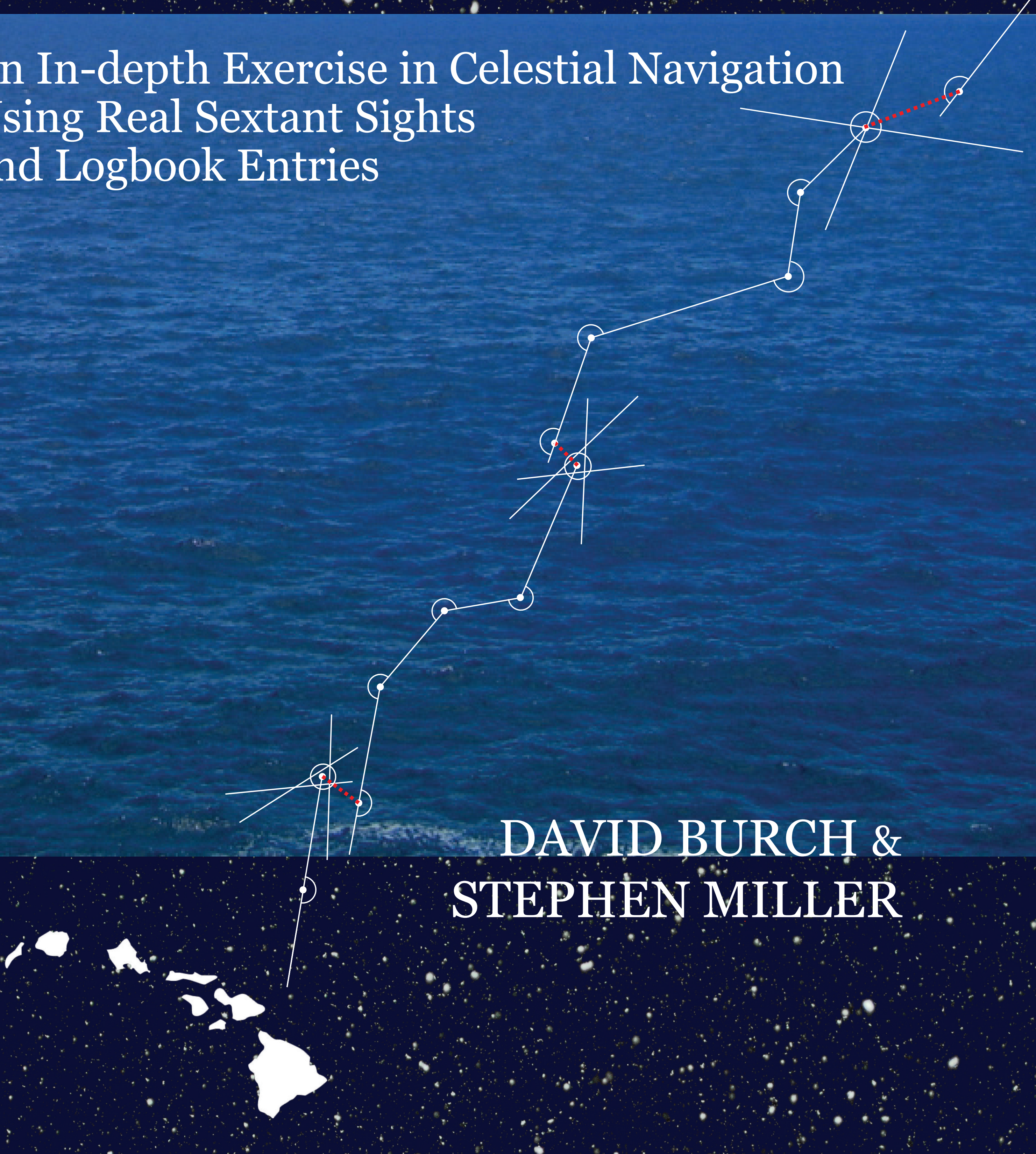
HAWAII BY SEXTANT

An In-depth Exercise in Celestial Navigation Using Real Sextant Sights and Logbook Entries



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Introduction

Overview

This book presents an exercise in ocean navigation carried out by celestial navigation alone. It is intended for those who wish to practice their skills in navigation that they have learned from other sources.

This is not a book on basic celestial navigation.

This book assumes you have learned cel nav basics from another source, and we provide here the best way we can think of for you to master what you have learned, and gain the confidence that you can navigate an ocean passage by cel nav alone if you chose to or had to.

It is based on a real voyage using the actual sextant sights taken, along with the logbook of dead reckoning between sights. The successful completion of this exercise becomes in effect the successful navigation of an ocean crossing.

The voyage was from Victoria, BC to Maui, HI in July of 1982. The vessel was taking part in the Victoria to Maui Yacht Race at a time when celestial navigation was not only required, it was the only option. The vessel was a 41' sloop (*SV Passages*) with an average speed of 6.3 kts over the 2,800-mile voyage.

All times, unless specified otherwise, are Watch Times (WT) with zone description ZD = +7. Any reference to GMT refers to Universal Time, with UTC = WT +ZD = WT + 7h.

Unless otherwise stated, height of eye = 9 ft, watch error = 0 sec, and index correction = 0.0'.

This was the last voyage we made by pure celestial navigation, without any electronic aids. In principle, Radio Direction Finding was allowed, but it was not needed at the departure and there were no dependable stations at the destination, so this was not used.

The voyage begins with a last visual fix off Cape Flattery, WA (in the old days, called taking our departure), after transiting 75 nmi of the Strait of Juan de Fuca and entering the ocean. The destination was Lahaina on Maui, HI, which is just under 2,400 miles to the southwest as the crow flies–the great circle route–but rather farther when sailing around local and global wind patterns. In this voyage a total of about 2,800 miles was sailed.

There is a total of 38 sight sessions over a 17-day voyage, with each session including 3 to 10 sights-a total of 227 recorded sights, making up 27 celestial fixes of various kinds.

Each day's navigation is summarized at the beginning of the day, and then again after the fix has been achieved. In all cases, the DR was started anew from the most recent fix. There are no adjustments for ocean currents needed, nor for leeway-which is not to say the vessel was not affected by currents; it is just that we did not have enough data at the time to justify any such corrections.

The exercise is presented in several parts, and working through the voyage will require referring back and forth among them as needed. The days of the voyage are marked in a gray band for quick location; the individual problems are numbered sequentially from the start of the voyage, and to further assist in organization, each sextant sight session is given a unique Sight Session number. Thus on July 10th, we have one problem (No. 8), which is made up of two Sight Sessions (#13 and #14).

Logbook

The logbook lists daily entries of log readings and courses steered. The log reading is the odometer for the trip, recording the total number of miles sailed through the water. Each time a position fix was achieved, the DR position was shifted to the fix position and the DR track continued on from that new position. Before doing the sight reduction of each position fix, it will be necessary to plot out the DR track from the time of the last fix to determine the DR position at the time of the new sight session. Normally the logbook would record the compass course on each heading, but to simplify matters a bit, we have converted the compass headings to true headings for each entry. (In this voyage in 1982 the magnetic variation changed from 21.3°E at departure to 11.1°E in Hawaii, but those corrections have already been applied.)

Although there are multiple entries on most days, there are frankly not as many as would be best practice. I became much more diligent on subsequent voyages with more logbook entries. If no one else would enter the logbook, I would do it myself, as it does not take long to appreciate how valuable it is. This exercise demonstrates that in some cases. It is often a challenge to get crew to enter the logbook.

