completed when necessary.

Step 3: Determine the entering arguments for HO229 by obtaining whole numbers of Latitude, Declination, and LHA (LHA is obtained by subtracting (western hemisphere) or adding (eastern hemisphere) the assumed longitude from the GHA of the body.

Step 4: Retrieve the computed height and azimuth from HO229, and correct each for increments of declination.

Stars

The stars are considered to be infinitely far away from Earth for the purposes of celestial navigation. The stars move through the sky in a regular pattern (1° per night to the west), and change declination extremely slowly. This makes star sights fairly straightforward. One simple change when observing planets is to be sure to use the "Stars and Planets" correction table near the front of the Nautical Almanac, instead of the table for the Sun.

The only major difference in star sight reductions is the concept of **sidereal hour angle**. Instead of recording GHAs for each star, for each hour, the stars are noted with a sidereal hour angle (SHA). The SHA must be added to the **GHA of Aries** for the time of observation to determine the exact GHA of the star.

GHA of the Star = GHA of Aries + Sidereal Hour Angle

Problem 12-1. The following question illustrates how to solve star sight problems.

While on watch aboard CGC SPENCER, on 6 April your 1830 zone time DR position is latitude 26° 33' N, longitude 64° 31' W. You are on course 082° T at a speed of 16 knots. You observe 3 stars and note the following table. Determine the latitude and longitude of your 1900 running fix.

Body	*Zone Time*	*GHA Aries*	*SHA Star*	*GHA Star*	*Observed Altitude*	*Declination*
Sirius	*1836*	*174° 07.3'*	*258° 55.4'*	*73° 02.7'*	*46° 00.5'*	*S 16° 41.7'*
Regulus	*1842*	*175° 37.5'*	*208° 09.4'*	*23° 46.9'*	*49° 07.2'*	*N 12° 03.5'*
Mirfak	*1900*	*180° 08.3'*	*309° 16.0'*	*129° 24.3'*	*35° 51.6'*	*N 49° 47.7'*

Answer: 26° 33' N, 64° 27' W

Step 1: Determine the DR position of the ship for each star sight. Note this solution uses a plotting sheet, but the position may also be advanced by mid-latitude sailing (see *The Cutterman's Guide to Navigation Problems, Part 5).*

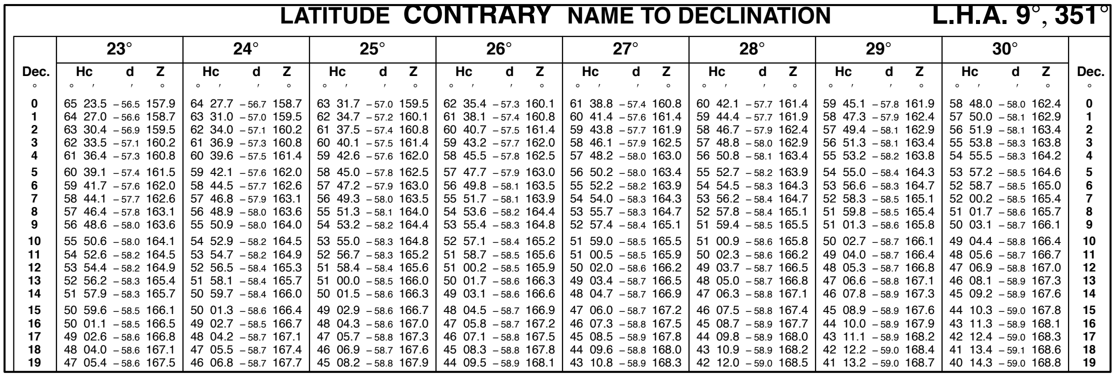
Sight	*Original DR (1830)*	*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
Course/Speed	082°, 16 knots	Same	Same	Same
Time difference	-	6 minutes	12 minutes	30 minutes
Distance covered	-	1.6 nm	3.2 nm	8 nm
DR latitude	26° 33.0' N	**26° 33' N**	**26° 33 N**	**26° 34' N**
DR longitude	64° 31.0' W	**64° 29' W**	**64° 28' W**	**64° 22' W**

Step 2: Given the GHA information presented in the question, determine the assumed position of the ship and the LHA for each star sight.

Sight		*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
DR latitude		26° 33’ N	26° 33 N	26° 34’ N
DR longitude		64° 29’ W	64° 28’ W	64° 22’ W
Assumed latitude		**27° N**	**27° N**	**27° N**
GHA (total)	*Given*	73° 02.7	23° 46.9’	129° 24.3’
Assumed longitude	*To ensure whole value of LHA*	**64° 02.7’ W**	**64° 46.9’ W**	**64° 24.3’ W**
LHA	*Subtract west, add east (±360°)*	**9°**	**319°**	**65°**

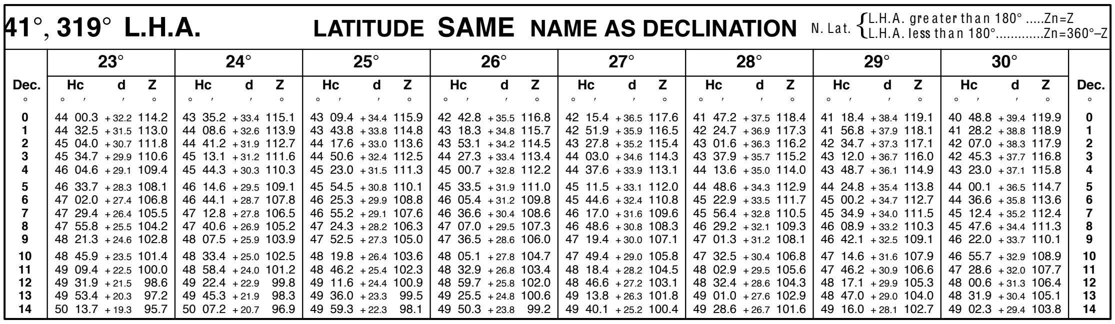
Step 3: Given the declination and altitude information presented in the question, as well as the LHA information determined in step 2, enter publication HO229 and construct a table with computed altitude (hc), altitude difference (a), and azimuth (zn).

Sight		*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
Assumed latitude		27° N	27° N	27° N
Declination		S 16° 41.7’	N 12° 03.5’	N 49° 47.7’
LHA		9° Contrary	319° Same	65° Same
Computed altitude (hc)	*From HO229*	**46° 07.3’**	**48° 46.6’**	**36° 08.0’**
Altitude difference (d)	*From HO229*	**-58.8’**	**27.2’**	**0.7’**
Azimuth (z)	*From HO229*	**167.5°**	**103.1°**	**47.4°**



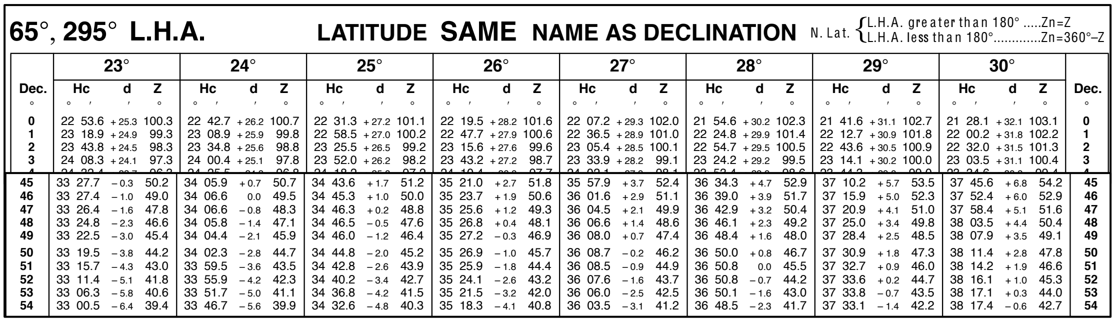
LATITUDE CONTRARY NAME TO DECLINATION L.H.A. 9°, 351°

	23°			24°			25°			26°			27°			28°			29°			30°			
Dec.	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	65 23.5	−56.5	157.9	64 27.7	−56.7	158.7	63 31.7	−57.0	159.5	62 35.4	−57.3	160.1	61 38.8	−57.4	160.8	60 42.1	−57.7	161.4	59 45.1	−57.8	161.9	58 48.0	−58.0	162.4	0
1	64 27.0	−56.6	158.7	63 31.0	−57.0	159.5	62 34.7	−57.2	160.1	61 38.1	−57.4	160.8	60 41.4	−57.6	161.4	59 44.4	−57.7	161.9	58 47.3	−57.9	162.4	57 50.0	−58.1	162.9	1
2	63 30.4	−56.9	159.5	62 34.0	−57.1	160.2	61 37.5	−57.4	160.8	60 40.7	−57.5	161.4	59 43.8	−57.7	161.9	58 46.7	−57.9	162.4	57 49.4	−58.1	162.9	56 51.9	−58.1	163.4	2
3	62 33.5	−57.1	160.2	61 36.9	−57.3	160.8	60 40.1	−57.5	161.4	59 43.2	−57.7	162.0	58 46.1	−57.9	162.5	57 48.8	−58.0	162.9	56 51.3	−58.1	163.4	55 53.8	−58.3	163.8	3
4	61 36.4	−57.3	160.8	60 39.6	−57.5	161.4	59 42.6	−57.6	162.0	58 45.5	−57.8	162.5	57 48.2	−58.0	163.0	56 50.8	−58.1	163.4	55 53.2	−58.2	163.8	54 55.5	−58.3	164.2	4
5	60 39.1	−57.4	161.5	59 42.1	−57.6	162.0	58 45.0	−57.8	162.5	57 47.7	−57.9	163.0	56 50.2	−58.0	163.4	55 52.7	−58.2	163.9	54 55.0	−58.4	164.3	53 57.2	−58.5	164.6	5
6	59 41.7	−57.6	162.0	58 44.5	−57.7	162.6	57 47.2	−57.9	163.0	56 49.8	−58.1	163.5	55 52.2	−58.2	163.9	54 54.5	−58.3	164.3	53 56.6	−58.3	164.7	52 58.7	−58.5	165.0	6
7	58 44.1	−57.7	162.6	57 46.8	−57.9	163.1	56 49.3	−58.0	163.5	55 51.7	−58.1	163.9	54 54.0	−58.3	164.3	53 56.2	−58.4	164.7	52 58.3	−58.5	165.1	52 00.2	−58.5	165.4	7
8	57 46.4	−57.8	163.1	56 48.9	−58.0	163.6	55 51.3	−58.1	164.0	54 53.6	−58.2	164.4	53 55.7	−58.3	164.7	52 57.8	−58.4	165.1	51 59.8	−58.5	165.4	51 01.7	−58.6	165.7	8
9	56 48.6	−58.0	163.6	55 50.9	−58.0	164.0	54 53.2	−58.2	164.4	53 55.4	−58.3	164.8	52 57.4	−58.4	165.1	51 59.4	−58.5	165.5	51 01.3	−58.6	165.8	50 03.1	−58.7	166.1	9
10	55 50.6	−58.0	164.1	54 52.9	−58.2	164.5	53 55.0	−58.3	164.8	52 57.1	−58.4	165.2	51 59.0	−58.5	165.5	51 00.9	−58.6	165.8	50 02.7	−58.7	166.1	49 04.4	−58.8	166.4	10
11	54 52.6	−58.2	164.5	53 54.7	−58.2	164.9	52 56.7	−58.3	165.2	51 58.7	−58.5	165.6	51 00.5	−58.5	165.9	50 02.3	−58.6	166.2	49 04.0	−58.7	166.4	48 05.6	−58.7	166.7	11
12	53 54.4	−58.2	164.9	52 56.5	−58.4	165.3	51 58.4	−58.4	165.6	51 00.2	−58.5	165.9	50 02.0	−58.6	166.2	49 03.7	−58.7	166.5	48 05.3	−58.7	166.8	47 06.9	−58.8	167.0	12
13	52 56.2	−58.3	165.4	51 58.1	−58.4	165.7	51 00.0	−58.5	166.0	50 01.7	−58.6	166.3	49 03.4	−58.7	166.5	48 05.0	−58.7	166.8	47 06.6	−58.8	167.1	46 08.1	−58.9	167.3	13
14	51 57.9	−58.3	165.7	50 59.7	−58.4	166.0	50 01.5	−58.6	166.3	49 03.1	−58.6	166.6	48 04.7	−58.7	166.9	47 06.3	−58.8	167.1	46 07.8	−58.9	167.3	45 09.2	−58.9	167.6	14
15	50 59.6	−58.5	166.1	50 01.3	−58.6	166.4	49 02.9	−58.6	166.7	48 04.5	−58.7	166.9	47 06.0	−58.7	167.2	46 07.5	−58.8	167.4	45 08.9	−58.9	167.6	44 10.3	−59.0	167.8	15
16	50 01.1	−58.5	166.5	49 02.7	−58.5	166.7	48 04.3	−58.6	167.0	47 05.8	−58.7	167.2	46 07.3	−58.8	167.5	45 08.7	−58.9	167.7	44 10.0	−58.9	167.9	43 11.3	−58.9	168.1	16
17	49 02.6	−58.6	166.8	48 04.2	−58.7	167.1	47 05.7	−58.8	167.3	46 07.1	−58.8	167.5	45 08.5	−58.9	167.8	44 09.8	−58.9	168.0	43 11.1	−58.9	168.2	42 12.4	−59.0	168.3	17
18	48 04.0	−58.6	167.1	47 05.5	−58.7	167.4	46 06.9	−58.7	167.6	45 08.3	−58.8	167.8	44 09.6	−58.8	168.0	43 10.9	−58.9	168.2	42 12.2	−59.0	168.4	41 13.4	−59.1	168.6	18
19	47 05.4	−58.6	167.5	46 06.8	−58.7	167.7	45 08.2	−58.8	167.9	44 09.5	−58.9	168.1	43 10.8	−58.9	168.3	42 12.0	−59.0	168.5	41 13.2	−59.0	168.7	40 14.3	−59.0	168.8	19



41°, 319° L.H.A. LATITUDE SAME NAME AS DECLINATION N. Lat. {L.H.A. greater than 180° .....Zn=Z
L.H.A. less than 180°............Zn=360°−Z

Dec.	23°			24°			25°			26°			27°			28°			29°			30°			Dec.
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	44 00.3	+32.2	114.2	43 35.2	+33.4	115.1	43 09.4	+34.4	115.9	42 42.8	+35.5	116.8	42 15.4	+36.5	117.6	41 47.2	+37.5	118.4	41 18.4	+38.4	119.1	40 48.8	+39.4	119.9	0
1	44 32.5	+31.5	113.0	44 08.6	+32.6	113.9	43 43.8	+33.8	114.8	43 18.3	+34.8	115.7	42 51.9	+35.9	116.5	42 24.7	+36.9	117.3	41 56.8	+37.9	118.1	41 28.2	+38.8	118.9	1
2	45 04.0	+30.7	111.8	44 41.2	+31.9	112.7	44 17.6	+33.0	113.6	43 53.1	+34.2	114.5	43 27.8	+35.2	115.4	43 01.6	+36.3	116.2	42 34.7	+37.3	117.1	42 07.0	+38.3	117.9	2
3	45 34.7	+29.9	110.6	45 13.1	+31.2	111.6	44 50.6	+32.4	112.5	44 27.3	+33.4	113.4	44 03.0	+34.6	114.3	43 37.9	+35.7	115.2	43 12.0	+36.7	116.0	42 45.3	+37.7	116.8	3
4	46 04.6	+29.1	109.4	45 44.3	+30.3	110.3	45 23.0	+31.5	111.3	45 00.7	+32.8	112.2	44 37.6	+33.9	113.1	44 13.6	+35.0	114.0	43 48.7	+36.1	114.9	43 23.0	+37.1	115.8	4
5	46 33.7	+28.3	108.1	46 14.6	+29.5	109.1	45 54.5	+30.8	110.1	45 33.5	+31.9	111.0	45 11.5	+33.1	112.0	44 48.6	+34.3	112.9	44 24.8	+35.4	113.8	44 00.1	+36.5	114.7	5
6	47 02.0	+27.4	106.8	46 44.1	+28.7	107.8	46 25.3	+29.9	108.8	46 05.4	+31.2	109.8	45 44.6	+32.4	110.8	45 22.9	+33.5	111.7	45 00.2	+34.7	112.7	44 36.6	+35.8	113.6	6
7	47 29.4	+26.4	105.5	47 12.8	+27.8	106.5	46 55.2	+29.1	107.6	46 36.6	+30.4	108.6	46 17.0	+31.6	109.6	45 56.4	+32.8	110.5	45 34.9	+34.0	111.5	45 12.4	+35.2	112.4	7
8	47 55.8	+25.5	104.2	47 40.6	+26.9	105.2	47 24.3	+28.2	106.3	47 07.0	+29.5	107.3	46 48.6	+30.8	108.3	46 29.2	+32.1	109.3	46 08.9	+33.2	110.3	45 47.6	+34.4	111.3	8
9	48 21.3	+24.6	102.8	48 07.5	+25.9	103.9	47 52.5	+27.3	105.0	47 36.5	+28.6	106.0	47 19.4	+30.0	107.1	47 01.3	+31.2	108.1	46 42.1	+32.5	109.1	46 22.0	+33.7	110.1	9
10	48 45.9	+23.5	101.4	48 33.4	+25.0	102.5	48 19.8	+26.4	103.6	48 05.1	+27.8	104.7	47 49.4	+29.0	105.8	47 32.5	+30.4	106.8	47 14.6	+31.6	107.9	46 55.7	+32.9	108.9	10
11	49 09.4	+22.5	100.0	48 58.4	+24.0	101.2	48 46.2	+25.4	102.3	48 32.9	+26.8	103.4	48 18.4	+28.2	104.5	48 02.9	+29.5	105.6	47 46.2	+30.9	106.6	47 28.6	+32.0	107.7	11
12	49 31.9	+21.5	98.6	49 22.4	+22.9	99.8	49 11.6	+24.4	100.9	48 59.7	+25.8	102.0	48 46.6	+27.2	103.1	48 32.4	+28.6	104.3	48 17.1	+29.9	105.3	48 00.6	+31.3	106.4	12
13	49 53.4	+20.3	97.2	49 45.3	+21.9	98.3	49 36.0	+23.3	99.5	49 25.5	+24.8	100.6	49 13.8	+26.3	101.8	49 01.0	+27.6	102.9	48 47.0	+29.0	104.0	48 31.9	+30.4	105.1	13
14	50 13.7	+19.3	95.7	50 07.2	+20.7	96.9	49 59.3	+22.3	98.1	49 50.3	+23.8	99.2	49 40.1	+25.2	100.4	49 28.6	+26.7	101.6	49 16.0	+28.1	102.7	49 02.3	+29.4	103.8	14