Section of the Logbook					
	Date	*Time PDT*	*Log*	*Course T*	*Speed kts*
21	8-Jul	0000	698	175	7.1
22		0800	755	165	6.4
23		1011	769	170	6.8

Notes on the Logbook

The left column just numbers the entries for reference only. In this case, on July 8 at 0000 PDT, the trip log read 698.0 nmi and the boat either turned to, or stayed, on course 175 T. (We do not know which without seeing the earlier log entry. We can certainly make a log entry without changing course, but we must make one when we do change course.

Then 8h later at 0800, the log read 755.0 and we turned to course 165T. Thus our DR track will show a leg that is 57 mi long (755-698) in direction 175, then the track will angle off 10º to 165 and the next leg will be 14 mi long (769-755), at which point it turns 5º back to course 170.

The speeds recorded here are speed made good (SMG) on the leg listed. That is, between 0800 and 1011 (2h 11m = 2.183h) we traveled by log 14 nmi (769-755), so our SMG = 14/2.183 = 6.41 kts. This SMG can be used to estimate DR positions in between the log book entries.

In this book the word mile and nautical mile are the same (as it is on the boat) and we use watch time (WT) to enter the logbook and record the sights, again just as we would do on the boat. Watch time in this case was Pacific Daylight Time, which is 7 h earlier than UTC, ie UTC = WT + 7h. This is the same throughout the voyage, which is the recommended system, as opposed to changing ship's time during a voyage.

This logbook only records logs to the nearest whole mile. That was the way I did it on this voyage, but at this point I am not sure why. *We should definitely record logs to nearest tenth of a mile.* Cel nav is not pinpoint nav, but we do not want to throw away any information we can easily obtain, even if it may not be fully accurate to the tenth.

Navigation Sights

This section presents each of the daily sextant sights in tabular form, along with a few brief notes. In each case the actual sextant reading (Hs) is given for the corresponding time of the sight, which is listed as both WT and UTC. You will use the former in coordinating with the logbook, and the latter for the cel nav sight reductions. In almost all cases, we tried to take multiple sights of each body used with the intention of averaging them in some way to obtain the best value for a single sight. This is standard good procedure. It is always better to take multiple sights of the same two or three bodies than to take just one or two sights each of many bodies.

There are various ways to evaluate the several sights of the same body. We recommend what we call the Fit Slope Method described in the Analysis section. There are other methods, and if you are using a calculator or computer program for the analysis, it may have an option built into it. A simple, but less efficient, method is just to plot all of them and judge for yourself which is representative of the set, or use all of them in concluding where the fix should be. The Automatic Advancement of LOPs method we describe in the Analysis may help with this.

Each set of sights offers a proposed practice problem. You can navigate the passage as you see best, but solving the fixes at the suggested problem times will offer an easier comparison with the solutions provided.

And to illustrate that the real world is not always like a classroom exercise, we start right out with an unusual sight combination–a running fix from a morning sight of Venus, being the only thing visible in a cloudy sky, and a sun sight taken shortly after sunrise.

Table Selections

To work the exercises you will need the *Nautical Almanac* data for the times underway in 1982, which are presented in the Tables Selection at the back of this book. This does not include the Increments and Corrections tables, which are the same from year to year and can be obtained from any almanac of any year. If you do not have access to an outdated or current *Nautical Almanac*, you can download a set of Increments and Corrections from starpath.com/HBS, which offers several other documents of interest to navigators.

Solutions

Because this book is intended as a self-guided training exercise, the solutions are presented in depth, in several formats. A DR track of the full voyage is presented in multiple pages, so the plotted celestial lines of position (LOP) can be shown plotted as they might be in your own work. Depending on how you do the DR and what assumed position you end up using, your plots could look somewhat different from these, but the fix positions should be the same, if we end up choosing the same sights to reduce.

Numerical solutions by computation are also given, as well as full solutions using tables alone. The latter include all almanac data used, along with each step of the sight reduction, presented in the Starpath Workforms. If you care to use these, there is a blank one at the back of the book, or you can download a pdf from starpath.com/HBS

We also include in the plotting part of the solutions a section of the last nautical chart used as we leave the coast and move on to plotting sheets for the ocean, as well as the nautical chart we move onto at the end of the voyage as we finally leave the plotting sheets for the approach to land.

What you will Need

To customize the exercise to your own style of celestial navigation, you will need a set of Sight Reduction Tables. You can use any set of tables you like.

Alternatively, you can do the sight reduction and dead reckoning with a calculator or computer program. There are numerous commercial versions, as well as quite a few free ones online as a download. See also starpath.com/calc.

You will also need Universal Plotting Sheets and plotting tools, both are available at starpath.com or other online and local outlets. There are also high-resolution plotting sheets online that can be downloaded and printed.

If you are accustomed to using workforms for sight reduction, you can use any form you prefer. We have included copies of the Starpath workforms in the Appendix that you can reproduce and use if you choose to. We use these forms to present the detailed, step by step solutions, but you can use any forms you choose.

Procedures

To navigate this voyage, do as you would do underway. Start by setting up a universal plotting sheet that puts your first known position in the top right corner (we are headed SW).

Then use the logbook data to plot out your DR track to the times of the first and second sights. The two sets of sights taken about three and a half hours apart, make up the first celestial fix of the voyage, which is the first position fix for more than a day.

At each fix, compare your fix location with what your DR would have been for that time or log reading. That is, if you get a fix at say 1422 WT, but the sights that made up the fix were based on a DR at 14:02, then DR from 1402 up to 1422 so you can make a careful comparison of how good your DR was at the time of the fix. Do this for each fix and save the results. In each case compute or get from a plot, the range and bearing from the DR to the Fix and enter these into the answer sheet provided.

A main goal of ocean navigation is to learn how well you can do DR, so you are prepared to navigate intelligently if you are stuck with nothing but DR to go by. By making and logging the DR to Fix difference for every fix taken you learn how well you are doing.

In the actual voyage, DR was done with log readings and courses, and then the average speeds made good (SMG) were computed from the times and log readings of sequential positions. The Logbook lists these SMGs, which can be used with the times listed to compute the DR positions.

For each set of sights, refer to the Logbook to get the course and speed of each leg. You will need this for the sight reductions and the running fixes. To simplify record keeping (and your self grading!) use the logbook format provided to fill in your answers and carry out the fixes at the times requested of each session that leads to a fix. You can use any form of sight reduction, books, calculator, or computer.

An important part of the exercise is to keep a clear, organized plot of your work on Universal Plotting Sheets. All of your DR plotting and cel nav LOPs can be plotted on them. If there is any question about how to lay them out, then take a quick peek at the answers to get a hint.

When you reach the bottom of a page, set up a new one, starting at the top, with where you left off at the bottom. For each set of sights, look ahead to the next pages of the book to be sure you have all the sights for that sight session.

You will see here a wide variety of celestial fixes. They are not all the textbook variety, because one has to deal with what is there, not just what we might wish for. However, this is a real voyage that was indeed navigated by exactly this data. We were sailing from 48 North, so even in the summer it was cloudy and bad weather for a while. As we got further south, there were more clear skies so we could do better navigation with star and planet sights.

One pervasive theme, however, is to take as many sights as you can and then average them. In most cases, you can improve the accuracy by evaluating the sights and then removing the ones that are most likely in error. In this exercise, however, as it was in the real voyage without Loran or GPS, you will not know for sure that you did it right until you progress to the next set of sights and check that your DR is now better or worse than it was.

We use the terms fix and running fix (rfix) throughout, but since almost all sight sessions include multiple sights, essentially all fixes are running fixes, so these terms mean the same thing in this context.