65°, 295° L.H.A. LATITUDE SAME NAME AS DECLINATION N. Lat. {L.H.A. greater than 180° .....Zn=Z
L.H.A. less than 180°............Zn=360°−Z

Dec.	23°			24°			25°			26°			27°			28°			29°			30°			Dec.
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	22 53.6	+25.3	100.3	22 42.7	+26.2	100.7	22 31.3	+27.2	101.1	22 19.5	+28.2	101.6	22 07.2	+29.3	102.0	21 54.6	+30.2	102.3	21 41.6	+31.1	102.7	21 28.1	+32.1	103.1	0
1	23 18.9	+24.9	99.3	23 08.9	+25.9	99.8	22 58.5	+27.0	100.2	22 47.7	+27.9	100.6	22 36.5	+28.9	101.0	22 24.8	+29.9	101.4	22 12.7	+30.9	101.8	22 00.2	+31.8	102.2	1
2	23 43.8	+24.5	98.3	23 34.8	+25.6	98.8	23 25.5	+26.5	99.2	23 15.6	+27.6	99.6	23 05.4	+28.5	100.1	22 54.7	+29.5	100.5	22 43.6	+30.5	100.9	22 32.0	+31.5	101.3	2
3	24 08.3	+24.1	97.3	24 00.4	+25.1	97.8	23 52.0	+26.2	98.2	23 43.2	+27.2	98.7	23 33.9	+28.2	99.1	23 24.2	+29.2	99.5	23 14.1	+30.2	100.0	23 03.5	+31.1	100.4	3
45	33 27.7	−0.3	50.2	34 05.9	+0.7	50.7	34 43.6	+1.7	51.2	35 21.0	+2.7	51.8	35 57.9	+3.7	52.4	36 34.3	+4.7	52.9	37 10.2	+5.7	53.5	37 45.6	+6.8	54.2	45
46	33 27.4	−1.0	49.0	34 06.6	0.0	49.5	34 45.3	+1.0	50.0	35 23.7	+1.9	50.6	36 01.6	+2.9	51.1	36 39.0	+3.9	51.7	37 15.9	+5.0	52.3	37 52.4	+6.0	52.9	46
47	33 26.4	−1.6	47.8	34 06.6	−0.8	48.3	34 46.3	+0.2	48.8	35 25.6	+1.2	49.3	36 04.5	+2.1	49.9	36 42.9	+3.2	50.4	37 20.9	+4.1	51.0	37 58.4	+5.1	51.6	47
48	33 24.8	−2.3	46.6	34 05.8	−1.4	47.1	34 46.5	−0.5	47.6	35 26.8	+0.4	48.1	36 06.6	+1.4	48.6	36 46.1	+2.3	49.2	37 25.0	+3.4	49.8	38 03.5	+4.4	50.4	48
49	33 22.5	−3.0	45.4	34 04.4	−2.1	45.9	34 46.0	−1.2	46.4	35 27.2	−0.3	46.9	36 08.0	+0.7	47.4	36 48.4	+1.6	48.0	37 28.4	+2.5	48.5	38 07.9	+3.5	49.1	49
50	33 19.5	−3.8	44.2	34 02.3	−2.8	44.7	34 44.8	−2.0	45.2	35 26.9	−1.0	45.7	36 08.7	−0.2	46.2	36 50.0	+0.8	46.7	37 30.9	+1.8	47.3	38 11.4	+2.8	47.8	50
51	33 15.7	−4.3	43.0	33 59.5	−3.6	43.5	34 42.8	−2.6	43.9	35 25.9	−1.8	44.4	36 08.5	−0.9	44.9	36 50.8	0.0	45.5	37 32.7	+0.9	46.0	38 14.2	+1.9	46.6	51
52	33 11.4	−5.1	41.8	33 55.9	−4.2	42.3	34 40.2	−3.4	42.7	35 24.1	−2.6	43.2	36 07.6	−1.6	43.7	36 50.8	−0.7	44.2	37 33.6	+0.2	44.7	38 16.1	+1.0	45.3	52
53	33 06.3	−5.8	40.6	33 51.7	−5.0	41.1	34 36.8	−4.2	41.5	35 21.5	−3.2	42.0	36 06.0	−2.5	42.5	36 50.1	−1.6	43.0	37 33.8	−0.7	43.5	38 17.1	+0.3	44.0	53
54	33 00.5	−6.4	39.4	33 46.7	−5.6	39.9	34 32.6	−4.8	40.3	35 18.3	−4.1	40.8	36 03.5	−3.1	41.2	36 48.5	−2.3	41.7	37 33.1	−1.4	42.2	38 17.4	−0.6	42.7	54

Step 4: Given the azimuth information in step 3 (which does not account for increments of declination), construct a table to determine correct azimuths.

Sight		*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
Base Azimuth (Z)	*From HO229*	167.5°	103.1°	47.4°
Next incremental Z		167.8°	101.8°	46.2°
Difference		0.3°	-1.3°	-1.2°
Declination Increment	*From given declination*	41.7’	3.5’	47.7’
Correction (Diff Z x Increment) / 60		+0.2°	-0.1°	-1.0°
Corrected azimuth (Z)		167.7°	103.0°	46.5°
Azimuth rules corrected azimuth (Zn)	*Check azimuth rules for LHA on top/bottom of HO229 pages*	**192.3°**	**103.0°**	**313.6°**

Dec. Inc.	Altitude Difference (d)																
	Tens					Decimals	Units									
	10′	**20′**	**30′**	**40′**	**50′**	⇓	**0′**	**1′**	**2′**	**3′**	**4′**	**5′**	**6′**	**7′**	**8′**	**9′**
′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
0.0	0.0	0.0	0.0	0.0	0.0	**.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
0.1	0.0	0.0	0.0	0.0	0.1	**.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.2	0.0	0.0	0.1	0.1	0.1	**.2**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.3	0.0	0.1	0.1	0.2	0.2	**.3**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.4	0.1	0.1	0.2	0.3	0.3	**.4**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.5	0.1	0.2	0.3	0.3	0.4	**.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.6	0.1	0.2	0.3	0.4	0.5	**.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.7	0.1	0.3	0.4	0.5	0.6	**.7**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.8	0.2	0.3	0.4	0.6	0.7	**.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.9	0.2	0.3	0.5	0.6	0.8	**.9**	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
27.0	4.5	9.0	13.5	18.0	22.5	**.0**	0.0	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.7	4.1
27.1	4.5	9.0	13.5	18.0	22.6	**.1**	0.0	0.5	1.0	1.4	1.9	2.3	2.8	3.3	3.7	4.2
27.2	4.5	9.0	13.6	18.1	22.6	**.2**	0.1	0.5	1.0	1.5	1.9	2.4	2.8	3.3	3.8	4.2
27.3	4.5	9.1	13.6	18.2	22.7	**.3**	0.1	0.6	1.1	1.5	2.0	2.4	2.9	3.3	3.8	4.3
27.4	4.6	9.1	13.7	18.3	22.8	**.4**	0.2	0.6	1.1	1.6	2.0	2.5	2.9	3.4	3.8	4.3
27.5	4.6	9.2	13.8	18.3	22.9	**.5**	0.2	0.7	1.1	1.6	2.1	2.5	3.0	3.4	3.9	4.4
27.6	4.6	9.2	13.8	18.4	23.0	**.6**	0.3	0.7	1.2	1.6	2.1	2.6	3.0	3.5	3.9	4.4
27.7	4.6	9.3	13.9	18.5	23.1	**.7**	0.3	0.8	1.2	1.7	2.2	2.6	3.1	3.5	4.0	4.4
27.8	4.7	9.3	13.9	18.6	23.2	**.8**	0.4	0.8	1.3	1.7	2.2	2.7	3.1	3.6	4.0	4.5
27.9	4.7	9.3	14.0	18.6	23.3	**.9**	0.4	0.9	1.3	1.8	2.2	2.7	3.2	3.6	4.1	4.5
58.0	9.6	19.3	29.0	38.6	48.3	**.0**	0.0	1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8
58.1	9.7	19.3	29.0	38.7	48.4	**.1**	0.1	1.1	2.0	3.0	4.0	5.0	5.9	6.9	7.9	8.9
58.2	9.7	19.4	29.1	38.8	48.5	**.2**	0.2	1.2	2.1	3.1	4.1	5.1	6.0	7.0	8.0	9.0
58.3	9.7	19.4	29.1	38.9	48.6	**.3**	0.3	1.3	2.2	3.2	4.2	5.2	6.1	7.1	8.1	9.1
58.4	9.7	19.5	29.2	38.9	48.7	**.4**	0.4	1.4	2.3	3.3	4.3	5.3	6.2	7.2	8.2	9.2
58.5	9.8	19.5	29.3	39.0	48.8	**.5**	0.5	1.5	2.4	3.4	4.4	5.4	6.3	7.3	8.3	9.3
58.6	9.8	19.5	29.3	39.1	48.8	**.6**	0.6	1.6	2.5	3.5	4.5	5.5	6.4	7.4	8.4	9.4
58.7	9.8	19.6	29.4	39.2	48.9	**.7**	0.7	1.7	2.6	3.6	4.6	5.6	6.5	7.5	8.5	9.5
58.8	9.8	19.6	29.4	39.2	49.0	**.8**	0.8	1.8	2.7	3.7	4.7	5.7	6.6	7.6	8.6	9.6
58.9	9.9	19.7	29.5	39.3	49.1	**.9**	0.9	1.9	2.8	3.8	4.8	5.8	6.7	7.7	8.7	9.7

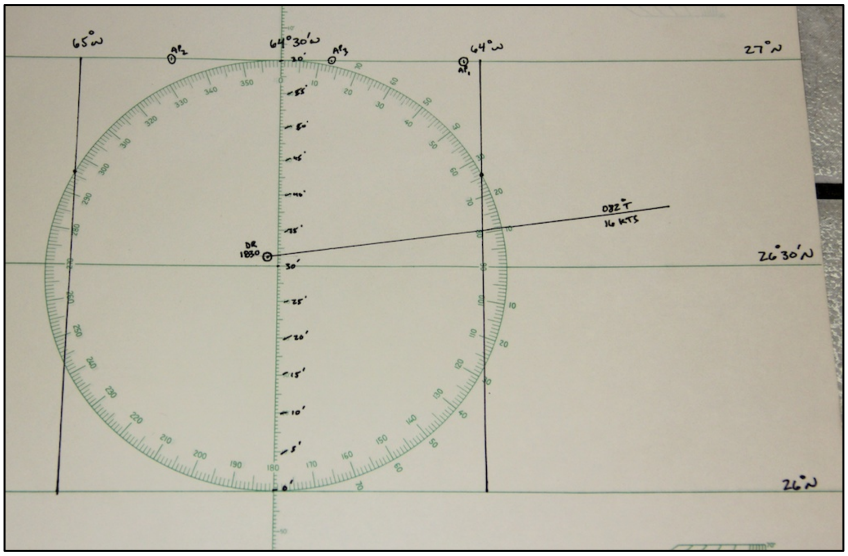
Step 5: Given the tabular HO229 information in step 3, determine the correct computed altitude (hc) for the three star sights.

Sight		*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
Tabular computed altitude	*From step 3*	**46° 07.3’**	**48° 46.6’**	**36° 08.0’**
Altitude difference (d)	*From step 3*	**-58.8’**	**27.2’**	**0.7’**
Declination increment	*From given declination*	41.7’	3.5’	47.7’
Altitude difference	*From HO229 interpolation table*	-40.9’	+1.6’	+0.6’
Correct computed altitude		**45° 26.4**	**48° 48.2’**	**36° 08.6’**

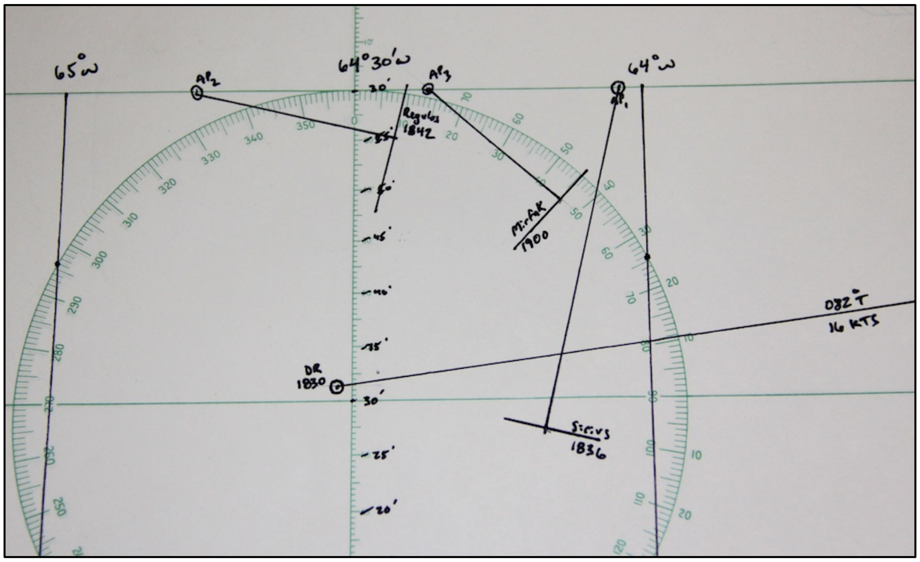
Step 6: Compare the observed altitudes (given) with the computed altitudes (determined in step 5), to compute intercepts (a) for the three star sights.

Sight		*Sirius (1836)*	*Regulus (1842)*	*Mirfak (1900)*
Observed altitude (ho)	*Given*	46° 00.5’	49° 07.2’	35° 51.6’
Correct computed altitude (hc)	*From step 5*	**45° 26.4’**	**48° 48.2’**	**36° 08.6’**
Intercept (a)	*hc – ho*	**34.1’**	**19.0’**	**17.0’**
Towards/Away	*If hc is greater, intercept is “away”*	**Towards**	**Towards**	**Away**
Azimuth	*Repeated from step 4*	192.3°	103.0°	313.6°

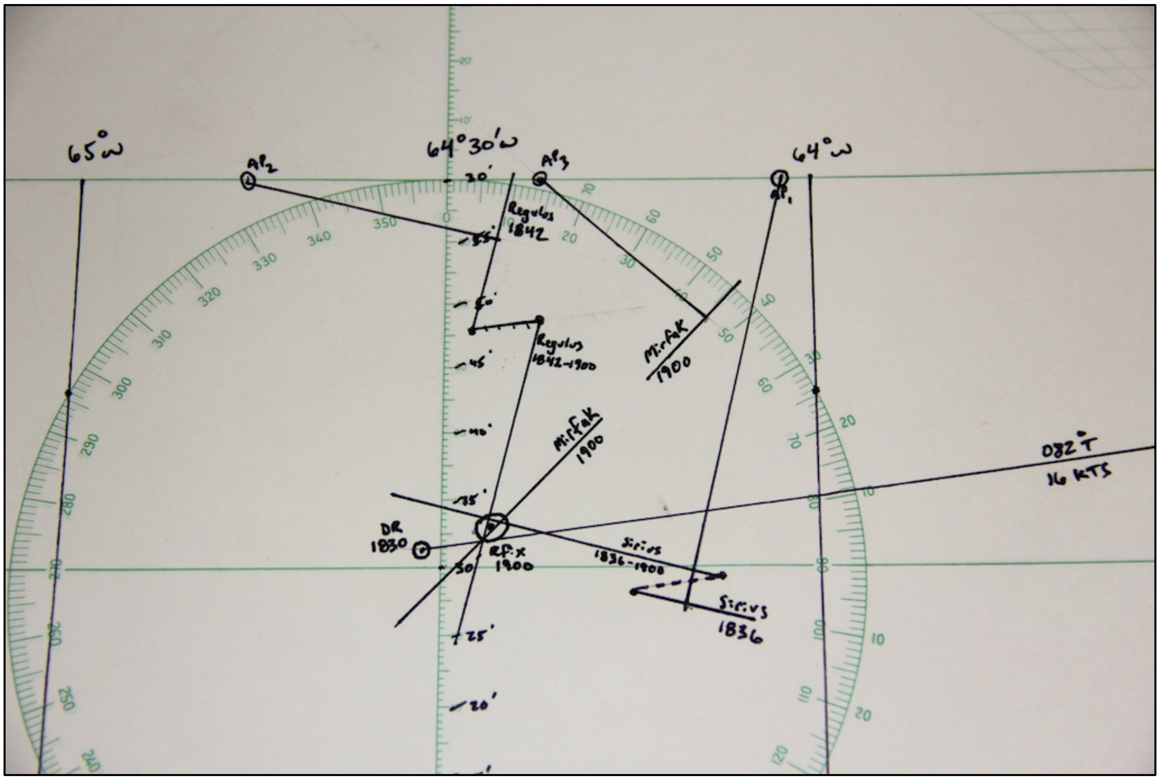
Step 7: Plot the assumed positions for each star sight.



Step 8: Plot each star sight's line of position.



Step 9: Advance the 1836 and 1842 star lines of position to 1900 to determine the running fix.
Fix: 26° 33' N, 64° 27' W



Planets

The planets Venus, Mars, Jupiter, and Saturn are excellent candidates for observation and sight reduction. The only difference between sun and planet sight reductions is the fact that planets move in a sometimes irregular pattern in the sky, and do not lend themselves to easy interpolation of declination and GHA.

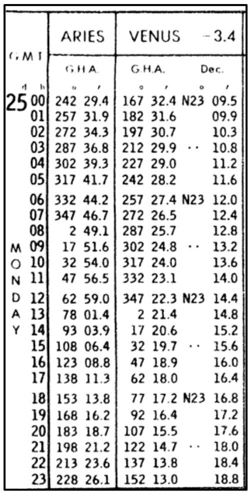
The first difference to account for is in the standard sextant corrections – the altitude correction. In the front cover of the Nautical Almanac, the planets have a different correction than the sun, and sometimes there are additional corrections, particularly for Venus and Mars.

The second difference accounts for changes in GHA over the course of an hour. While the sun moves in a regular pattern through the sky (15 degrees of arc every hour), the planets are slightly different. The planets have a "v" correction that must be applied when determining the exact GHA for the time of observation. This correction is applied in the increment and corrections pages of the Nautical Almanac, exactly as if it were a "d" correction for declination.

Problem 12-2. The following question illustrates how to solve celestial sight reduction problems involving planets.

You are scheduled to work aids to navigation in the western Pacific aboard CGC KUKUI. On 25 May your vessel's 1858 zone time DR position is latitude 21° 05' N, longitude 143° 27' E. At that time a sextant observation of the planet Venus was made. The sextant altitude is 12° 53.4' and the chronometer reads 08h 59m 15s. The index error is 4.5' off the arc and the chronometer error is 1m 25s fast. Your height of eye is determined to be 55 feet. What is the computed height (hc) and azimuth (zn) of the sight using the assumed position?

Answer: 12° 28.7'; 290.3° T. Note that several steps (involving the sextant measurement) are not technically required to answer the specific question posed, but are shown here for training purposes.



G.M.T.		ARIES	VENUS −3.4	
		G.H.A.	G.H.A.	Dec.
d	h	° ′	° ′	° ′
25	00	242 29.4	167 32.4	N23 09.5
	01	257 31.9	182 31.6	09.9
	02	272 34.3	197 30.7	10.3
	03	287 36.8	212 29.9	· · 10.8
	04	302 39.3	227 29.0	11.2
	05	317 41.7	242 28.2	11.6
	06	332 44.2	257 27.4	N23 12.0
	07	347 46.7	272 26.5	12.4
	08	2 49.1	287 25.7	12.8
M	09	17 51.6	302 24.8	· · 13.2
O	10	32 54.0	317 24.0	13.6
N	11	47 56.5	332 23.1	14.0
D	12	62 59.0	347 22.3	N23 14.4
A	13	78 01.4	2 21.4	14.8
Y	14	93 03.9	17 20.6	15.2
	15	108 06.4	32 19.7	· · 15.6
	16	123 08.8	47 18.9	16.0
	17	138 11.3	62 18.0	16.4
	18	153 13.8	77 17.2	N23 16.8
	19	168 16.2	92 16.4	17.2
	20	183 18.7	107 15.5	17.6
	21	198 21.2	122 14.7	· · 18.0
	22	213 23.6	137 13.8	18.4
	23	228 26.1	152 13.0	18.8

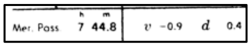
Step 1: Determine the GMT of the sight.
Chronometer time: 08h 59m 15s
Chronometer error: 1m 25s fast
Correct chronometer time: 08h 59m 15s – 1m 25s = 08:57:50
Ship time: 1858 zone time.
DR longitude: 143° 27' E corresponds to (-10 ZD)
GMT of sight: 08:57:50 GMT, 25 May

Step 2: Determine the apparent altitude (ha).

hs = 12° 53.4’ (Given)
Index error: 4.5’ off the arc (index correction = +4.5’)
Height of eye: 55 ft (dip correction = -7.2’)
ha = 12° 53.4 + 4.5’ – 7.2’ = 12° 50.7’

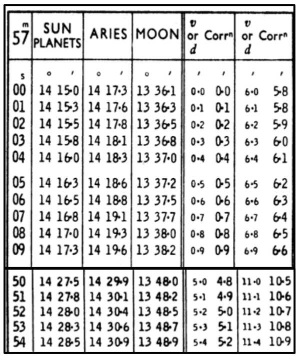
Step 3: Determine observed altitude.
Apparent altitude: 12° 50.7’
Apparent altitude correction: - 4.2’
Additional Venus correction: +0.1’
Total main correction: -4.2’ + 0.1’ = -4.1’
Observed altitude (ho): 12° 50.7’ – 4.1’ = 12° 46.6’

Step 4: Determine the declination of Venus.
Declination (hours): N 23° 12.8’ (d number: +0.4)
Declination (increment): +0.4’
Declination (total): N 23° 12.8’ + 0.4’ = N 23° 13.2’



	h m				
Mer. Pass.	7 44.8	*v*	−0.9	*d*	0.4

Step 5: Determine the GHA of Venus.
GHA (hours): 287° 25.7’ (v number: -0.9)
GHA (increment): 14° 27.5’
GHA (v correction): -0.9’
GHA (total): 287° 25.7 + 14° 27.5’ – 0.9’ = 301° 52.3’



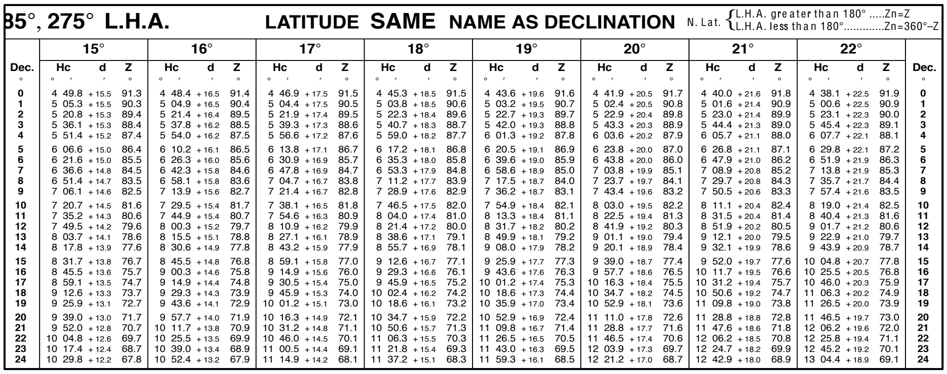
57 m	SUN PLANETS	ARIES	MOON	*v* or *d*	Corrⁿ	*v* or *d*	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′
00	14 15·0	14 17·3	13 36·1	0·0	0·0	6·0	5·8
01	14 15·3	14 17·6	13 36·3	0·1	0·1	6·1	5·8
02	14 15·5	14 17·8	13 36·5	0·2	0·2	6·2	5·9
03	14 15·8	14 18·1	13 36·8	0·3	0·3	6·3	6·0
04	14 16·0	14 18·3	13 37·0	0·4	0·4	6·4	6·1
05	14 16·3	14 18·6	13 37·2	0·5	0·5	6·5	6·2
06	14 16·5	14 18·8	13 37·5	0·6	0·6	6·6	6·3
07	14 16·8	14 19·1	13 37·7	0·7	0·7	6·7	6·4
08	14 17·0	14 19·3	13 38·0	0·8	0·8	6·8	6·5
09	14 17·3	14 19·6	13 38·2	0·9	0·9	6·9	6·6
50	14 27·5	14 29·9	13 48·0	5·0	4·8	11·0	10·5
51	14 27·8	14 30·1	13 48·2	5·1	4·9	11·1	10·6
52	14 28·0	14 30·4	13 48·5	5·2	5·0	11·2	10·7
53	14 28·3	14 30·6	13 48·7	5·3	5·1	11·3	10·8
54	14 28·5	14 30·9	13 48·9	5·4	5·2	11·4	10·9

Step 6: Determine the assumed position of the ship.
DR latitude: 21° 05’ N
Assumed latitude: 21° N
DR longitude: 143° 27’ E
Assumed longitude (to ensure whole number of LHA): 143° 07.7’ E

Step 7: Determine the LHA for Venus for the time of sight.
GHA (Venus): 301° 52.3’
Assumed longitude: 143° 07.7’ E
LHA (Moon): 301° 52.3’ + 143° 07.7’ E (-360°) = 85° (-west, +east)

Step 8: Entering publication HO229 with assumed latitude, declination, and LHA, retrieve the computed altitude (hc), altitude difference (d), and azimuth (z) for the assumed position.
Assumed latitude: 21° N
Declination: N 23° (increments solved in step 9)
LHA: 85° (Same Pages)

HO 229 values:
Computed altitude (hc): 12° 24.7’
Altitude difference (d): + 18.2’



85°, 275° L.H.A. LATITUDE SAME NAME AS DECLINATION N. Lat. {L.H.A. greater than 180° .....Zn=Z
L.H.A. less than 180°............Zn=360°–Z

Dec.	15°			16°			17°			18°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
0	4 49.8	+15.5	91.3	4 48.4	+16.5	91.4	4 46.9	+17.5	91.5	4 45.3	+18.5	91.5
1	5 05.3	+15.5	90.3	5 04.9	+16.5	90.4	5 04.4	+17.5	90.5	5 03.8	+18.5	90.6
2	5 20.8	+15.3	89.4	5 21.4	+16.4	89.5	5 21.9	+17.4	89.5	5 22.3	+18.4	89.6
3	5 36.1	+15.3	88.4	5 37.8	+16.2	88.5	5 39.3	+17.3	88.6	5 40.7	+18.3	88.7
4	5 51.4	+15.2	87.4	5 54.0	+16.2	87.5	5 56.6	+17.2	87.6	5 59.0	+18.2	87.7
5	6 06.6	+15.0	86.4	6 10.2	+16.1	86.5	6 13.8	+17.1	86.7	6 17.2	+18.1	86.8
6	6 21.6	+15.0	85.5	6 26.3	+16.0	85.6	6 30.9	+16.9	85.7	6 35.3	+18.0	85.8
7	6 36.6	+14.8	84.5	6 42.3	+15.8	84.6	6 47.8	+16.9	84.7	6 53.3	+17.9	84.8
8	6 51.4	+14.7	83.5	6 58.1	+15.8	83.6	7 04.7	+16.7	83.8	7 11.2	+17.7	83.9
9	7 06.1	+14.6	82.5	7 13.9	+15.6	82.7	7 21.4	+16.7	82.8	7 28.9	+17.6	82.9
10	7 20.7	+14.5	81.6	7 29.5	+15.4	81.7	7 38.1	+16.5	81.8	7 46.5	+17.5	82.0
11	7 35.2	+14.3	80.6	7 44.9	+15.4	80.7	7 54.6	+16.3	80.9	8 04.0	+17.4	81.0
12	7 49.5	+14.2	79.6	8 00.3	+15.2	79.7	8 10.9	+16.2	79.9	8 21.4	+17.2	80.0
13	8 03.7	+14.1	78.6	8 15.5	+15.1	78.8	8 27.1	+16.1	78.9	8 38.6	+17.1	79.1
14	8 17.8	+13.9	77.6	8 30.6	+14.9	77.8	8 43.2	+15.9	77.9	8 55.7	+16.9	78.1
15	8 31.7	+13.8	76.7	8 45.5	+14.8	76.8	8 59.1	+15.8	77.0	9 12.6	+16.7	77.1
16	8 45.5	+13.6	75.7	9 00.3	+14.6	75.8	9 14.9	+15.6	76.0	9 29.3	+16.6	76.1
17	8 59.1	+13.5	74.7	9 14.9	+14.4	74.8	9 30.5	+15.4	75.0	9 45.9	+16.5	75.2
18	9 12.6	+13.3	73.7	9 29.3	+14.3	73.9	9 45.9	+15.3	74.0	10 02.4	+16.2	74.2
19	9 25.9	+13.1	72.7	9 43.6	+14.1	72.9	10 01.2	+15.1	73.0	10 18.6	+16.1	73.2
20	9 39.0	+13.0	71.7	9 57.7	+14.0	71.9	10 16.3	+14.9	72.1	10 34.7	+15.9	72.2
21	9 52.0	+12.8	70.7	10 11.7	+13.8	70.9	10 31.2	+14.8	71.1	10 50.6	+15.7	71.3
22	10 04.8	+12.6	69.7	10 25.5	+13.5	69.9	10 46.0	+14.5	70.1	11 06.3	+15.5	70.3
23	10 17.4	+12.4	68.7	10 39.0	+13.4	68.9	11 00.5	+14.4	69.1	11 21.8	+15.4	69.3
24	10 29.8	+12.2	67.8	10 52.4	+13.2	67.9	11 14.9	+14.2	68.1	11 37.2	+15.1	68.3

19°			20°			21°			22°			Dec.
Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	
° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
4 43.6	+19.6	91.6	4 41.9	+20.5	91.7	4 40.0	+21.6	91.8	4 38.1	+22.5	91.9	0
5 03.2	+19.5	90.7	5 02.4	+20.5	90.8	5 01.6	+21.4	90.9	5 00.6	+22.5	90.9	1
5 22.7	+19.3	89.7	5 22.9	+20.4	89.8	5 23.0	+21.4	89.9	5 23.1	+22.3	90.0	2
5 42.0	+19.3	88.8	5 43.3	+20.3	88.9	5 44.4	+21.3	89.0	5 45.4	+22.3	89.1	3
6 01.3	+19.2	87.8	6 03.6	+20.2	87.9	6 05.7	+21.1	88.0	6 07.7	+22.1	88.1	4
6 20.5	+19.1	86.9	6 23.8	+20.0	87.0	6 26.8	+21.1	87.1	6 29.8	+22.1	87.2	5
6 39.6	+19.0	85.9	6 43.8	+20.0	86.0	6 47.9	+21.0	86.2	6 51.9	+21.9	86.3	6
6 58.6	+18.9	85.0	7 03.8	+19.9	85.1	7 08.9	+20.8	85.2	7 13.8	+21.9	85.3	7
7 17.5	+18.7	84.0	7 23.7	+19.7	84.1	7 29.7	+20.8	84.3	7 35.7	+21.7	84.4	8
7 36.2	+18.7	83.1	7 43.4	+19.6	83.2	7 50.5	+20.6	83.3	7 57.4	+21.6	83.5	9
7 54.9	+18.4	82.1	8 03.0	+19.5	82.2	8 11.1	+20.4	82.4	8 19.0	+21.4	82.5	10
8 13.3	+18.4	81.1	8 22.5	+19.4	81.3	8 31.5	+20.4	81.4	8 40.4	+21.3	81.6	11
8 31.7	+18.2	80.2	8 41.9	+19.2	80.3	8 51.9	+20.2	80.5	9 01.7	+21.2	80.6	12
8 49.9	+18.1	79.2	9 01.1	+19.0	79.4	9 12.1	+20.0	79.5	9 22.9	+21.0	79.7	13
9 08.0	+17.9	78.2	9 20.1	+18.9	78.4	9 32.1	+19.9	78.6	9 43.9	+20.9	78.7	14
9 25.9	+17.7	77.3	9 39.0	+18.7	77.4	9 52.0	+19.7	77.6	10 04.8	+20.7	77.8	15
9 43.6	+17.6	76.3	9 57.7	+18.6	76.5	10 11.7	+19.5	76.6	10 25.5	+20.5	76.8	16
10 01.2	+17.4	75.3	10 16.3	+18.4	75.5	10 31.2	+19.4	75.7	10 46.0	+20.3	75.9	17
10 18.6	+17.3	74.4	10 34.7	+18.2	74.5	10 50.6	+19.2	74.7	11 06.3	+20.2	74.9	18
10 35.9	+17.0	73.4	10 52.9	+18.1	73.6	11 09.8	+19.0	73.8	11 26.5	+20.0	73.9	19
10 52.9	+16.9	72.4	11 11.0	+17.8	72.6	11 28.8	+18.8	72.8	11 46.5	+19.7	73.0	20
11 09.8	+16.7	71.4	11 28.8	+17.7	71.6	11 47.6	+18.6	71.8	12 06.2	+19.6	72.0	21
11 26.5	+16.5	70.5	11 46.5	+17.4	70.6	12 06.2	+18.5	70.8	12 25.8	+19.4	71.1	22
11 43.0	+16.3	69.5	12 03.9	+17.3	69.7	12 24.7	+18.2	69.9	12 45.2	+19.2	70.1	23
11 59.3	+16.1	68.5	12 21.2	+17.0	68.7	12 42.9	+18.0	68.9	13 04.4	+18.9	69.1	24

Azimuth (z): 69.9°

Step 9: Determine the azimuth correction for the sight (to account for increments of declination ignored in step 8).