Standing Exercises

Beyond the regular exercises, which usually take the form of asking for a fix at a particular time, you can also carry out nearly daily exercises that are not crucial to the navigation but help understand the process of cel nav underway.

An example of that would be to predict the time that sights will become available for the given date and location and when they will no longer be available in the morning or evening. These are the times of civil and nautical twilight in the evening and the reverse in the morning. A few of these are specifically asked for, but this is a question that would come up every day. Or we might ask: how much do these times vary over such a voyage? That you can learn by looking them up.

Likewise, for each of the evening or morning sight sessions, you can also compare how long we were taking sights compared to how long we had according to these predictions. As a rule in practical cel nav, you generally use all the time you have, but you have here the perfect way to check what really took place.

Another example of a standing exercise would be to predict, by whatever method you have learned, what would be the best triad of celestial bodies to use for a fix in each of the situations, and then compare that to what was actually taken. Again, a couple samples are asked for, but the question comes up every night. And again: how does this change over a voyage of this length and duration?

Another thing you can ask yourself at the end of each sight session after you establish your position, is what is the desired or shortest course to our destination, or more realistically, to our next waypoint. Crossing the ocean in a sailboat is rarely point to point navigation. We have to follow the wind. But since it is such a long trip, we do not know where the wind will be when we get halfway there, so we have to make some guesses bases on climatic behavior for July.

This route usually calls for sailing around the Pacific High, with a corner at about 31.5N, 140W, near the former location of the last weather ship in the Pacific, called *November (30N, 140W)*. Ocean charts we sailed on at the time of this voyage (1982) still showed a big N at that location, long after the ship was retired in 1974. The location is a pure coincidence, but it made an easy waypoint to keep in mind. Put another way, the vast majority of the boats that have won the Victoria to Maui Yacht Race have gone within 100 miles of that location on their way across the Pacific.

Thus for practice you can ask yourself, what is course to that waypoint and our SMG in that direction for points north of there, and then once we get close or past that region, what is then the course and SMG to the destination at Pailolo Channel, the entrance to Lahaina, which is our destination. The SMG in the direction of a specific waypoint is called the waypoint closing velocity (WCV).

In such a long passage, it is tempting to think about our WCV to the destination right from the beginning, but that can be very misleading. It could be that early in the voyage we could indeed make good progress in that direction, but doing so from early in the voyage could drive us right into the middle of the Pacific High, with no wind at all, and once that happens it is very difficult to correct it. Thus the prudent route is go the way you are most likely to have good wind, and not get suckered into the direct route, at least not for more than a day or so. Every race there are numerous boats that try it. Periodically one sneaks through with grand success. More often it leaves the navigator with only visions of glory and a very poor showing.

You can plot out the full route to watch your progress on chart 530, which can be downloaded as a free pdf BookletChart, nicely divided into letter size pages for printing. Then paste them together for a full chart. See starpath.com/getcharts. Or just make a series of Placemarks for your fixes in Google Earth and save them. A sample of that is given and explained at starpath.com/HBS along with a gpx file of the fixes that can be loaded into any echart program or Google Earth. WCV data as described above is presented in the Solutions.

There is much to be learned from the data in this exercise!

Philosophy

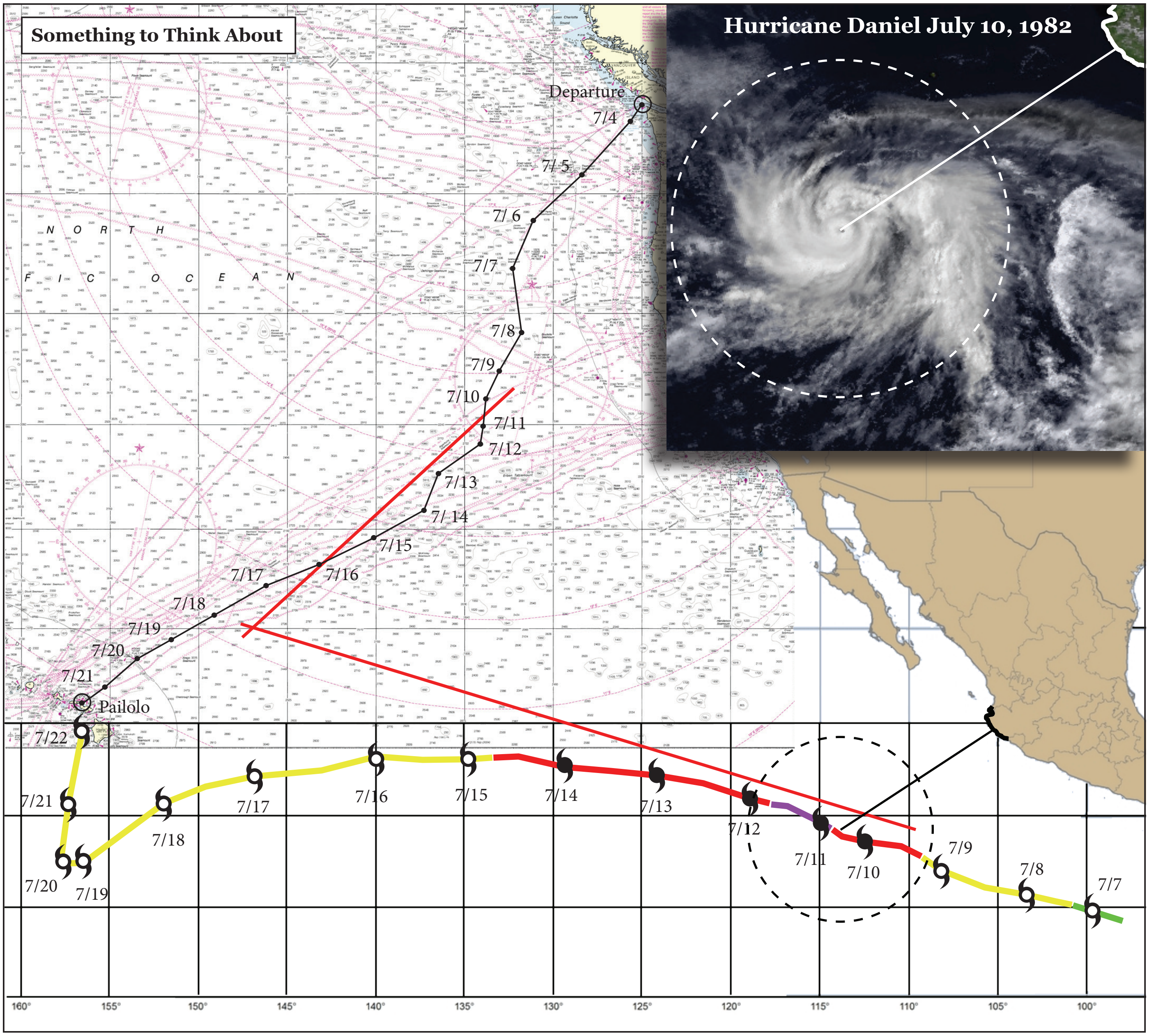
There is no rush in the process. You can take your time. You can even maintain real time by spending as much as a full day on each position fix. One of the facts of life when relying on cel nav alone is it takes some time to get it done properly. It is not uncommon at all to spend an hour or more to analyze a set of sights to come up with the best fix, and if a mistake is made along the way, this can stretch out more. But the beauty of cel nav is, if you do make a mistake, you will eventually discover it, so you can go back over your work to find it.