By increasing the value of each argument by 1 whole increment, triple interpolate for the exact values of azimuth (for detailed instructions see Part 14).

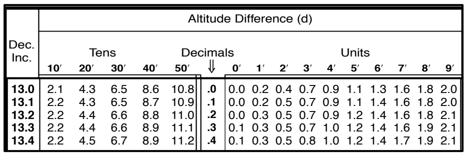
	Base Value	Base Z	Next incremental Z	Difference in Z	Increment	Correction *(Diff Z x Increment) / 60*
Latitude – N	21°	69.9°	-	-	00.0’	0
Declination – N	23°	69.9°	68.9°	-1.0’	13.2’	-0.2°
LHA	85°	69.9°	-	-	00.0’	0

Total correction = -<u>0.2°</u>

Step 10: Apply the correction to the base values to determine true azimuth.
Base azimuth: 69.9°
Correction: -0.2°
Corrected azimuth: 69.9° - 0.2° = 69.7°
Note - Check azimuth rules: if LHA less than 180°, then zn = 360° - z.
Corrected azimuth: 360° - 69.7° = **290.3° T**

Step 11: Determine the computed altitude (hc).
Tabular computed altitude: 12° 24.7’
Altitude difference (d): 18.2’
Declination: N 23° 13.2’
Declination increments: 13.2’

Altitude difference correction:
Tens: 2.2’
Units/decimals: 1.9’
Total correction: 2.2’+1.8’ = +<u>4.0’</u>



Dec. Inc.	Altitude Difference (d)															
	Tens					Decimals	Units									
	10′	20′	30′	40′	50′	⇓	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′
13.0	2.1	4.3	6.5	8.6	10.8	**.0**	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0
13.1	2.2	4.3	6.5	8.7	10.9	**.1**	0.0	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.0
13.2	2.2	4.4	6.6	8.8	11.0	**.2**	0.0	0.3	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1
13.3	2.2	4.4	6.6	8.9	11.1	**.3**	0.1	0.3	0.5	0.7	1.0	1.2	1.4	1.6	1.9	2.1
13.4	2.2	4.5	6.7	8.9	11.2	**.4**	0.1	0.3	0.5	0.8	1.0	1.2	1.4	1.7	1.9	2.1

Tabular hc: 12° 24.7’
Altitude difference correction: +4.0’
hc: 12° 24.7’ + 4.0’ = <u>12° 28.7’</u>

Step 12: Determine the intercept (a).
Computed altitude (hc): 12° 28.7’
Observed altitude (ho): 12° 46.6’
Intercept (a): 12° 46.6’ – 12° 28.7’ = **<u>17.9’</u>**
If ho is greater, intercept is **<u>towards</u>**.

Moon

The moon is the most complex body in the night sky to work with, because it is so close to earth and has clear phases of illumination.

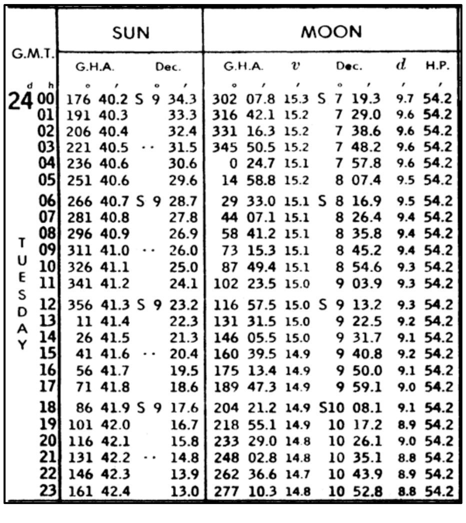
The moon has a "v" and "d" correction (similar to planets) that must be applied, using the increments and corrections pages of the Nautical Almanac.

In addition, the moon has a **horizontal parallax** correction that must be made due to the body's proximity to the earth. This correction is made using the Moon Altitude Correction Tables on the last page of the Nautical Almanac.

Finally, the moon has its own height of eye (dip) corrections, also located on the last page of the Nautical Almanac.

Problem 12-3. The following question illustrates how to solve celestial sight reduction problems involving the Moon.

You are on your way home from Antarctica aboard CGC POLAR STAR. On 25 February at 0622 zone time, you observe the upper limb of the Moon with a sextant altitude of 59° 58.6'. Your DR position is latitude 30° 28.3' S, longitude 102° 39.3' E. The chronometer reading at the time of the sight is 11h 21m 18s and the chronometer is 48s slow. The height of eye is 59 feet and the index error is 2.5' on the arc. What are the azimuth (zn) and intercept (a) of this sight using the assumed position?



G.M.T.		SUN		MOON				
		G.H.A.	Dec.	G.H.A.	v	Dec.	d	H.P.
d	h	° '	° '	° '	'	° '	'	'
24	00	176 40.2	S 9 34.3	302 07.8	15.3	S 7 19.3	9.7	54.2
	01	191 40.3	33.3	316 42.1	15.2	7 29.0	9.6	54.2
	02	206 40.4	32.4	331 16.3	15.2	7 38.6	9.6	54.2
	03	221 40.5	· · 31.5	345 50.5	15.2	7 48.2	9.6	54.2
	04	236 40.6	30.6	0 24.7	15.1	7 57.8	9.6	54.2
	05	251 40.6	29.6	14 58.8	15.2	8 07.4	9.5	54.2
	06	266 40.7	S 9 28.7	29 33.0	15.1	S 8 16.9	9.5	54.2
	07	281 40.8	27.8	44 07.1	15.1	8 26.4	9.4	54.2
	08	296 40.9	26.9	58 41.2	15.1	8 35.8	9.4	54.2
TUESDAY	09	311 41.0	· · 26.0	73 15.3	15.1	8 45.2	9.4	54.2
	10	326 41.1	25.0	87 49.4	15.1	8 54.6	9.3	54.2
	11	341 41.2	24.1	102 23.5	15.0	9 03.9	9.3	54.2
	12	356 41.3	S 9 23.2	116 57.5	15.0	S 9 13.2	9.3	54.2
	13	11 41.4	22.3	131 31.5	15.0	9 22.5	9.2	54.2
	14	26 41.5	21.3	146 05.5	15.0	9 31.7	9.1	54.2
	15	41 41.6	· · 20.4	160 39.5	14.9	9 40.8	9.2	54.2
	16	56 41.7	19.5	175 13.4	14.9	9 50.0	9.1	54.2
	17	71 41.8	18.6	189 47.3	14.9	9 59.1	9.0	54.2
	18	86 41.9	S 9 17.6	204 21.2	14.9	S10 08.1	9.1	54.2
	19	101 42.0	16.7	218 55.1	14.9	10 17.2	8.9	54.2
	20	116 42.1	15.8	233 29.0	14.8	10 26.1	9.0	54.2
	21	131 42.2	· · 14.8	248 02.8	14.8	10 35.1	8.8	54.2
	22	146 42.3	13.9	262 36.6	14.7	10 43.9	8.9	54.2
	23	161 42.4	13.0	277 10.3	14.8	10 52.8	8.8	54.2

Answer: zn = 304.1° T, a = 4.2' towards.

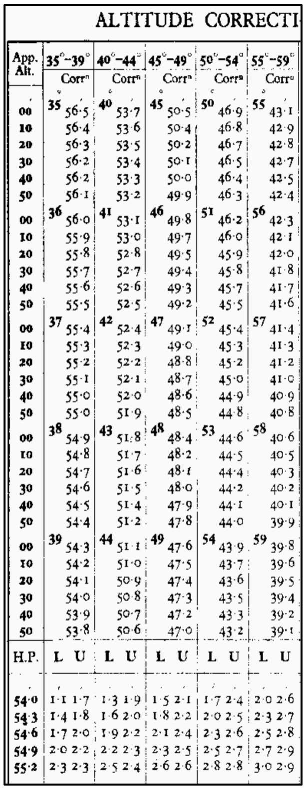
Step 1: Determine the GMT of the sight.
Chronometer time: 11h 21m 18s
Chronometer error: 48s slow
Correct chronometer time: 11h 21m 18s + 48s = 11:22:06
Ship time: 0622 zone time.
DR longitude: 102° 39.3' E corresponds to (-7 ZD)
GMT of sight: <u>23:22:06 GMT, 24 February</u>

Step 2: Determine the sextant altitude (hs).
hs = 59° 58.6' (Given)

Step 3: Determine the index correction (IC).
Index error: 2.5' on the arc.
Index correction: -2.5'

Step 4: Determine the dip correction.

Height of eye: 59 feet.
Dip correction: -7.5’



ALTITUDE CORRECTI

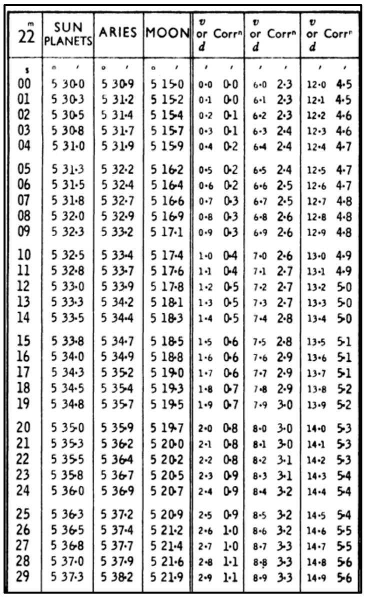
App. Alt.	35°–39°	40°–44°	45°–49°	50°–54°	55°–59°
	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ	Corrⁿ
′	° ′	° ′	° ′	° ′	° ′
00	**35** 56·5	**40** 53·7	**45** 50·5	**50** 46·9	**55** 43·1
10	56·4	53·6	50·4	46·8	42·9
20	56·3	53·5	50·2	46·7	42·8
30	56·2	53·4	50·1	46·5	42·7
40	56·2	53·3	50·0	46·4	42·5
50	56·1	53·2	49·9	46·3	42·4
00	**36** 56·0	**41** 53·1	**46** 49·8	**51** 46·2	**56** 42·3
10	55·9	53·0	49·7	46·0	42·1
20	55·8	52·8	49·5	45·9	42·0
30	55·7	52·7	49·4	45·8	41·8
40	55·6	52·6	49·3	45·7	41·7
50	55·5	52·5	49·2	45·5	41·6
00	**37** 55·4	**42** 52·4	**47** 49·1	**52** 45·4	**57** 41·4
10	55·3	52·3	49·0	45·3	41·3
20	55·2	52·2	48·8	45·2	41·2
30	55·1	52·1	48·7	45·0	41·0
40	55·0	52·0	48·6	44·9	40·9
50	55·0	51·9	48·5	44·8	40·8
00	**38** 54·9	**43** 51·8	**48** 48·4	**53** 44·6	**58** 40·6
10	54·8	51·7	48·2	44·5	40·5
20	54·7	51·6	48·1	44·4	40·3
30	54·6	51·5	48·0	44·2	40·2
40	54·5	51·4	47·9	44·1	40·1
50	54·4	51·2	47·8	44·0	39·9
00	**39** 54·3	**44** 51·1	**49** 47·6	**54** 43·9	**59** 39·8
10	54·2	51·0	47·5	43·7	39·6
20	54·1	50·9	47·4	43·6	39·5
30	54·0	50·8	47·3	43·5	39·4
40	53·9	50·7	47·2	43·3	39·2
50	53·8	50·6	47·0	43·2	39·1
H.P.	L U	L U	L U	L U	L U
′	′ ′	′ ′	′ ′	′ ′	′ ′
54·0	1·1 1·7	1·3 1·9	1·5 2·1	1·7 2·4	2·0 2·6
54·3	1·4 1·8	1·6 2·0	1·8 2·2	2·0 2·5	2·3 2·7
54·6	1·7 2·0	1·9 2·2	2·1 2·4	2·3 2·6	2·5 2·8
54·9	2·0 2·2	2·2 2·3	2·3 2·5	2·5 2·7	2·7 2·9
55·2	2·3 2·3	2·5 2·4	2·6 2·6	2·8 2·8	3·0 2·9

Step 5: Determine the apparent altitude (ha).
Apparent altitude (ha) = hs ± IC ± dip
ha = 59° 58.6’ – 2.5’ – 7.5’ = 59° 48.6’

Step 6: Determine the horizontal parallax (HP) of the Moon.
For 24 February at 2322, the HP is 54.2’

Step 7: Determine main correction.
Apparent altitude: 59° 48.6’
Apparent altitude correction 1: +39.1’
Horizontal parallax: 54.2’
Limb observed (correction): Upper (-30’)
Apparent altitude correction 2: +2.7’
Total altitude correction: 39.1’ + 2.7’ – 30.0’ = +11.8’

Step 8: Determine the observed altitude (ho).
Observed altitude = ha ± MC
Observed altitude = 59° 48.6’ + 11.8’ = 60° 00.4’