Remember if you rule out blunders, which will show up because you have multiple sights, then an individual sight done properly should typically not be wrong by more than a couple miles, maybe a bit more in bad conditions. So when you see sights disagreeing by more than 5 or 10 miles, then something is clearly wrong, either with the analysis or with the sight. Most errors in analysis cause even larger discrepancies.

With that in mind, you have a philosophical choice. When you decide where you are, you can evaluate it as likely right and just carry on till the next day's sights, or doubt it, and go back over the work. Or you can peek ahead to the solutions, and correct yourself as you proceed.

Choose whichever approach seems the best way to learn or enjoy the venture. Not looking at the answers at all obviously provides the biggest challenge, and most closely matches the real world experience of navigating across the ocean with nothing but celestial navigation and dead reckoning.

Bon Voyage!



What was going on south of us. *There is always something to think about on an ocean passage, but we had a bonus on this one. From July 12th onward, we had the threat of Hurricane Daniel. We were on a collision course most of the voyage, which was rather worse than it looks here, because the normal path of such storms is to curve north. Thus we had both good luck and bad luck. The bad luck was most Eastern Pacific Hurricanes do not go all the way to Hawaii (only roughly 1 every 5 years), so it was rare to occur at all; the good luck was this one did not curve away from the equator and go north and meet us. Normally they would either dissipate or turn north before reaching the longitude of November. Solid symbols are hurricane force winds. Daniel peaked at about 100 kts on the 11th (purple segment). Red section (7/9 to 7/15) is hurricane; yellow is tropical storm; green is tropical depression (7/7). Open symbols are tropical storms.*

We did, nevertheless, both get to Maui at about the same time! When Daniel turned north and ran up the Alenuihaha Channel and dissipate on the east side of Maui the winds were down to 30 kts or so. We did sail in violent rain and 40-kt squalls on the approach, which was likely influenced by the storm to the south.

We just lost a day or so of sunny skies once in Hawaii, but it could have been very serious underway. Sometimes tropical storms that curve north approaching Hawaii get caught in a deep dip of the winds aloft that captures them, and not only pulls them right up our track line here, but intensifies them as well. The three worst storms to ever hit the Pacific Northwest began in that manner. It is valuable for all mariners in the tropics to review what the NWS calls the 34-kt Rule and the Mariner's 1-2-3 Rule. We have a link at starpath.com/HBS.

Daily Ocean Entries*

#	July	WT	Log	C	S	Comments
1	4	0400	75	274	7.0	Departure: 48º 23' N, 124º 45' W
2	4	0500	82	220	7.7	
3	4	1247	142	267	5.3	
4	4	1609	160	222	7.0	
5	5	0000	215	222	7.0	
6	5	0504	250	197	6.0	
7	5	0844	272	197	7.0	After P1 FIX
8	5	1335	306	267	7.0	
9	5	2200	365	226	7.0	
10	6	0000	379	226	7.0	
11	6	0534	418	209	5.4	
12	6	1046	446	200	7.3	
13	6	1527	480	188	7.3	After P2 FIX
14	7	0000	539	188	7.3	
15	7	0832	599	180	6.5	
16	7	1400	634	176	6.4	After P3 FIX
17	8	0000	698	176	6.4	
18	8	1009	769	169	6.7	
19	8	1307	789	156	6.5	After P4 FIX
20	8	2021	836	256	6.0	
21	9	0000	858	256	6.0	

** Notes (Please refer to the plots for further clarification of the logbook interpretation)*

(1) First column just numbers the entries this sheet; no nav significance.

(2) Column 2 is the date; column 3 is the time, WT = PDT (ZD = +7).

(3) All courses True; speeds in knots.

(4) Px labels Problem x, which marks the times of the position fixes.

(5) We only have log data to the nearest mile for this passage, but good practice would call for keeping log records accurate to the tenth of a mile.

(6) A new DR track begins with each new position fix.

See also important information on the logbook entries given in the Introduction.

Navigation Sights

Daily Sight Data

July 4

This is the start of the ocean navigation. We had, however, already sailed some 75 miles out the Strait of Juan de Fuca from back in Victoria, BC, which we left at 1100 the previous day. It has taken 17hr to get here in everything from light easterlies to strong westerlies, to flat calm. Here we are leaving land, and heading slowly out into the ocean, but weather and other factors will soon force us onto a more southerly course. Refer to the logbook for course and speed at the various sight times. This last visual piloting fix was about 0.7 mi SW of Tatoosh Island Light, at Cape Flattery, WA. Thus we take and record our *departure*, the official name for the last land-based fix of an ocean voyage.

Date: July 4, 1982

Fix Time: 0400 WT, Fix Log: 0075

Fix Position 48° 23.0'N, 124° 45.0' W

July 5

We start with an unusual running fix between Venus and the Sun, dawn to mid-morning, which were the only sights available in cloudy skies. Venus just peeked out of the clouds long enough for a few quick sights. It was not certain at the time whether or not we would see the sun that day at all, but we did. There was a cold front moving east over us that morning at about 20 kts. Seas about 7 ft, according to notes on Sights #2.

Sights #1	**Date: July 5, 1982**	**Body: Venus**
WT	*UTC*	*Hs*
05:03:58	12:03:58	12° 06.5'
05:06:24	12:06:24	12° 29.0'
05:09:27	12:09:27	13° 00.0'

Sights #2	**Date: July 5, 1982**	**Body: Sun LL**
WT	*UTC*	*Hs*
08:41:22	15:41:22	26° 54.5'
08:43:55	15:43:55	27° 24.0'
08:45:38	15:43:58	27° 41.0'
08:47:30	15:47:30	28° 03.0'

Problem 1

1A. Find a running fix at 0844 on July 5, enter it in the logbook, then from there DR to the time of the next sights (Sights #3) using logbook data.

1B. Find the WT of Nautical Twilight, Civil Twilight, and Sunrise for July 5, 1982 at 46N, 127 W. What was the stage of the twilight for the Venus sights done above, and how long after sunrise were the sun sights taken?

Reminder. For all sights in the book:
Height of Eye = 9 ft
Index Correction = 0
Watch Error = 0
Zone Description = +7, ie UTC = WT +7h

The Boat

"PASSAGES" — Sail No. 59450 — Islander 40, LOA: 39.5'. Corinthian Seattle Yacht Club, Owner/Skipper: G. Bell, Crew: D. Burch, T. Clark, J. Taylor, W. Harvey-Smith, P. Fredrickson, J. Green, D. Bawden.

This is the image that appeared in the Vic-Maui Yacht Race brochure for 1982. It is still online. The boat owner and skipper was Dick Bell, now an active member of the Seattle Yacht Club. The Doug Petersen-designed yacht is still actively sailing in the Pacific Northwest under a new owner. Paul Fredrickson is a naval architect specializing in super yacht design. We have sadly lost contact with the other crew members.

Solutions

Instructions

The solutions are presented in several formats to facilitate checking answers worked by various means.

Recording and Checking Answers

You can use the main Logbook as a place to record answers, or there is an optional, printable answer form at starpath.com/HBS. There is a Logbook with detailed answers at the end of this section.

One option is to work the exercises without looking at the answers at all. Instead, you judge the quality of your own fix each time, and if that seems reasonable, just carry on with the DR to the next set of sights, and see then how well you are doing. This could be an instructive approach, and in this case you would just refer to the answers if there appears to be some mistake that you cannot find.

On the other hand, it could be even more valuable to know there must be some mistake in your analysis, and try again till it works out. Once you get underway on your own real voyage, there is obviously no answer sheet to refer to.

Computed Solutions

These results are typical of what you would get doing the sight reduction with a calculator or computer program. For this type of solution you do not need to choose an Assumed Position, but can do the sight reduction directly from a DR position of your choice.