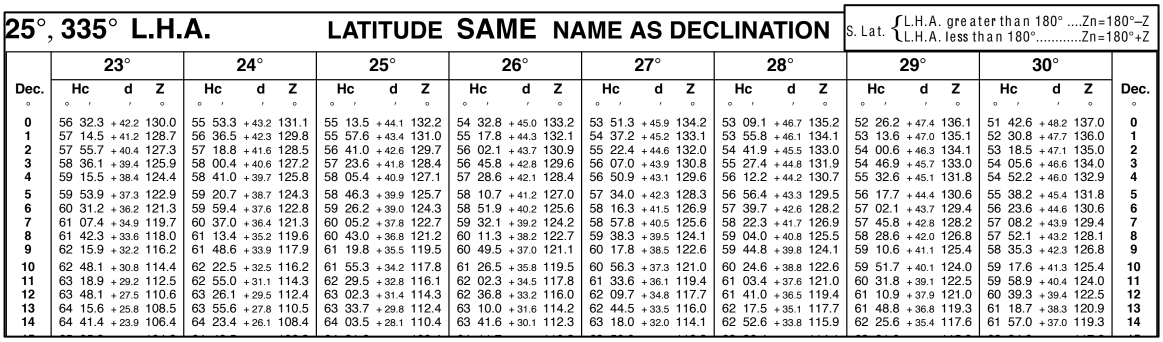
22ᵐ	SUN PLANETS	ARIES	MOON	v or d	Corrⁿ	v or d	Corrⁿ	v or d	Corrⁿ
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 30·0	5 30·9	5 15·0	0·0	0·0	6·0	2·3	12·0	4·5
01	5 30·3	5 31·2	5 15·2	0·1	0·0	6·1	2·3	12·1	4·5
02	5 30·5	5 31·4	5 15·4	0·2	0·1	6·2	2·3	12·2	4·6
03	5 30·8	5 31·7	5 15·7	0·3	0·1	6·3	2·4	12·3	4·6
04	5 31·0	5 31·9	5 15·9	0·4	0·2	6·4	2·4	12·4	4·7
05	5 31·3	5 32·2	5 16·2	0·5	0·2	6·5	2·4	12·5	4·7
06	5 31·5	5 32·4	5 16·4	0·6	0·2	6·6	2·5	12·6	4·7
07	5 31·8	5 32·7	5 16·6	0·7	0·3	6·7	2·5	12·7	4·8
08	5 32·0	5 32·9	5 16·9	0·8	0·3	6·8	2·6	12·8	4·8
09	5 32·3	5 33·2	5 17·1	0·9	0·3	6·9	2·6	12·9	4·8
10	5 32·5	5 33·4	5 17·4	1·0	0·4	7·0	2·6	13·0	4·9
11	5 32·8	5 33·7	5 17·6	1·1	0·4	7·1	2·7	13·1	4·9
12	5 33·0	5 33·9	5 17·8	1·2	0·5	7·2	2·7	13·2	5·0
13	5 33·3	5 34·2	5 18·1	1·3	0·5	7·3	2·7	13·3	5·0
14	5 33·5	5 34·4	5 18·3	1·4	0·5	7·4	2·8	13·4	5·0
15	5 33·8	5 34·7	5 18·5	1·5	0·6	7·5	2·8	13·5	5·1
16	5 34·0	5 34·9	5 18·8	1·6	0·6	7·6	2·9	13·6	5·1
17	5 34·3	5 35·2	5 19·0	1·7	0·6	7·7	2·9	13·7	5·1
18	5 34·5	5 35·4	5 19·3	1·8	0·7	7·8	2·9	13·8	5·2
19	5 34·8	5 35·7	5 19·5	1·9	0·7	7·9	3·0	13·9	5·2
20	5 35·0	5 35·9	5 19·7	2·0	0·8	8·0	3·0	14·0	5·3
21	5 35·3	5 36·2	5 20·0	2·1	0·8	8·1	3·0	14·1	5·3
22	5 35·5	5 36·4	5 20·2	2·2	0·8	8·2	3·1	14·2	5·3
23	5 35·8	5 36·7	5 20·5	2·3	0·9	8·3	3·1	14·3	5·4
24	5 36·0	5 36·9	5 20·7	2·4	0·9	8·4	3·2	14·4	5·4
25	5 36·3	5 37·2	5 20·9	2·5	0·9	8·5	3·2	14·5	5·4
26	5 36·5	5 37·4	5 21·2	2·6	1·0	8·6	3·2	14·6	5·5
27	5 36·8	5 37·7	5 21·4	2·7	1·0	8·7	3·3	14·7	5·5
28	5 37·0	5 37·9	5 21·6	2·8	1·1	8·8	3·3	14·8	5·6
29	5 37·3	5 38·2	5 21·9	2·9	1·1	8·9	3·3	14·9	5·6

Step 9: Determine the declination of the Moon.
Declination (hours): S 10° 52.8’ (d number: 8.8)
Declination (increment): 3.3’
Declination (total): 10° 52.8’ + 3.3’ = S 10° 56.1’

Step 10: Determine the GHA of the Moon.
GHA (hours): 277° 10.3’ (v number: 14.8)
GHA (increment): 5° 16.4’
GHA (v correction): 5.6’
GHA (total): 277° 10.3 + 5° 16.4’ + 5.6’ = 282° 32.3’

Step 11: Determine the assumed position of the ship.
DR latitude: 30° 28.3’ S
Assumed latitude: 30° S
DR longitude: 102° 39.3’ E
Assumed longitude (to ensure whole number of LHA): 102° 27.7’ E

Step 12: Determine the LHA for the Moon for the time of sight.



25°, 335° L.H.A. LATITUDE SAME NAME AS DECLINATION

S. Lat. {L.H.A. greater than 180° ....Zn=180°–Z
L.H.A. less than 180°............Zn=180°+Z

Dec.	23°			24°			25°			26°			27°			28°			29°			30°			Dec.
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	56 32.3	+42.2	130.0	55 53.3	+43.2	131.1	55 13.5	+44.1	132.2	54 32.8	+45.0	133.2	53 51.3	+45.9	134.2	53 09.1	+46.7	135.2	52 26.2	+47.4	136.1	51 42.6	+48.2	137.0	0
1	57 14.5	+41.2	128.7	56 36.5	+42.3	129.8	55 57.6	+43.4	131.0	55 17.8	+44.3	132.1	54 37.2	+45.2	133.1	53 55.8	+46.1	134.1	53 13.6	+47.0	135.1	52 30.8	+47.7	136.0	1
2	57 55.7	+40.4	127.3	57 18.8	+41.6	128.5	56 41.0	+42.6	129.7	56 02.1	+43.7	130.9	55 22.4	+44.6	132.0	54 41.9	+45.5	133.0	54 00.6	+46.3	134.1	53 18.5	+47.1	135.0	2
3	58 36.1	+39.4	125.9	58 00.4	+40.6	127.2	57 23.6	+41.8	128.4	56 45.8	+42.8	129.6	56 07.0	+43.9	130.8	55 27.4	+44.8	131.9	54 46.9	+45.7	133.0	54 05.6	+46.6	134.0	3
4	59 15.5	+38.4	124.4	58 41.0	+39.7	125.8	58 05.4	+40.9	127.1	57 28.6	+42.1	128.4	56 50.9	+43.1	129.6	56 12.2	+44.2	130.7	55 32.6	+45.1	131.8	54 52.2	+46.0	132.9	4
5	59 53.9	+37.3	122.9	59 20.7	+38.7	124.3	58 46.3	+39.9	125.7	58 10.7	+41.2	127.0	57 34.0	+42.3	128.3	56 56.4	+43.3	129.5	56 17.7	+44.4	130.6	55 38.2	+45.4	131.8	5
6	60 31.2	+36.2	121.3	59 59.4	+37.6	122.8	59 26.2	+39.0	124.3	58 51.9	+40.2	125.6	58 16.3	+41.5	126.9	57 39.7	+42.6	128.2	57 02.1	+43.7	129.4	56 23.6	+44.6	130.6	6
7	61 07.4	+34.9	119.7	60 37.0	+36.4	121.3	60 05.2	+37.8	122.7	59 32.1	+39.2	124.2	58 57.8	+40.5	125.6	58 22.3	+41.7	126.9	57 45.8	+42.8	128.2	57 08.2	+43.9	129.4	7
8	61 42.3	+33.6	118.0	61 13.4	+35.2	119.6	60 43.0	+36.8	121.2	60 11.3	+38.2	122.7	59 38.3	+39.5	124.1	59 04.0	+40.8	125.5	58 28.6	+42.0	126.8	57 52.1	+43.2	128.1	8
9	62 15.9	+32.2	116.2	61 48.6	+33.9	117.9	61 19.8	+35.5	119.5	60 49.5	+37.0	121.1	60 17.8	+38.5	122.6	59 44.8	+39.8	124.1	59 10.6	+41.1	125.4	58 35.3	+42.3	126.8	9
10	62 48.1	+30.8	114.4	62 22.5	+32.5	116.2	61 55.3	+34.2	117.8	61 26.5	+35.8	119.5	60 56.3	+37.3	121.0	60 24.6	+38.8	122.6	59 51.7	+40.1	124.0	59 17.6	+41.3	125.4	10
11	63 18.9	+29.2	112.5	62 55.0	+31.1	114.3	62 29.5	+32.8	116.1	62 02.3	+34.5	117.8	61 33.6	+36.1	119.4	61 03.4	+37.6	121.0	60 31.8	+39.1	122.5	59 58.9	+40.4	124.0	11
12	63 48.1	+27.5	110.6	63 26.1	+29.5	112.4	63 02.3	+31.4	114.3	62 36.8	+33.2	116.0	62 09.7	+34.8	117.7	61 41.0	+36.5	119.4	61 10.9	+37.9	121.0	60 39.3	+39.4	122.5	12
13	64 15.6	+25.8	108.5	63 55.6	+27.8	110.5	63 33.7	+29.8	112.4	63 10.0	+31.6	114.2	62 44.5	+33.5	116.0	62 17.5	+35.1	117.7	61 48.8	+36.8	119.3	61 18.7	+38.3	120.9	13
14	64 41.4	+23.9	106.4	64 23.4	+26.1	108.4	64 03.5	+28.1	110.4	63 41.6	+30.1	112.3	63 18.0	+32.0	114.1	62 52.6	+33.8	115.9	62 25.6	+35.4	117.6	61 57.0	+37.0	119.3	14

GHA (Moon): 282° 32.3’
Assumed longitude: 102° 27.7’ E
LHA (Moon): 282° 32.3’ + 102° 27.7’ E (-360°) = 25° (-west, +east)

Step 13: Entering publication HO229 with assumed latitude, declination, and LHA, retrieve the computed altitude (hc), altitude difference (d), and azimuth (z) for the assumed position.

Assumed latitude: 30° S
Declination: S 10° (increments solved in step 14)
LHA: 25° (Same Pages)

HO 229 values:
Computed altitude (hc): 59° 17.6’
Altitude difference (d): + 41.3’
Azimuth (z): 125.4°

Step 14: Determine the azimuth correction for the sight (to account for increments of declination ignored in step 13).

By increasing the value of each argument by 1 whole increment, triple interpolate for the exact values of azimuth (for detailed instructions see Part 14).

	Base Value	Base Z	Next incremental Z	Difference in Z	Increment	Correction *(Diff Z x Increment) / 60*
Latitude – S	30°	125.4°	-	-	00.0’	0
Declination – S	10°	125.4°	124.0°	-1.4’	56.1’	-1.3°
LHA	25°	125.4°	-	-	00.0’	0

Total correction = -1.3°

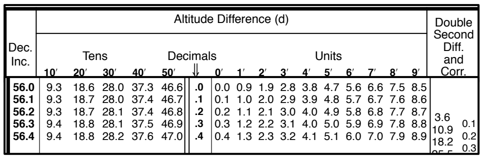
Step 15: Apply the correction to the base values to determine true azimuth.
Base azimuth: 125.4°
Correction: -1.3°
Corrected azimuth: 125.4° - 1.3° = 124.1°
Note - Check azimuth rules: if LHA less than 180°, then zn = 180° + z.

Corrected azimuth: 180° + 124.1° = **304.1° T**

Step 16: Determine the computed altitude (hc).
Tabular computed altitude: 59° 17.6’
Altitude difference (d): +41.3’
Declination: S 10° 56.1’
Declination increments: 56.1’

Altitude difference correction:
Tens: 37.4’
Units/decimals: 1.2’
Total correction: 37.4’+1.2’ = 38.6’

Tabular hc: 59° 17.6’
Altitude difference correction:
+38.6’
hc: 59° 17.6’ + 38.6’ = 59° 56.2’

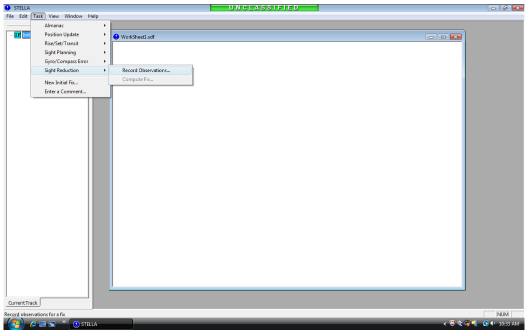


Dec. Inc.	Altitude Difference (d)																Double Second Diff. and Corr.
	Tens					Decimals	Units										
	10′	20′	30′	40′	50′	⇓	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	
56.0	9.3	18.6	28.0	37.3	46.6	**.0**	0.0	0.9	1.9	2.8	3.8	4.7	5.6	6.6	7.5	8.5	
56.1	9.3	18.7	28.0	37.4	46.7	**.1**	0.1	1.0	2.0	2.9	3.9	4.8	5.7	6.7	7.6	8.6	
56.2	9.3	18.7	28.1	37.4	46.8	**.2**	0.2	1.1	2.1	3.0	4.0	4.9	5.8	6.8	7.7	8.7	3.6
56.3	9.4	18.8	28.1	37.5	46.9	**.3**	0.3	1.2	2.2	3.1	4.0	5.0	5.9	6.9	7.8	8.8	0.1 10.9
56.4	9.4	18.8	28.2	37.6	47.0	**.4**	0.4	1.3	2.3	3.2	4.1	5.1	6.0	7.0	7.9	8.9	0.2 18.2 0.3

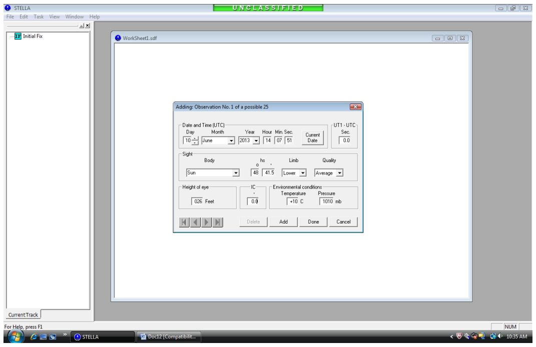
Step 17: Determine the intercept (a).
Computed altitude (hc): 59° 56.2’
Observed altitude (ho): 60° 00.4’
Intercept (a): ho - hc = 60° 00.4’ – 59° 56.2’ = **4.2’**
If ho is greater, intercept is **towards.**
If hc is greater, intercept is away.

STELLA Calculations (for any Celestial Body)

Step 1: Task>Sight Reduction>Record Observations.



Step 2: Enter appropriate data.



Adding: Observation No. 1 of a possible 25

Date and Time (UTC): Day 10, Month June, Year 2013, Hour 14, Min. 07, Sec. 51

UT1 - UTC Sec.: 0.0

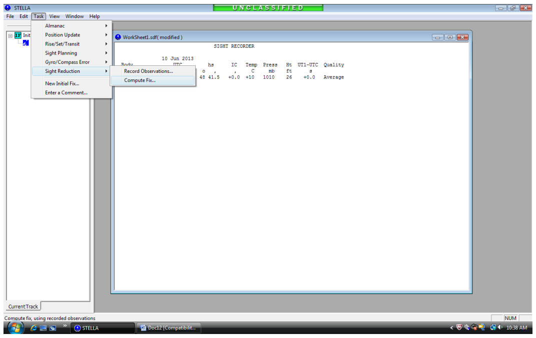
Sight: Body Sun, hs 48° 41.5', Limb Lower, Quality Average

Height of eye: 026 Feet

IC ': 0.0

Environmental conditions: Temperature +10 C, Pressure 1010 mb

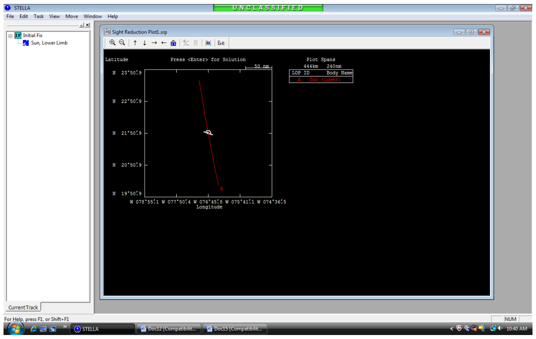
Step 3: Task>Sight Reduction> Compute Fix.



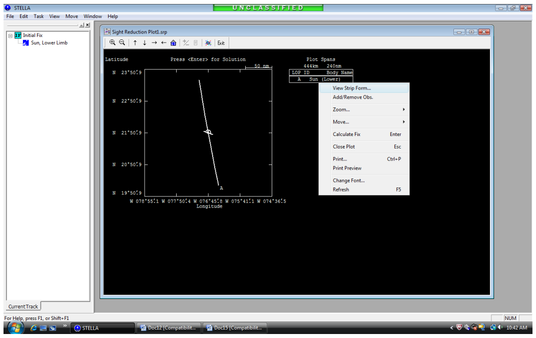
```
                    SIGHT RECORDER

           10 Jun 2013
Body        UTC       hs      IC   Temp  Press  Ht  UT1-UTC  Quality
                    o  ,      ,     C     mb    ft     s
                   48 41.5  +0.0  +10   1010   26    +0.0   Average
```

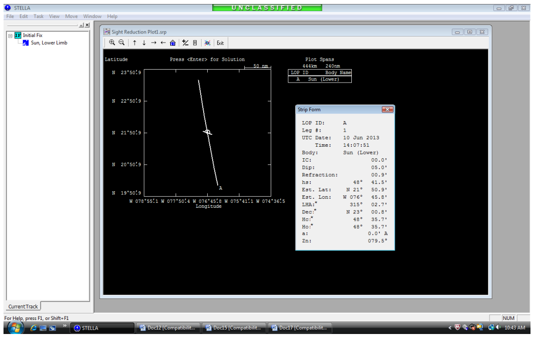
Step 4: Observe LOP and hit “Enter”



Step 5: Right click and "View Strip Form"



Step 6: Record observation data in ship's navigation log.



```
LOP ID:       A
Leg #:        1
UTC Date:     10 Jun 2013
    Time:     14:07:51
Body:         Sun (Lower)
IC:                    00.0'
Dip:                   05.0'
Refraction:            00.9'
hs:              48°   41.5'
Est. Lat:      N 21°   50.9'
Est. Lon:     W 076°   45.8'
LHA:*           315°   02.7'
Dec:*          N 23°   00.8'
Hc:*             48°   35.7'
Ho:*             48°   35.7'
a:                    0.0' A
Zn:                   079.5°
```

Advanced Theory

It is possible to directly calculate the computed height and azimuth angle to any body at any time, without using the Sight Reduction Tables (HO229). The formulae are:

$\sin Hc = \sin(L) \sin(d) + \cos(L) \cos(d) \cos(LHA)$ Equation (1)

$\cos A = (\sin(d) - \sin(L) \sin(Hc)) / \cos(L) \cos(Hc)$ Equation (2)

Where the variables (all in decimal notation) are:
Hc is computed height
L is latitude
d is declination
LHA is LHA

Part 6: Learning and Teaching

In which we discuss opportunities for practicing celestial navigation, other helpful resources, and a primer for teaching celestial navigation to shipmates, even if you are not a master yourself.

Chapter 13: Opportunities for Learning

Practice Makes Perfect

Learning celestial navigation is like any other great challenge in life: losing weight, learning a language, or figuring out what they served for lunch in the galley. The hardest part is the beginning. After that it gets easier.

However, it is *definitely* a skill that disappears with age…you must practice to maintain proficiency. Each time you get underway, at least try to determine gyro error by amplitude of the sun or latitude at local apparent noon to keep yourself fresh.

Zero to Hero in One Patrol

Long patrols and boring watches are the best time to learn celestial navigation! Review this text and the paragraphs below, and break up your patrol into 10 sections, covering each topic listed below, and by the time you return to homeport, you'll be the ship's expert in celestial navigation, guaranteed!

How to Learn Celestial Navigation

If you face the unenviable task of having to teach yourself celestial navigation, the best method is to avoid strip-forms and STELLA completely.

If you can master the concepts behind basic celestial navigation, the rest will come exceptionally easy. Try to begin with a good book, such as "Celestial Navigation in a Nutshell," or "Commonsense Celestial Navigation" (or this text) and stick with the tasks until they are mastered.

Begin with the sun – it is the biggest object in the sky and the easiest to measure. Once the concepts with the sun are mastered, planets, stars, the moon, and other tasks are only slight variations on the theme.

Spend lots of time in the Nautical Almanac familiarizing yourself with its tables and figures.

Try to seek out as many different sources of knowledge as possible – each person learns differently, and a combination of books, videos, and internet articles will generally suffice for most people.

Recommended Methods of Teaching Celestial Navigation

The best way to teach celestial navigation is through measured progress in a particular course of study, over the course of 10 lessons. Try to keep each lesson to less than 30 minutes, but ensure students have time in between lessons to completely master the concepts, either through "homework problems" or through additional sessions of the same topic.

For an example of the recommended celestial navigation teaching process, refer to the Practical Navigator website (www.practicalnavigator.org) and watch the Celestial Navigation Video Series.

If possible, master each task completely before moving on!

Task 1: Time of Phenomenon

Task 2: Gyro Error by Amplitude

Task 3: The Marine Sextant and Standard Corrections

Task 4: The Noon Sight

Task 5: The Pole Star

Task 6: The Sunline and Running Fix

Task 7: Gyro Error by Azimuth

Task 8: The Planets and Stars

Task 9: The Moon

Task 10: Advanced Concepts

Chapter 14: Going Further in Celestial Navigation

Understanding Accuracy

People are often frustrated by the fact that their "fix" is several miles away from the GPS position of the ship. No doubt GPS has relegated celestial navigation to a background in the toolbox of navigation. However, when simply navigating from place to place, it is seldom necessary to be extremely accurate in your position fixing.

Certainly when in the vicinity of reefs or hazards, knowing your position to within 10 meters is a huge advantage. But when in the deep ocean, celestial lines of position which are within 3-5 miles of the "actual" ship's position are excellent work. Within 5-10 miles, the work is still satisfactory for ocean navigation. Beyond 10 miles, there was likely a mistake in the procedures.

Any sights which come out less than 3 miles from the actual position of the ship are all statistically equivalent – so if you are "right on," good job – but it is likely a statistical fluke – the human eye is not capable of observing objects to such a resolution regularly. So no boasting about your fix, please!

When learning celestial navigation, be patient, and realize that it is not an exact science – in fact it is more art than science.

Recommended Resources

The free website www.practicalnavigator.org features written texts such as the one you are reading, as well as:

The Cutterman's Guide to Navigation Problems – a 320 page text which covers all manner of navigational mathematics, from fuel consumption problems, to visibility of light problems, to complex celestial navigation problems and everything in between. Designed for advanced Coast Guard and Naval Watch Officers, as well as Professional Merchant Mariners up to the 1600 ton Oceans level. Solves every type of navigational mathematics problems found on Merchant Mariner exams.

The Bridge Navigation Refresher Guidebook – an 88 page primer for refreshing Coast Guard bridge crews on navigational mathematics and maneuvering board techniques. Covers contact determination, true wind, desired wind, and avoidance/intercept problems on the maneuvering board, as well as other topics useful to bridge crews such as the 6 rules of dead reckoning, anchoring swing and drag circles, and the radian rule.

The Cutterman's Guide to Maneuvering Boards – coming soon.

Additionally, the site features dozens of training videos including an 11 part celestial navigation course which receives positive reviews on YouTube, as well as maneuvering board and bridge fundamental training videos.

Recommended Books

The Barefoot Navigator
http://www.amazon.com/The-Barefoot-Navigator-Jack-Lagan/dp/1574092324

Emergency Navigation
http://www.amazon.com/Emergency-Navigation-Improvised-No-Instrument-Methods/dp/0071481842/

Celestial Navigation in a Nutshell (an awesome primer for the basic theory)
http://www.amazon.com/Celestial-Navigation-Nutshell-Seafarer-Books/dp/1574090585/

Celestial Navigation for Yachtsmen
http://www.amazon.com/Celestial-Navigation-Yachtsmen-Mary-Blewitt/dp/0070059284/

Celestial Navigation in the GPS Age (deals more with the math behind the theory)
http://www.amazon.com/Celestial-Navigation-GPS-John-Karl/dp/0939837757/

Celestial Navigation
http://www.amazon.com/Celestial-Navigation-Tom-Cunliffe-ebook/dp/B00EQ8J4I6/

Appendices

Simplified Steps for Manual Calculation of All Problems

SUNRISE or SUNSET

Step 1: Locate bracketing values for your latitude from the Nautical Almanac.

Step 2: Identify the difference from the bracketing values to your latitude.

Step 3: Correct the sunrise/sunset values for latitude, either using mental interpolation or Table 1 in the Nautical Almanac.

Step 4: Determine the difference in longitude from your DR position to the standard meridian being observed by your ship's clocks.

Step 5: Convert the difference obtained in step 4 to time using the Conversion of Arc to Time table in the Nautical Almanac.

Step 6: Correct the value from step 3 for longitude to obtain your answer.

MOONRISE or MOONSET

Step 1: Locate bracketing values for your latitude from the Nautical Almanac.

Step 2: Identify the difference from the bracketing values to your latitude.

Step 3: Correct the sunrise/sunset values for latitude, either using mental interpolation or Table 1 in the Nautical Almanac.

Step 4: Determine the difference in longitude from your DR position to the standard meridian being observed by your ship's clocks.

Step 5: Convert the difference obtained in step 4 to time using the Conversion of Arc to Time table in the Nautical Almanac.

Step 6: Correct the value from step 3 for longitude.

Step 7: Perform the same calculation for the following day (west longitude) or preceding day (east longitude) and utilize Table 2 in the Nautical Almanac to determine your answer.

GYRO ERROR BY AMPLITUDE

Step 1: Determine the declination of the sun using the Nautical Almanac (interpolate if necessary).

Step 2: Determine the ship's latitude at the time of observation.

Step 3: Utilize Table 22 in Bowditch to determine the Amplitude of the Sun (interpolate if necessary).

Step 4: Determine the calculated bearing to sunrise or sunset, and compare it to the measured value to determine Gyro Compass Error using the following aid:

G-E-T or (Gyro Best, Error West! Gyro Least, Error East!)

LATITUDE AT LAN

Step 1: Measure the sun's altitude at the time of meridian passage (when the sun is highest in the sky, either due south or due north of you).

Step 2: Determine declination of the sun for the time of observation.

Step 3: Determine the observed altitude of the sun, by making all three standard sextant corrections.

Step 4: Determine the zenith distance of the sight by subtracting the observed altitude from 90°.

Step 5: Determine latitude by using one of the four situations:

If the ship is in the opposite hemisphere as the sun:
Latitude = Zenith Distance - Body's Declination.

If the ship is directly beneath the sun:
Latitude = Body's Declination

If ship is in same hemisphere as sun, but higher latitude:
Latitude = Zenith Distance + Declination

If the ship is in same hemisphere as sun, but lower latitude:
Latitude = Declination – Zenith Distance

LATITUDE BY POLARIS

Step 1: Observe Polaris and determine the apparent altitude by correcting the sextant reading for 3 standard corrections.

Step 2: Determine the GHA of Aries for the time of the sight.

Step 3: Determine the LHA of Polaris (LHA = GHA – (Long W) or (+Long E))

Step 4: Enter Polaris Tables and compute Latitude.

GYRO ERROR BY POLARIS

Step 1: Determine the GHA of Aries for the time of the sight.

Step 2: Determine the LHA of Polaris (LHA = GHA – (Long W) or (+Long E))

Step 3: Enter Polaris Tables and retrieve calculated azimuth.

Step 4: Compare the calculated azimuth to the measured value to determine Gyro Compass Error using the following aid:

G-E-T or "Gyro Best, Error West. Gyro Least, Error East"

GYRO ERROR BY AZIMUTH OF THE SUN

Step 1: Determine the declination of the sun using the Nautical Almanac (interpolate if necessary).

Step 2: Determine the GHA of the Sun for the time of sight.

Step 2: Determine the LHA of the Sun for the time of sight.

Step 3: Enter the Sight Reduction Tables (HO229) with Latitude, Declination, and LHA.

Step 4: After correcting the azimuth figure if necessary (using the conversion table at the top and bottom of each page), utilize a triple interpolation table method to determine the final azimuth.

Step 5: Compare the calculated azimuth to the observed azimuth to determine gyro compass error utilizing the acronym:

G-E-T or "Gyro Best, Error West. Gyro Least, Error East"

In summary, the steps to determine an LOP from the Sun:

Step 1: Measure the altitude of the body using a sextant and make 3 standard sextant corrections.

Step 2: Determine the Geographic Position (GHA and Declination) of the body.

Step 3: Determine the entering arguments for HO229 by obtaining whole numbers of Latitude, Declination, and LHA (LHA is obtained by subtracting (western hemisphere) or adding (eastern hemisphere) the assumed longitude from the GHA of the sun.

Step 4: Retrieve the computed height and azimuth from HO229, and correct each for increments of declination.

Step 5: Plot the line of position.

In summary, the steps to determine an LOP from any body:

Step 1: Measure the altitude of the body using a sextant and make 3 standard sextant corrections.

Step 2: Determine the Geographic Position (GHA and Declination) of the body.
For stars: GHA = GHA (Aries) + SHA
For planets: ensure v corrections are completed when necessary
For the Moon: ensure v and HP corrections are completed when necessary.

Step 3: Determine the entering arguments for HO229 by obtaining whole numbers of Latitude, Declination, and LHA (LHA is obtained by subtracting (western hemisphere) or adding (eastern hemisphere) the assumed longitude from the GHA of the body.

Step 4: Retrieve the computed height and azimuth from HO229, and correct each for increments of declination.

Step 5: Plot the line of position.

Primer on Basic Calculations Used in this Text

Reproduced from *The Cutterman's Guide to Navigation Problems* (Preface)

Certain basic calculations are necessary for successfully solving later, more advanced problems. This serves as a refresher for basic navigational calculations.

Converting Positions to and from Decimal Notation

Given a standard position in latitude and longitude, converting to decimal notation is completed by dividing the minutes of position by 60.

Problem A-1. Convert 24° 15.7' N into decimal notation.

Step 1: Break the initial position into degrees and minutes of position.
24° 15.7' = 24° + 15.7'

Step 2: Divide the minutes of position by 60.
$\frac{15.7'}{60} = 0.262°$

Step 3: Combine the degrees and decimals of position into a final answer.
24° + 0.262° = **24.262° N**

Given a decimal position in latitude and longitude, converting to standard notation is completed by multiplying the decimal portion of the position by 60.

Problem A-2. Convert 133.673° W into standard notation.

Step 1: Break the initial position into degrees and decimals of position.
133.673° = 133° + 0.673°

Step 2: Multiply the decimal of position by 60.
0.673° × 60 = 40.38'

Step 3: Combine the degrees and minutes of position into a final answer.
133° + 40.38' = **133° 40.38' W**

Converting Time into Decimal Notation

Given a standard time, converting to decimal notation is completed by dividing the minutes by 60.

Problem A-3. Convert 3 hours and 16 minutes into decimal notation.

Step 1: Break the initial position into degrees and minutes of position.
3 hours, 16 minutes = 3 hours + 16 minutes.

Step 2: Divide the minutes of position by 60.
$\frac{16}{60}$ = 0.266 hours.

Step 3: Combine the degrees and decimals of position into a final answer.
3 hours + 0.266 hours = **3.266 hours**

Given a decimal time, converting to standard notation is completed by multiplying the decimal portion by 60.

Problem A-4. Convert 4.277 hours into standard notation of hours and minutes, and then again into hours, minutes, and seconds.

Step 1: Break the initial position into degrees and decimals of position.
4.277 hours = 4 hours + 0.277 hours.

Step 2: Multiply the decimal portion by 60.
0.277 × 60 = 16.62 minutes.

Step 3: Combine the degrees and minutes of position into a final answer.
4 hours + 16.62 minutes = **4 hours, 16.62 minutes.**

Step 4: If necessary, converting decimal minutes to seconds is accomplished the same way.
16.62 minutes = 16 minutes + 0.62 minutes.
0.62 × 60 = 37.2 seconds.
16.62 minutes = 16 minutes, 37.2 seconds.
Thus the total answer would be **4 hours, 16 minutes, 37.2 seconds.**

Converting Time Between Zone Time and GMT

Depending on the problem, it is sometimes convenient to work exclusively in Zone Time or GMT. So if a problem describes times in multiple formats, it is necessary to convert to or from GMT.

Problem A-5. If the current ship time is 0834 and the ship is observing ZD (+4), what is the time in GMT?

Step 1: To correct zone time to GMT in the western hemisphere, add the zone descriptor to the ship time.
0834 + 0400 = **1234.**

Problem A-6. If the current ship time is 0834, and the ship is observing ZD (-4), what is the time in GMT?

Step 1: To correct zone time to GMT in the eastern hemisphere, subtract the zone descriptor from the ship time.
0834 - 0400 = **0434.**

Adding Degrees and Minutes

Adding degrees and minutes causes the most arithmetic errors when solving navigation problems, because the degree system is based on 60, not 100. It is usually best to complete the math in two steps:

Problem A-7. Add the following two latitudes. 23° 47.3’ N and 11° 33.9’ N.

Step 1: Add the whole degrees first and then the minutes.
23° 47.3 + 11° 33.9’ = (23° + 11°) + (47.3’ + 33.9’) = 34° + 81.2’

Step 2: Convert the minutes into degrees and minutes.
81.2’ = 1° + 21.2’

Step 3: Sum the parts.
34° + 1° + 21.2’ = **35° 21.2’ N**

Problem A-8. Sum the following two latitudes. 23° 17.3’ N and 11° 33.9’ S. Sometimes when subtracting minutes, it is helpful convert 1° to minutes (e.g. subtract 1° but add 60’ to the minutes value).

Step 1: Subtract 1° and then add 60’ to the first value to make the math easy.
$\underline{23° 17.3’}$ + (-11° 33.9’) = $\underline{22° 77.3’}$ + (-11.33.9’)

Step 2: Add the whole degrees first and then the minutes.
(22° + (-11°)) + (77.3’ + (-33.9)) = 11° + 43.4’

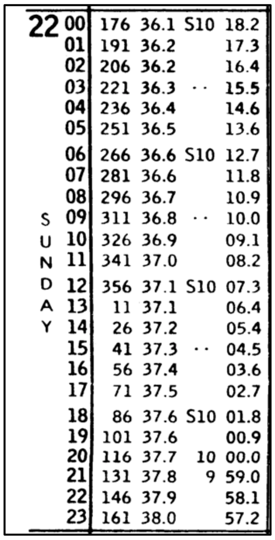
Step 3: Sum the parts.
11° + 43.4’ = **11° 43.4’ N**

Interpolating for Values of Greenwich Hour Angle

In order to save space in the almanac, values of Greenwich Hour Angle in the Nautical Almanac are given only for whole hours. Unless observations are made on the hour, interpolation is necessary. This principle applies for all celestial bodies, and the correction is always added.