For the solutions listed, the DR position often corresponds to the time of the sight used for a sample workform sight reduction. The choice of DR (unless way wrong) does not affect the final computed values if the course and speed are correct.

All intercepts shown have taken the course and speed into account at the times of the sights. The fix shown with this data is a running fix taking all sights into account, weighted according to the size of the a-value relative to the average of all a-values for a particular body (least squares).

An asterisk (*) marks the sample sight that was chosen for the workform solution. It was intended to represent the average, but it might not be the optimum choice in all cases. If you analyze them carefully, you may find a better choice to represent the set, and may well end up with a better fix when plotting than we show in the plots.

Plots of the computed solutions are in Appendix 4. In some cases, the best fix would call for removing some of these sights as discussed in the Analysis section. These plots are just to show the relative lay of the LOPs for each fix.

Sample Workform Solutions

The workform solutions use Publication 229 and the Starpath Workforms, given in Appendix 2. Only a sample is shown from the usual set of several. The course and speed shown in the form are usually the ones that would be used to advance the lines for a running fix. Often the course changed right after the last sight of a session.

Keep in mind, these are presented in a *solutions* section. You can decide which sights to do, in which manner, from the sight data itself, without looking at any of these sample solutions. These forms simply give you a way to practice sight reduction using real sight data if you care to. They are samples only, *not necessarily the best or most representative sight of the session in each case*. In principle you could get a better fix by choosing the best average sight by the Fit Slope Method we illustrate in the Analysis section. A form of that method was used in the actual voyage to choose the best sights for a fix.

The starting time and date at the top of each workform in Box 1 is the watch time of the sight. It gets converted to UTC before moving into Box 2 of the form. The Sights session number is given as well.

Plotted Workform Solutions

This section is the main results of the navigation. The lines of position from the cel nav sight reduction are plotted out on universal plotting sheets, along with the DR track before and after each sight session.

Your own plot may end up using different sights to represent each session, but they should look similar to these. That is, if you choose a different assumed position your lines will originate from different locations, and if you choose a different sight to represent the set, you may get a slightly different LOP, but it should be very similar, and the fix should be similar as well–though not exactly the same, and indeed your fix could be more accurate in some cases.

A key step to carry out after each fix has been found and plotted is to then measure the range and bearing from the DR position that corresponds to the time of the fix to the fix itself. This is the key information you get from each celestial fix. Record these in the logbook or a table of your own to compare with the ones we present. This tells you how good your DR is in the conditions at hand. If for any reason you lose the opportunity to take more cel nav sights, this tells you the accuracy of your DR as you proceed from there.

Log 942	Problem 5	July 9

Sights #9

Sun LL—July 9, 1982

DR 37° 57' N, 132° 14' W

WT	a-value	Zn
10:32:45	12.0 T	095.1
10:35:06	7.7 T	095.5
10:36:28	7.2 T	095.7
10:37:33*	8.5 T	095.9
10:40:26	9.3 T	096.4

Sights #10

Sun LL—July 9, 1982

DR 37° 44' N, 132° 30' W

WT	a-value	Zn
13:21:55	5.5 T	152.8
13:23:02	3.9 T	153.6
13:24:55*	4.5 T	155.0
13:26:22	6.2 T	156.1

►**Problem 5**. 1325 FIX using C222, S6.7
37° 42.7' N, 132° 18.6'W

Log 945	Problem 6	July 9

Sights #11

Sun LL—July 9, 1982

DR 37° 22.8' N, 131° 52' W

WT	a-value	Zn
13:53:13	1.2 T	179.7
13:54:41	0.0 T	181.0
13:55:56	1.9 T	182.1
13:57:44	3.0 T	183.6
13:58:51	0.5 T	184.6
14:01:01	1.0 T	186.5

►**Problem 6**. 1355 LAN Lat using C197, S6.0
Lat = 37° 43.8'N

Reminder
Plots of the computed solutions are in Appendix A4.

Log 992	Problem 7	July 9

Sights #12

Jupiter—July 9, 1982

DR 36° 56.5' N, 132° 32' W

WT	a-value	Zn
21:44:32*	9.9 A	202.5
21:49:54	11.0 A	204.1
21:55:34	9.1 A	205.8

Vega (49)—July 9, 1982

DR 36° 56.5' N, 132° 32' W

WT	a-value	Zn
21:47:41	4.5 T	071.0
21:53:07	4.9 T	071.4
21:59:07*	0.9 T	071.8

►**Problem 7**. 2159 FIX using C197, S6.0
37° 06.5'N, 132° 32.1'W

Log 1082	Problem 8	July 10

Sights #13

Sun LL—July 10, 1982

DR 36° 34' N, 133° 32' W

WT	a-value	Zn
10:55:29	22.7 T	096.8
10:56:57	21.1 T	097.1
10:58:45	25.6 T	097.4
11:02:02*	24.7 T	098.0
11:04:43	25.7 T	098.5

Sights #14

Sun LL—July 10, 1982

DR 36° 32' N, 133° 46' W

WT	a-value	Zn
13:31:36	18.4 T	154.5
13:33:03	17.0T	155.7
13:34:46*	16.9 T	157.1

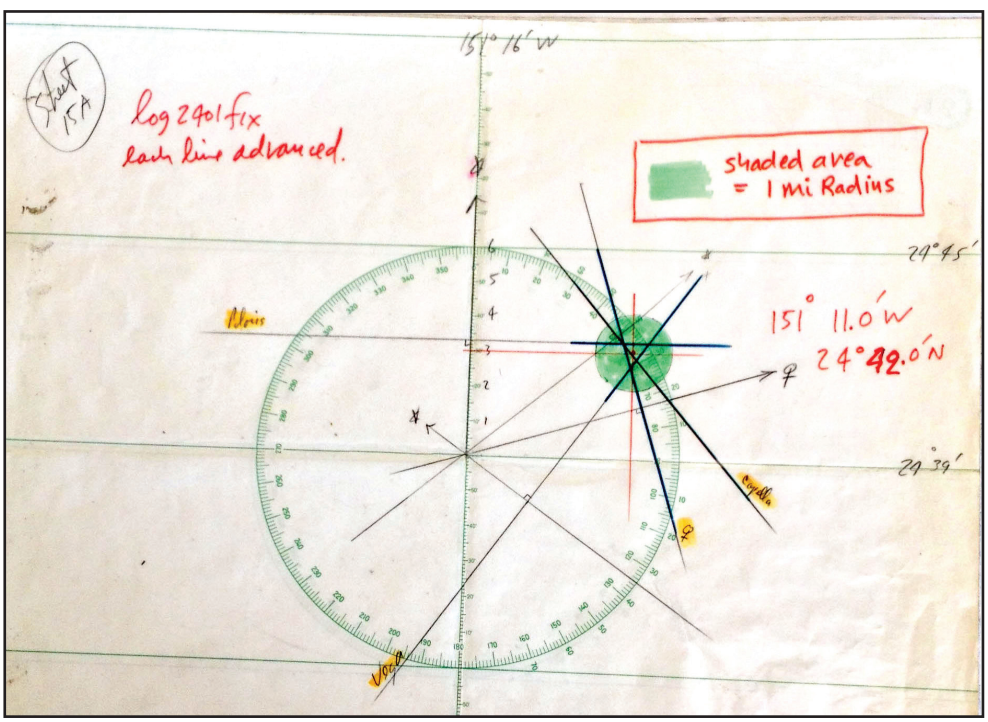
►**Problem 8**. 1334 FIX using C263, S4.5
36° 22.9'N, 133° 17.8'W

Problem 22. July 19 - Cont.

1 WT	7 h	53 m	18 s	date	19-Jul-1982	body	Venus	Hs	18°	28.4'
WE +S-F		m	0 s	DR Lat	24° 38' N	log	2401	index corr. + off, - on		0 '
ZD +W-E	7			DR Lon	151° 12' W	HE ft	9	DIP -	-	-2.9 '
GMT	14 h	53 m	18 s	GMT date / LOP label		C-	232 T	Ha	18°	25.5 '
				Sights #32 19-Jul-1982		S-	6.3 Kt			
2 GHA ♈ hr.	58°	27.9'	v moon planets	-0.8	DEC hr	N 22°	36.6'	d + −	+0.1	HP moon
3 GHA + m.s.	373°	19.5'			d corr.	+ -	0.1'	additional altitude corr. moon, mars, venus +		0.1 '
SHA + or v corr.	°	-0.7 '	stars or moon, planets		DEC deg	N 22°	DEC min 36.7'	altitude corr. all sights +-		-2.9 '
GHA	431°	46.7'						upper limb moon subtract 30'		'
		'	tens d	12.3	d upper			Ho T	18°	22.7 '
a-Lon -W+E	151°	46.7'	units d	0.5	d lower					
LHA	280°	00' W/60' E	dsd corr. +		dsd			Hc A	17°	55.5 '
			d corr. Pub. 229	12.8					a = 26.7 T	
4 LHA	280		**5** tab Hc	17°	42.7'	d + -	20.8	Z 73.4	Zn =	073.4
Dec deg	22	N S: N	d corr. Pub.249 & 229		12.8'	Dec min.	36.7		a - Lat =	25 N
a-Lat	25	N S: N	Hc	17°	55.5'			**6**	a - Lon =	151° 46.7' W

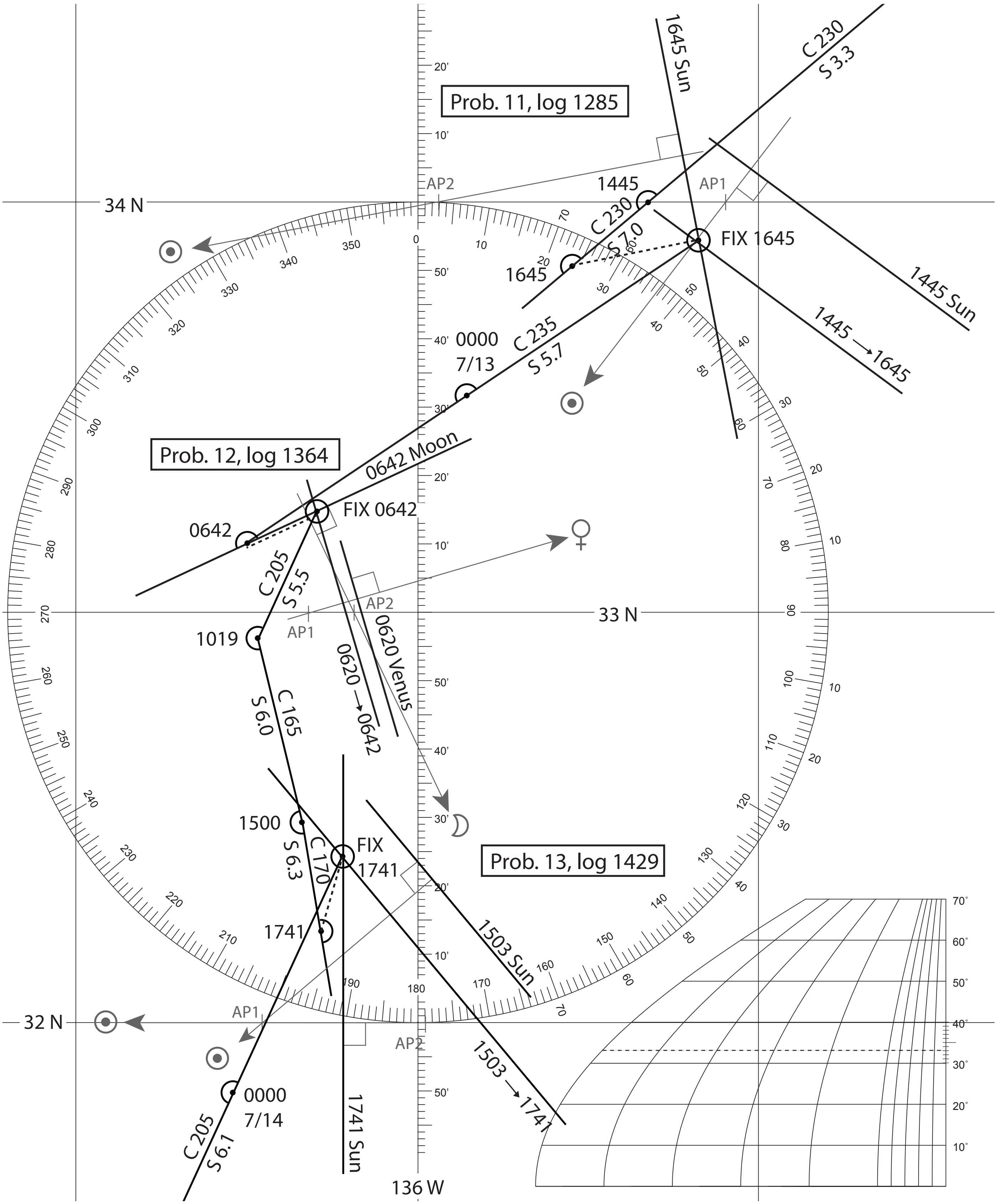
N Lat L.H.A. greater than 180 .... Zn = Z
L.H.A. less than 180 .... Zn = 360 - Z