Problem A-9. It is 22 February and you make an observation of the sun at 15:48:13 UTC. The tabular value of GHA of the sun for 1500 UTC is 41° 37.3’. What is the calculated GHA of the sun for the time of observation?

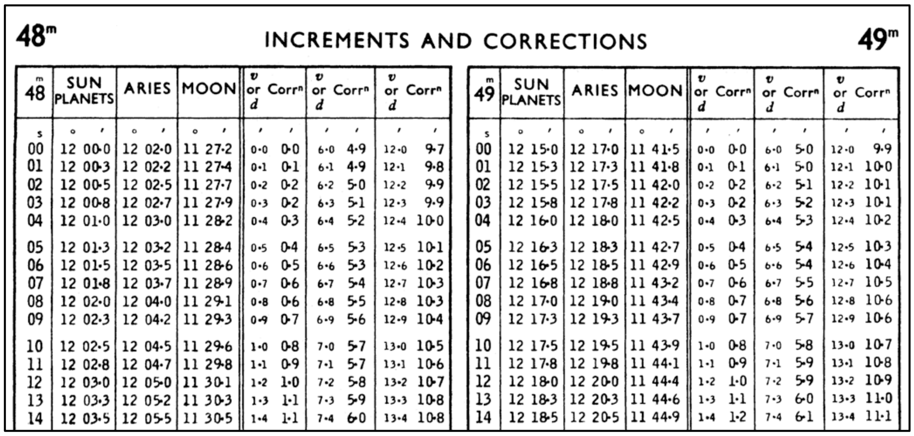
Step 1: Note the tabular value of GHA for the next lower whole hour (1500 UTC in this case).
1500 UTC = 41° 37.3’.



22	00	176 36.1	S10	18.2
	01	191 36.2		17.3
	02	206 36.2		16.4
	03	221 36.3	· ·	15.5
	04	236 36.4		14.6
	05	251 36.5		13.6
	06	266 36.6	S10	12.7
	07	281 36.6		11.8
	08	296 36.7		10.9
S	09	311 36.8	· ·	10.0
U	10	326 36.9		09.1
N	11	341 37.0		08.2
D	12	356 37.1	S10	07.3
A	13	11 37.1		06.4
Y	14	26 37.2		05.4
	15	41 37.3	· ·	04.5
	16	56 37.4		03.6
	17	71 37.5		02.7
	18	86 37.6	S10	01.8
	19	101 37.6		00.9
	20	116 37.7	10	00.0
	21	131 37.8	9	59.0
	22	146 37.9		58.1
	23	161 38.0		57.2

Step 2: Determine the difference in time between the time of observation and the next lower whole hour (1500 UTC in this case).
Observation – 15:48:13
Whole Hours – 15:00:00
Difference = 15:48:13 – 15:00:00 = 00:48:13

Step 3: Enter the Increments and Corrections pages in the Nautical Almanac and find the value for 48 minutes and 13 seconds in the “Sun/Planets” column.
48 minutes 13 seconds: 12° 03.3’ correction



48^{m} INCREMENTS AND CORRECTIONS 49^{m}

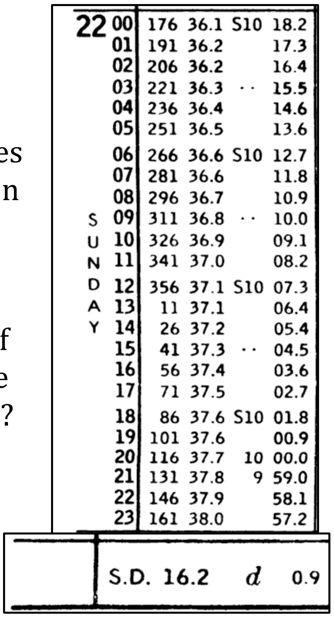
m 48	SUN PLANETS	ARIES	MOON	v or d	Corr^{n}	v or d	Corr^{n}	v or d	Corr^{n}
s	° ′	° ′	° ′	′	′	′	′	′	′
00	12 00·0	12 02·0	11 27·2	0·0	0·0	6·0	4·9	12·0	9·7
01	12 00·3	12 02·2	11 27·4	0·1	0·1	6·1	4·9	12·1	9·8
02	12 00·5	12 02·5	11 27·7	0·2	0·2	6·2	5·0	12·2	9·9
03	12 00·8	12 02·7	11 27·9	0·3	0·2	6·3	5·1	12·3	9·9
04	12 01·0	12 03·0	11 28·2	0·4	0·3	6·4	5·2	12·4	10·0
05	12 01·3	12 03·2	11 28·4	0·5	0·4	6·5	5·3	12·5	10·1
06	12 01·5	12 03·5	11 28·6	0·6	0·5	6·6	5·3	12·6	10·2
07	12 01·8	12 03·7	11 28·9	0·7	0·6	6·7	5·4	12·7	10·3
08	12 02·0	12 04·0	11 29·1	0·8	0·6	6·8	5·5	12·8	10·3
09	12 02·3	12 04·2	11 29·3	0·9	0·7	6·9	5·6	12·9	10·4
10	12 02·5	12 04·5	11 29·6	1·0	0·8	7·0	5·7	13·0	10·5
11	12 02·8	12 04·7	11 29·8	1·1	0·9	7·1	5·7	13·1	10·6
12	12 03·0	12 05·0	11 30·1	1·2	1·0	7·2	5·8	13·2	10·7
13	12 03·3	12 05·2	11 30·3	1·3	1·1	7·3	5·9	13·3	10·8
14	12 03·5	12 05·5	11 30·5	1·4	1·1	7·4	6·0	13·4	10·8

m 49	SUN PLANETS	ARIES	MOON	v or d	Corr^{n}	v or d	Corr^{n}	v or d	Corr^{n}
s	° ′	° ′	° ′	′	′	′	′	′	′
00	12 15·0	12 17·0	11 41·5	0·0	0·0	6·0	5·0	12·0	9·9
01	12 15·3	12 17·3	11 41·8	0·1	0·1	6·1	5·0	12·1	10·0
02	12 15·5	12 17·5	11 42·0	0·2	0·2	6·2	5·1	12·2	10·1
03	12 15·8	12 17·8	11 42·2	0·3	0·2	6·3	5·2	12·3	10·1
04	12 16·0	12 18·0	11 42·5	0·4	0·3	6·4	5·3	12·4	10·2
05	12 16·3	12 18·3	11 42·7	0·5	0·4	6·5	5·4	12·5	10·3
06	12 16·5	12 18·5	11 42·9	0·6	0·5	6·6	5·4	12·6	10·4
07	12 16·8	12 18·8	11 43·2	0·7	0·6	6·7	5·5	12·7	10·5
08	12 17·0	12 19·0	11 43·4	0·8	0·7	6·8	5·6	12·8	10·6
09	12 17·3	12 19·3	11 43·7	0·9	0·7	6·9	5·7	12·9	10·6
10	12 17·5	12 19·5	11 43·9	1·0	0·8	7·0	5·8	13·0	10·7
11	12 17·8	12 19·8	11 44·1	1·1	0·9	7·1	5·9	13·1	10·8
12	12 18·0	12 20·0	11 44·4	1·2	1·0	7·2	5·9	13·2	10·9
13	12 18·3	12 20·3	11 44·6	1·3	1·1	7·3	6·0	13·3	11·0
14	12 18·5	12 20·5	11 44·9	1·4	1·2	7·4	6·1	13·4	11·1

Step 4: Apply the correction to the tabular GHA for whole hours. The correction is always added.
GHA for 1500 UTC = 41° 37.3’
Correction = 12° 03.3’
Total GHA = 41° 37.3’ + 12° 03.3’ = **53° 40.6’**

Interpolating for Values of Declination

In order to save space in the almanac, values of declination in the Nautical Almanac are given only for whole hours. Unless observations are made on the hour, interpolation is necessary. This principle applies for all celestial bodies. The correction is either added or subtracted, depending on the trend of hourly declination.



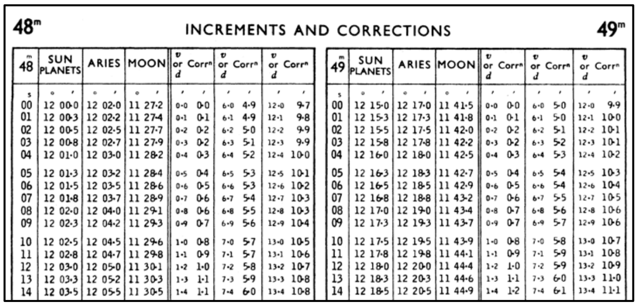
22	00	176 36.1	S10 18.2
	01	191 36.2	17.3
	02	206 36.2	16.4
	03	221 36.3	· · 15.5
	04	236 36.4	14.6
	05	251 36.5	13.6
	06	266 36.6	S10 12.7
	07	281 36.6	11.8
	08	296 36.7	10.9
S	09	311 36.8	· · 10.0
U	10	326 36.9	09.1
N	11	341 37.0	08.2
D	12	356 37.1	S10 07.3
A	13	11 37.1	06.4
Y	14	26 37.2	05.4
	15	41 37.3	· · 04.5
	16	56 37.4	03.6
	17	71 37.5	02.7
	18	86 37.6	S10 01.8
	19	101 37.6	00.9
	20	116 37.7	10 00.0
	21	131 37.8	9 59.0
	22	146 37.9	58.1
	23	161 38.0	57.2
		S.D. 16.2	*d* 0.9

Typically, mental interpolation is sufficient, however, the concept of *d* correction ensures accuracy. The abbreviated process is to note the daily *d* value at the bottom of each daily page. Then, enter the Increments and Corrections pages for the minutes necessary, finding the appropriate *d* value on that page and noting the correction.

<u>Problem A-10</u>. It is 22 February and you make an observation of the sun at 15:48:13 UTC. The tabular value of declination of the sun at 1500 UTC is S 10° 04.5'. What is the calculated declination of the sun for the time of observation?

Step 1: Note the tabular value of declination for the next lower whole hour (1500 UTC in this case).
1500 UTC = <u>S 10° 04.5'</u>.

Step 2: Determine the difference in time between the time of observation and the next lower whole hour (1500 UTC in this case). Rounding to the nearest minute is sufficient.
Observation – 15:48:13
Whole Hours – 15:00:00
Difference = 15:48:13 – 15:00:00 = <u>48 min.</u>



48^m INCREMENTS AND CORRECTIONS 49^m

48^m	SUN PLANETS	ARIES	MOON	v or d	Corr^n	v or d	Corr^n	v or d	Corr^n
s	° ′	° ′	° ′	′	′	′	′	′	′
00	12 00·0	12 02·0	11 27·2	0·0	0·0	6·0	4·9	12·0	9·7
01	12 00·3	12 02·2	11 27·4	0·1	0·1	6·1	4·9	12·1	9·8
02	12 00·5	12 02·5	11 27·7	0·2	0·2	6·2	5·0	12·2	9·9
03	12 00·8	12 02·7	11 27·9	0·3	0·2	6·3	5·1	12·3	9·9
04	12 01·0	12 03·0	11 28·2	0·4	0·3	6·4	5·2	12·4	10·0
05	12 01·3	12 03·2	11 28·4	0·5	0·4	6·5	5·3	12·5	10·1
06	12 01·5	12 03·5	11 28·6	0·6	0·5	6·6	5·3	12·6	10·2
07	12 01·8	12 03·7	11 28·9	0·7	0·6	6·7	5·4	12·7	10·3
08	12 02·0	12 04·0	11 29·1	0·8	0·6	6·8	5·5	12·8	10·3
09	12 02·3	12 04·2	11 29·3	0·9	0·7	6·9	5·6	12·9	10·4
10	12 02·5	12 04·5	11 29·6	1·0	0·8	7·0	5·7	13·0	10·5
11	12 02·8	12 04·7	11 29·8	1·1	0·9	7·1	5·7	13·1	10·6
12	12 03·0	12 05·0	11 30·1	1·2	1·0	7·2	5·8	13·2	10·7
13	12 03·3	12 05·2	11 30·3	1·3	1·1	7·3	5·9	13·3	10·8
14	12 03·5	12 05·5	11 30·5	1·4	1·1	7·4	6·0	13·4	10·8

49^m	SUN PLANETS	ARIES	MOON	v or d	Corr^n	v or d	Corr^n	v or d	Corr^n
s	° ′	° ′	° ′	′	′	′	′	′	′
00	12 15·0	12 17·0	11 41·5	0·0	0·0	6·0	5·0	12·0	9·9
01	12 15·3	12 17·3	11 41·8	0·1	0·1	6·1	5·0	12·1	10·0
02	12 15·5	12 17·5	11 42·0	0·2	0·2	6·2	5·1	12·2	10·1
03	12 15·8	12 17·8	11 42·2	0·3	0·2	6·3	5·2	12·3	10·1
04	12 16·0	12 18·0	11 42·5	0·4	0·3	6·4	5·3	12·4	10·2
05	12 16·3	12 18·3	11 42·7	0·5	0·4	6·5	5·4	12·5	10·3
06	12 16·5	12 18·5	11 42·9	0·6	0·5	6·6	5·4	12·6	10·4
07	12 16·8	12 18·8	11 43·2	0·7	0·6	6·7	5·5	12·7	10·5
08	12 17·0	12 19·0	11 43·4	0·8	0·7	6·8	5·6	12·8	10·6
09	12 17·3	12 19·3	11 43·7	0·9	0·7	6·9	5·7	12·9	10·6
10	12 17·5	12 19·5	11 43·9	1·0	0·8	7·0	5·8	13·0	10·7
11	12 17·8	12 19·8	11 44·1	1·1	0·9	7·1	5·9	13·1	10·8
12	12 18·0	12 20·0	11 44·4	1·2	1·0	7·2	5·9	13·2	10·9
13	12 18·3	12 20·3	11 44·6	1·3	1·1	7·3	6·0	13·3	11·0
14	12 18·5	12 20·5	11 44·9	1·4	1·2	7·4	6·1	13·4	11·1

Step 3: Note the *d* value at the bottom of the daily page.
d = 0.9

Step 4: Enter the Increments and Corrections pages in the Nautical Almanac and find the page for 48 minutes. On that page, find the "*v* or *d Corr*" column, and locate the heading for a *d* value of 0.9. Note the correction *d* value – 0.9.
Correction = 0.7'

Step 5: Apply the correction to the tabular GHA for whole hours. In this case the correction is subtracted because the tabular values of declination are decreasing with time (winter and spring in the northern hemisphere).
Dec for 1500 UTC = S 10° 04.5’ (decreasing)
d Correction = 0.7’
Total Dec = 10° 04.5’ – 0.7’= **S 10° 03.8’**

Note – this value can be easily estimated with direct interpolation in most cases as follows:

a) The declination value for 1500 UTC is S 10° 04.5’
b) The declination value for 1600 UTC is S 10° 03.6’, for a difference of 0.9’ (same as the *d* value)
c) The time of observation is 15:48:13, or approximately 15.8 hours, for a difference of 0.8 hours.
d) $\frac{0.8\ hours}{1.0\ hours} = \frac{x\ minutes}{0.9\ minutes}$
e) $0.8 = \frac{x}{0.9}$
f) $x = \mathbf{0.7}'$ = declination correction to be applied.

Calculating the Local Hour Angle (LHA) of Any Body

Local Hour Angle (LHA) defines the angle between the observer and a celestial body. LHA ranges from 0° to 359° 59.9’.

In the western hemisphere, Local Hour Angle (LHA) is equal to Greenwich Hour Angle (GHA) minus the observer’s longitude (or DR longitude).

In the eastern hemisphere, LHA is equal to GHA plus the observer’s longitude (or DR longitude).

Glossary

This glossary should be used to supplement the excellent glossary found in Bowditch. It is written primarily to be of use to students of celestial navigation and occasionally makes simplifications to illustrate a learning point. For a more complete definition of any term, see Bowditch.

Alidade, Telescopic – a piece of navigational equipment used for measuring the **azimuth** (bearing) of any object or body.

Altitude – Intercept Method – by assuming a nearby position and computing an altitude measurement for a celestial body, and then comparing the computed height, you can determine a line of position from a celestial body. The process, in brief, is: observe the celestial body; determine the geographic position of the body; assume a nearby position; enter HO229 with whole numbers of latitude, declination, and LHA; retrieve a computed height and azimuth; compare the computed height to the observed height; and plot from the assumed position either towards or away (depending on the circumstance) a distance equal to the difference between the computed height and observed height; draw a perpendicular line of position.

Altitude Correction – Another term for **Main Correction.**

Altitude Correction Tables – Tables in the Nautical Almanac which correct for the apparent altitude of any sextant measurement. There are different tables for the Sun, the Moon, and the Stars/Planets. Also called **Main Correction**.

Altitude – the height in degrees and minutes of a celestial body above the horizon, as measured with a sextant.

Amplitude - the difference in bearing between true east/west and the actual bearing of sunrise/set. For example if the amplitude were 20° and the season was summer in the northern hemisphere, the calculated bearing would be 070° for sunrise and 290° for sunset.