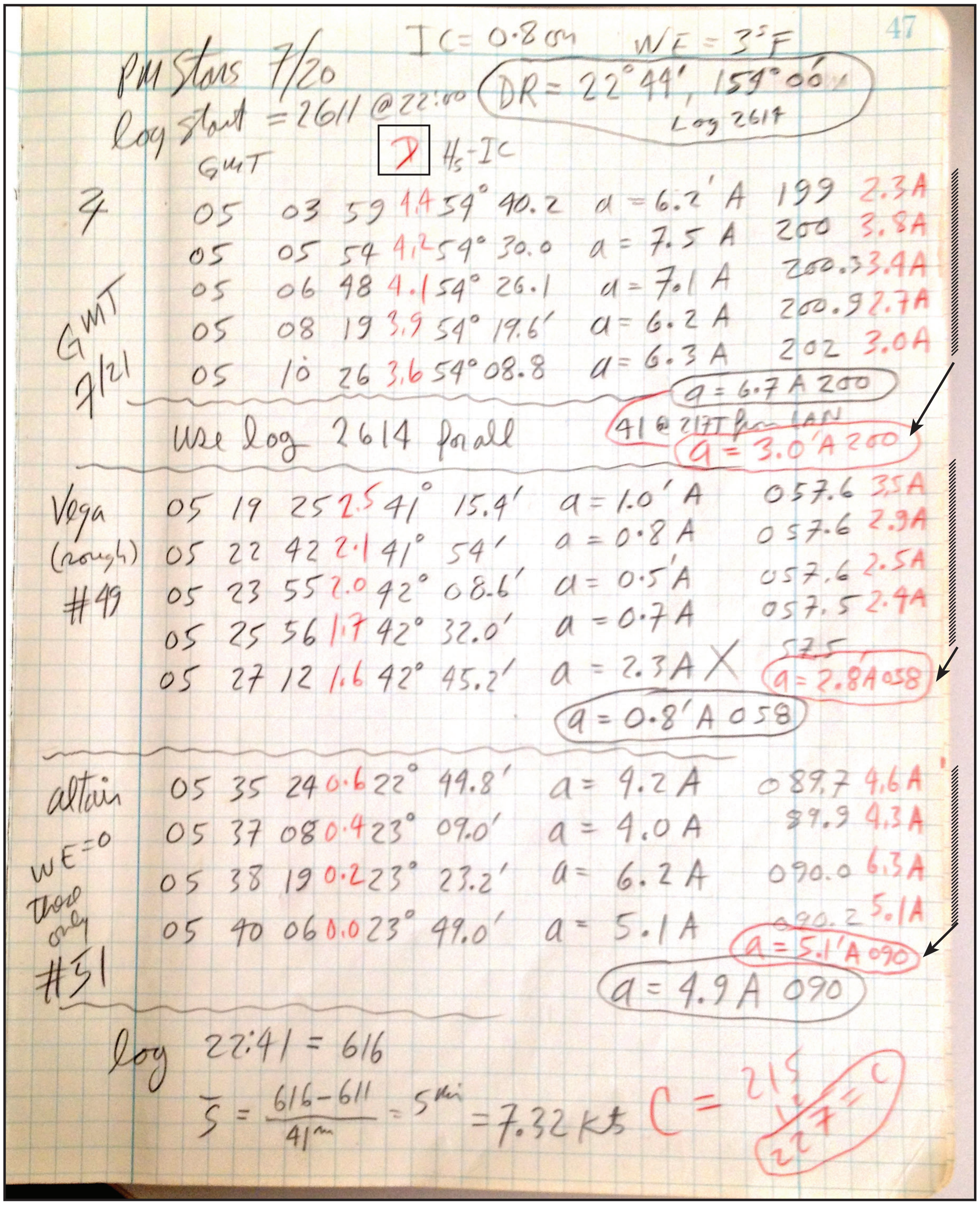
S Lat L.H.A. greater than 180 .... Zn = 180 - Z
L.H.A. less than 180 .... Zn = 180 + Z



A plot of Problem 22 from the original plotting sheets in 1982. This is Sheet 15a. We also found Sheet 17 (page 71), but the rest of the sheets are missing. This was a computed solution with auto advancement (Analysis section) plotted on an expanded scale.

1445 July 12th → 0000 July 14th





Problem 26

Distance Run, D

Corrected a-values

Figure A2. *Page from original logbook showing analysis done underway of a set of star sights, called Problem 26 in this book. Viewed in color, the red additions are the automatic advancement computations. In our present analysis we came up with slightly different DR, and resulting SMG and CMG. Our procedure underway was to record log before and after each sight session and compute SMG from that data. In the present analysis, we found SMG and CMG from successive logbook entries. The former approach is more accurate, but we did not have enough surviving data to do that for all sights, so we adopted the method used. In most cases the difference is not significant.*

4.9 to 5.1. In the Vega sights we could tell from the first level analysis that the 0527 sight was too low (a Away too big), and it can be discarded before further analysis.

It did not show up in this example, but in some cases a sight that looks out of the average in the uncorrected sights does not stand out at all in the corrected ones. The fit-slope method discussed next is the best way to identify outlying sights.

In this example, a fix plotted with and without advancing LOPs differs by about 2 nmi, and clearly the one without the advancement is wrong.

The next step is to see how to choose the best average sight from each set to be representative of the full set, so that we do not have to plot every one of them–though often we learn most by both analyzing and plotting.

Fit-Slope Method

This is good procedure for routine work, but crucial for times when we must rely on sights taken in poor conditions. For convenience, we use computer solutions here to demonstrate the process, but we want to stress that a great virtue of this method is it does not take a computer to solve underway. The only requirement is plotting a few points on graph paper and adding two extra standard sight reductions.

Since any one sight can be off somewhat, it is standard procedure to take multiple sights of any body and then average them in some manner, or figure which one of the set might be the best representative of all of them.

A simple numerical average of the Hs values will not work: first they are changing with time as the body rises or sets, and second we are moving as well during the time we take the sights. So it is not a trivial task to figure the best way to average a set of sights, and we must be prepared to spend some time on the project when it is called for.

The analysis is easier when doing sight reduction by computation, because then you can simply find the a-values for all of them, correct each one for the vessel motion, and then average these a-values. That is not a bad approach, but it is still not taking advantage of all we know about the sights.

Instead, we can do this fairly quickly by just analyzing the Hs and WT values, with just two special sight reductions required. We will use Problem 1 to explain the method, then give more examples from this passage.

Figure A3 shows the issue at hand in Problem 1. It is a plot of all of the sights taken, each corrected to a common time. This is three Venus sights, then four sun sights taken 3h 40m later, all in poor conditions, which means they are not the best sights, so we need to study them carefully to get the best results. Furthermore, they have nearly the same azimuth, which makes things even worse. Such a challenge is not uncommon in any real voyage that relies solely on cel nav.

This case, as poor as it looks, is not as bad as some. We have 4 sunlines that even without analysis looks like include two reasonable ones and two outliers; and with the Venus sights, maybe two good ones and one outlier. In other sight sessions, there might not be this type of guess to be made from just looking at the plotted LOPs corrected for course and speed.

To see if this interpretation makes sense, we plot the lines as Hs vs. WT and compare their trend to the predicted slope of the line as would be viewed from our changing position. Lines that are equally good should all have the same slope–that is, the same rate of change of Hs with WT.

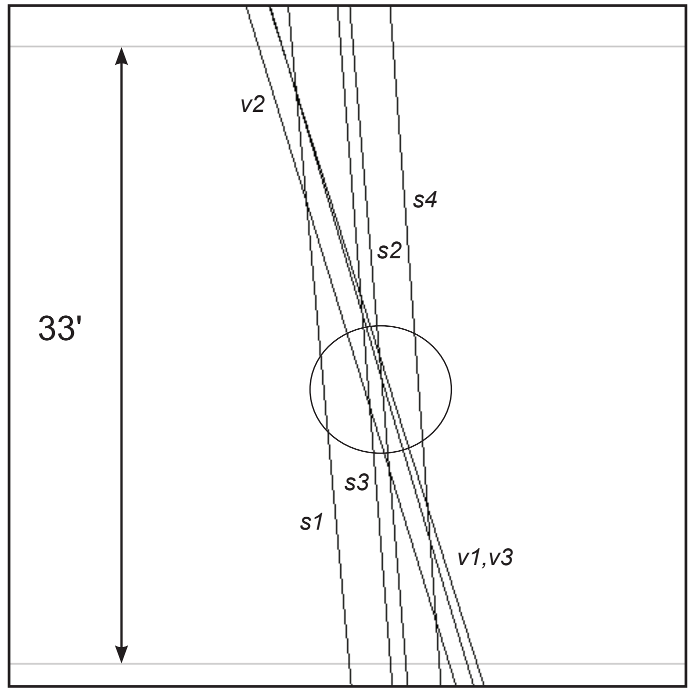


Figure A3. *Problem 1 all sights corrected to 0847 using S5.7, C197. These were all sights in poor conditions of rough seas and broken clouds and only intermittent views of the bodies being sighted. Three Venus sights, then 3 hr later four sun sights (the more vertical set). Without some analysis here, the fix is fairly uncertain. If all sights were equal, we might consider the fix as roughly at the center of the circle shown, with the radius as an estimate of the uncertainty. With some analysis we can do better.*

In other words, we do not know where we are, so we do not know what the heights will be, but we do know the computed height for any time and place on earth, so we just compute the heights from our DR positions and compare, not the values, but the rate of change. We call this process the fit-slope method.