Aries – A constellation. Also, a fictitious point in the sky which serves as a zero point for star sight reductions. This point corresponds to the spot in the celestial sphere which is marked by the sun crossing the Greenwich Meridian on the **equinox.**

Assumed Position – when completing a celestial sight reduction, you must assume a position close to yours in order to calculate a "baseline" sight, from which you compare your actual sight to. When assuming a position, you choose the nearest whole degree of latitude, and you choose a nearby longitude, which when added or subtracted from the **Greenwich Hour Angle (GHA)** of the sun, results in a whole number of **Local Hour Angle (LHA).** In the western hemisphere, subtract the assumed longitude from the GHA to result in a whole number of LHA. In the eastern hemisphere, add the assumed longitude to the GHA to result in a whole number of LHA. This enables rapid problem solving, without interpolation, in the **Sight Reduction Tables (HO229).**

Azimuth (Z) – another word for "bearing." For example, the azimuth of the sun is the exact bearing to the sun's geographic position.

Azimuth Circle – a piece of navigational equipment used for measuring the **azimuth** (bearing) of a celestial object, utilizing mirrors to reflect the rays of light from the body to a gyro compass repeater.

Celestial Horizon – where the **celestial sphere** intersects a line projected outward from the earth's equator. Occasionally used when calculating time of phenomenon or **amplitude** problems.

Celestial Sphere – an imaginary sphere of infinite radius upon which are imprinted the stars and other celestial bodies. Used conceptually in celestial navigation.

Computed Height – the calculated height of any celestial body if the observer were to be standing at a pre-determined assumed position. Used in celestial navigation to compare to an observed height of the same object to plot a line of position.

d correction – a correction in the **Nautical Almanac** that accounts for the rate of change in **declination** of any body. Used to correct all celestial bodies during sight reduction.

Declination – The latitude of the celestial body's **geographic position**.

Dip – One of three **standard sextant corrections** that should be made for each sighting. This correction corresponds to the fact that the observer is some amount of feet/meters above sea level, and corrects for this **height of eye** error.

Equinox – the date that the sun's **geographic position** crosses the Earth's equator. Usually near 21 March and 21 September. The time of day will be identical across the entire Earth.

First Point of Aries – A term for the fictitious point in the sky which serves as a zero point for star sight reductions. This point corresponds to the spot in the celestial sphere which is marked by the sun crossing the Greenwich Meridian on the **equinox.**

Geographic Position – Imagine the earth as the center of the universe, unmoving and constant. All the heavenly bodies rotate around the earth, rising in the east, and setting in the west. At any point, each heavenly body is directly over a specific point on the surface of the earth. This point is called the object's "Geographic Position."

All objects in the sky have a geographic position. For example, if you were in the Caribbean in July around noon, and the sun happened to be directly overhead, the sun's geographic position would be the same as your latitude and longitude. If you were to describe the sun's geographic position, you could use your latitude and longitude as a coordinate system, however it is conventionally referred to in a different way: **Declination** and **Greenwich Hour Angle**.

Greenwich Hour Angle (GHA) – the longitude of the celestial body's **geographic position**. It is different from longitude in that hemisphere has nothing to do with it (i.e. there is no eastern and western hemisphere). Greenwich Hour Angle is measured from Greenwich, at longitude zero towards the west, all the way around the planet, back to Greenwich, at longitude zero. For example, one mile to the west of Greenwich, the longitude is 0 degrees and 01 minute West, while the Greenwich Hour Angle is 0 degrees and 01 minute. One mile to the east of Greenwich, the longitude is 0 degrees and 01 minute East, while the Greenwich Hour Angle is 359 degrees and 59 minutes.

Height of Eye – The observer's height of eye above sea level, in feet or meters. This must be accounted for in all sextant measurements, with a **Dip** correction.

Horizontal Parallax – a correction in the Nautical Almanac that accounts for the fact that rays of light reflected from the moon do not strike the Earth in a parallel way. This correction is only used when completing a moon sight reduction.

Index Correction – One of three standard sextant corrections that should be made for each sighting. This correction is used to eliminate index error, which is an error in the sextant itself. It can be determined by setting the sextant to 0° 0' and looking at a distant horizon. If the sextant has index error, the horizon will not appear continuous. Next, bring the horizon into line with itself and note the sextant reading. If the reading is above zero (e.g. 2.0'), the error is "on the arc" and the value must be subtracted from all measurements. Conversely, if the error is less than zero (e.g. 57.5'), the error is "off the arc" and the value must be added to all measurements.

Interpolation – to ascertain some desired value by calculating it based on nearby tabulated values (bracketing values). For example if the tabulated time of sunrise at latitude 20° N is 0600, and the tabulated time of sunrise at latitude 22° N is 0606, the interpolated value of sunrise at 21° N is 0603. Serves as a mathematical approximation of true values, and is typically accurate enough for navigation.

Local Apparent Noon – the time of day when the sun crosses the observer's line of longitude (meridian). At this time, the sun will bear due south or due north. At Local Apparent Noon, an observation of the sun's **altitude** will determine a line of position that equates to the latitude of the observer.

Local Hour Angle (LHA) – equivalent to **Greenwich Hour Angle (GHA)** minus longitude in the western hemisphere, and Greenwich Hour Angle (GHA) plus longitude in the eastern hemisphere. Local Hour Angle (LHA) is the angle measured westward around the earth from the longitude of the observer to the Greenwich Hour Angle (GHA), or the longitude of the geographic position. For example, if the observer's longitude is 75° W, and the GHA of the body is 76°, the LHA is 1 degree. If the observer's longitude is 75° W, and the GHA of the body is 200°, LHA is 125 degrees. If the observer's longitude is 75° E, and the GHA of the body is 200°, LHA is 275 degrees. Occasionally you must add or subtract 360 degrees (1 circle), to make the math work in your favor. This is allowed and encouraged. Put concisely:

LHA = GHA – Longitude (western hemisphere)
LHA = GHA + Longitude (eastern hemisphere)

Main Correction – On of three standard sextant corrections that should be made for each sighting. This correction combines a correction for the thickness of any body measured (e.g. the sun is nearly 30' wide), as well as for atmospheric refraction depending on the apparent altitude. The correction is noted in the front cover of the **Nautical Almanac**, and there are different tables for the Sun, the Moon, and the Stars/Planets.

Nautical Almanac – A publication which lists, among other things, the **Greenwich Hour Angle (GHA)** and **Declination** of various navigational bodies, as well as the time of various celestial phenomena such as sunrise, moonset, or local apparent noon. Useful in celestial navigation primarily for the retrieval of this information as part of a sight reduction or computation.

Polaris – the North Star. The observable star with a **geographic position** closest to the Earth's north pole, used in celestial navigation primarily to quickly calculate latitude at night in the northern hemisphere or to compute gyro error. *Alpha Ursae Minoris*.

Sidereal Hour Angle – a conversion factor to help determine the **Greenwich Hour Angle (GHA)** of any star. Since there are so many stars in the night sky, and over 40 used regularly for navigation, it is impractical to record the Greenwich Hour Angle (GHA) of each star in the Nautical Almanac. Instead, the GHA of **Aries** is provided for all hours of the year, and the Sidereal Hour Angle for each star is provided. The Sidereal Hour Angle of the star is added to the GHA of Aries to determine the exact GHA of the star for any given time. Put concisely:

SHA + GHA (Aries) = GHA (star)

Sight Reduction Tables – HO229, a publication which is designed to solve spherical trigonometry problems. Lists computed **altitudes** and **azimuths** which can be compared to observed altitudes to help determine a line of position in celestial navigation. Also useful for great circle sailing solutions.

Standard Meridians – A term for 15° increments of longitude, proceeding west from the Greenwich meridian. Standard meridians are used in time of phenomenon problems. For example, they include 0°, 15°, 30°, 45°, 60°, etc. They correspond to global time zones, and arise from the fact that there are 360 degrees in a circle and 24 hours in a day – 360/24 = 15°.

Standard Sextant Corrections – Corrections which should be made to sextant readings for each observation. They include corrections for **Dip, Index Error, and Main Correction.**

Telescopic Alidade – See **Alidade**.

v correction – a correction in the **Nautical Almanac** that accounts for the rate of change in **Greenwich Hour Angle** of any body. Typically used for Venus, Mars, and the Moon most often.

Visible Horizon – the furthest one can see, the horizon line as seen by an observer near sea level.

Zenith – The spot in the sky directly above an observer's position.

Zenith Distance – The "**zenith**" is the spot directly above your head. The distance from the zenith to a celestial body is the "zenith distance," and is the compliment/opposite to the sextant height, or equivalent to 90 minus the sextant height. For example, if you measure a celestial body to be 30 degrees above the horizon, the zenith distance is 60 degrees. In more technical terms, the zenith distance is the angular distance on the earth's surface from the **geographic position** to your position.

Coast Guard Deck Watch Officer PQS Section 136 (Celestial Navigation)

Section 136 of the US Coast Guard Deck Watch Officer Professional Qualification Standards deals with celestial navigation. After using this text, the reader should be familiar with most concepts. Many of the topics are intended to teach a more theoretical understanding of celestial navigation, at odds with this text. Following are abbreviated/suggested PQS "answers."

136. 1 Define the following:

a. Sight Reduction Tables - HO229, a publication which is designed to solve spherical trigonometry problems. Lists computed **altitudes** and **azimuths** which can be compared to observed altitudes to help determine a line of position in celestial navigation. Also useful for great circle sailing solutions.

b. Navigational Triangle – a theoretical triangle constructed for each celestial sight defined by the **Geographic Position** of the body, the elevated pole (north or south pole), and the observer's assumed position. This triangle is solved by the **sight reduction tables** to provide a **computed height** and **azimuth** angle to the body, used to determine a line of position from the body.

c. Sunline – see chapter 11 and 12.

d. Azimuth of the Sun – see chapter 10.

e. Amplitude of the Sun – see chapter 6.

f. LAN – see chapter 7.

g. Twilight (Nautical and Civil) – see chapter 4. This calculation is carried out in the same manner as sunrise/sunset, but using the appropriate column in the Nautical Almanac.

h. Celestial LOP/Fix – see chapter 11 and 12.

136.2 Discuss the following sections of the Nautical Almanac and explain how each is used:

a. Introduction – Contains basic material regarding celestial navigation and use of the almanac, as well as yearly ephemeris data such as holidays and eclipses.

b. Explanation – Contains detailed instructions regarding sight reduction procedures using the nautical almanac.

c. Daily Pages – Contains tabular data for each hour of each day allowing calculation of the **Greenwich Hour Angle** and **Declination** of any celestial body, as well as other useful data such as times of sunrise and set.

d. Increments and Corrections Pages – Tabular data which is used to adjust daily/hourly tabulated figures to gain precision to the second.

e. Front/Back Covers – Contains tabular data for the correction of sextant readings for two of the three **standard sextant corrections** of height of eye and apparent altitude. Also contains data for correction of sights in abnormal conditions of temperature or pressure.

136.3 Explain the use of the following instruments in celestial navigation:

a. Marine sextant – a device used to measure the altitude of any celestial body above the horizon. It contains two mirrors which move independently of each other which can bring a celestial body and the horizon into coincidence, enabling a reliable measurement of the altitude.

b. Rude Starfinder – a device used to pre-calculate the altitude and azimuth of navigational stars and planets. It can also be used to identify unknown celestial objects after observation. It is used by selecting the appropriate latitude card, and calculating the **local hour angle (LHA)** of **Aries** for a particular time.

c. Azimuth circle – a device used to determine the **azimuth** (bearing) of a celestial object. It contains mirrors which can be oriented to reflect the light of a body onto a gyro compass repeater, enabling the observation of the body's azimuth (bearing).

136.4 Discuss the purpose of each of the following terms associated with the celestial system of coordinates:

a. Celestial Sphere – see entry in glossary.

b. Celestial Poles – the north and south poles of the celestial sphere.

c. Elevated Poles – the Earth's pole (north or south) which is closer to the observer.

d. Equinoctial – of or pertaining to the **equinox.**

e. Celestial Meridian – an hour circle which passes through the observer's zenith.

f. Hour Circle – a great circle projected onto the celestial sphere which passes through the celestial poles. Used to define longitude in the celestial sphere.

g. Declination – see entry in glossary.

h. GHA – see entry in glossary.

i. LHA – see entry in glossary.

j. Ecliptic – The apparent path of the sun through the stars over the course of the year. A great circle on the celestial sphere.

k. Diurnal Circle – the path of a celestial object through the sky for a given day.

l. First point of Aries – see entry in glossary.

m. SHA – see entry in glossary.

n. Meridian Angle – the angular distance east or west of the local celestial meridian. An example would be when calculating amplitude of a body – the body is some number of degrees away from true east or west. The number of degrees difference would be the meridian angle.

o. Polar Distance – the opposite value of **declination**, such that declination plus polar distance equals 90°. Also called co-declination.

<u>136.5 Discuss the purpose of each of the following terms associate with the horizon system of coordinates:</u>

a. Zenith – see entry in glossary.

b. Nadir – the opposite of zenith. The spot directly beneath an observer, when projected through the center of the earth and onto the celestial sphere in the opposite direction of zenith, yields another celestial position.

c. Celestial Horizon – see entry in glossary.

d. Vertical Circle – a celestial great circle which passes through the zenith and is perpendicular to the horizon.

e. Prime Vertical – the vertical circle perpendicular to the prime vertical circle which is used to define the east and west points of the horizon for an observer.

f. Altitude – see entry in glossary.

g. Zenith Distance – see entry in glossary.

h. Azimuth – see entry in glossary.

i. Azimuth Angle – the bearing from an observer to the **geographic position** of a celestial object.

j. Latitude of Observer – self explanatory.

k. Polar Distance of the Zenith – the opposite of the observers latitude, such that latitude plus polar distance = 90°. Also called co-latitude.

136.6 Discuss the procedures for determining the following:

a. Sunrise/Sunset – see chapter 4.

b. Moonrise/Moonset – see chapter 5.

c. Nautical Twilight – see chapter 4. This calculation is carried out in the same manner as sunrise/sunset, but using the appropriate column in the Nautical Almanac.

d. Civil Twilight – see chapter 4. This calculation is carried out in the same manner as sunrise/sunset, but using the appropriate column in the Nautical Almanac.

e. LAN – see chapter 7.

f. Sunlines – see chapter 11.

g. Celestial LOP/Fixes – see chapter 11 and 12.

h. Azimuths of Celestial Bodies – see chapter 10.

i. Amplitude – see chapter 6.

j. Gyro Error by azimuth/amplitude – see chapter 6 and 10.

k. Side Error – This is a sextant correction which can be completed by placing the sextant on it's side, index arm near 45° and placing identical objects (dominoes, machine nuts, etc) on either side of the index arm along the arc scale. When looking through the index mirror from above the sextant, adjust the index arm until the objects are in coincidence. The objects should be at the same level. If they are not, the index mirror needs to be adjusted for side error. See *The Sextant Handbook* for adjustment procedures.

l. Collimation Error – This is a sextant correction which can be completed by setting the sextant to zero and looking at a distant horizon. If, when the sextant is rotated, the horizon is not continuous, the horizon mirror needs to be corrected for collimation error. See *The Sextant Handbook* for adjustment procedures.

m. Index Error – see entry in glossary.

About

The Practical Navigator website: www.practicalnavigator.org was originally created for Coast Guard Deck Watch Officers, Boatswains Mates, and Operations Specialists to have free access to videos and texts which would increase their proficiency in navigation and radar tasks. Since then, it has found a following with merchant mariners, sailors, and naval personnel around the world.

Christopher D. Nolan graduated with honors from the US Coast Guard Academy in 2002. He has over 8 years of sea-time aboard the cutters:

ALEX HALEY (WMEC-39) – Kodiak, AK. First Lieutenant (3rd Mate)
DORADO (WPB-87306) – Crescent City, CA. Commanding Officer (Master)
EAGLE (WIX-327) – New London, CT. Navigator/Operations Officer (2nd Mate)
JEFFERSON ISLAND (WPB-1340) – Portland, ME. Commanding Officer (Master)

After completing service in the USCG, he sailed as a master of the sailing school vessels CORWITH CRAMER and ROBERT C. SEAMANS and taught as an assistant professor of Nautical Science with Sea Education Association in Woods Hole, MA.

After obtaining his original mariner's license in 2006, he now holds an STCW license as Master, less than 3000 GT and a domestic license as Master up to 1600 GRT upon oceans. He holds a B.S. in Marine Science from the USCG Academy and a P.S.M. in Fisheries and Wildlife Administration from Oregon State University.

He is the co-author of "Eagle Seamanship – A Manual for Square Rigger Sailing" and the author of "The Bridge Navigation and Seamanship Refresher Guidebook," and "The Cutterman's Guide to Navigation Problems." Additionally, he maintains the training program website www.practicalnavigator.org and a YouTube channel dedicated to Navigation Training.