Figure A4 shows the sunlines plotted this way, and then in Figure A5 we add the computed slope. The top figure is raw sextant data and no DR position is called for, but for the predicted sights we do need a DR. In fact, we need the DR at the start of the sights and at the end of the sights. Then we look up the GHA and dec for these two times and compute Hc in each case. We do not care about Zn. It is best at this point to compute the Hc rather than try to use tables. (This can be done with Pub 229, but for the precision we want from given DR positions it a lot of work). The formula for Hc computation is given in textbooks (Appendix A5) and it can be programmed into calculators, or use starpath.com/calc to get the answers, among other sources.

Then plot the two Hc values on the same page as the Hs data, and draw a line between them. Note we assume here that the sights are not too far apart in time, because if too far apart the line joining the sights is a curve, not a straight line. If in doubt about this, compute also an Hc for the midpoint between the two.

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Increments and Corrections

Use from any *Nautical Almanac*, or download from starpath.com/HBS

1982 JULY 6, 7, 8 (TUES., WED., THURS.)

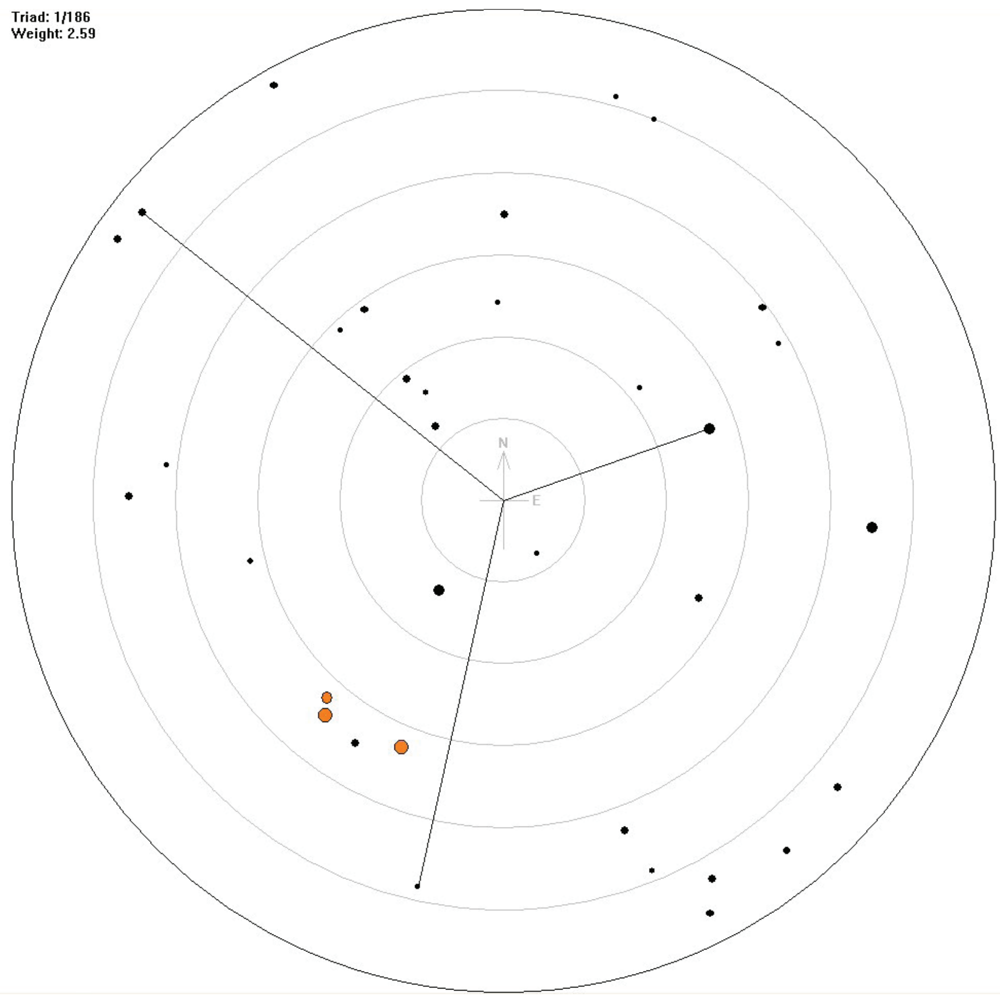
G.M.T. d	h	SUN G.H.A. ° ′	SUN Dec. ° ′	MOON G.H.A. ° ′	v ′	MOON Dec. ° ′	d ′	H.P. ′
6 TUESDAY	00	178 51.6	N22 44.7	2 34.2	11.3	S22 45.5	0.4	54.0
	01	193 51.5	44.4	17 04.5	11.3	22 45.9	0.3	54.0
	02	208 51.4	44.2	31 34.8	11.3	22 46.2	0.2	54.0
	03	223 51.3	·· 44.0	46 05.1	11.3	22 46.4	0.1	54.0
	04	238 51.2	43.7	60 35.4	11.3	22 46.5	0.0	54.0
	05	253 51.1	43.5	75 05.7	11.2	22 46.5	0.1	54.0
	06	268 51.0	N22 43.2	89 35.9	11.3	S22 46.4	0.3	54.0
	07	283 50.9	43.0	104 06.2	11.3	22 46.1	0.3	54.1
	08	298 50.8	42.7	118 36.5	11.2	22 45.8	0.4	54.1
	09	313 50.7	·· 42.5	133 06.7	11.3	22 45.4	0.6	54.1
	10	328 50.6	42.2	147 37.0	11.2	22 44.8	0.7	54.1
	11	343 50.5	42.0	162 07.2	11.3	22 44.1	0.7	54.1
	12	358 50.3	N22 41.7	176 37.5	11.2	S22 43.4	0.9	54.1
	13	13 50.2	41.5	191 07.7	11.3	22 42.5	1.0	54.1
	14	28 50.1	41.2	205 38.0	11.2	22 41.5	1.1	54.1
	15	43 50.0	·· 41.0	220 08.2	11.3	22 40.4	1.2	54.1
	16	58 49.9	40.7	234 38.5	11.3	22 39.2	1.3	54.1
	17	73 49.8	40.5	249 08.8	11.2	22 37.9	1.4	54.1
	18	88 49.7	N22 40.2	263 39.0	11.3	S22 36.5	1.5	54.1
	19	103 49.6	40.0	278 09.3	11.3	22 35.0	1.7	54.1
	20	118 49.5	39.7	292 39.6	11.3	22 33.3	1.7	54.1
	21	133 49.4	·· 39.5	307 09.9	11.3	22 31.6	1.8	54.1
	22	148 49.3	39.2	321 40.2	11.3	22 29.8	2.0	54.1
	23	163 49.2	38.9	336 10.5	11.3	22 27.8	2.1	54.1
7 WEDNESDAY	00	178 49.1	N22 38.7	350 40.8	11.3	S22 25.7	2.1	54.2
	01	193 49.0	38.4	5 11.1	11.3	22 23.6	2.3	54.2
	02	208 48.9	38.2	19 41.4	11.3	22 21.3	2.4	54.2
	03	223 48.8	·· 37.9	34 11.7	11.4	22 18.9	2.5	54.2
	04	238 48.7	37.6	48 42.1	11.3	22 16.4	2.5	54.2
	05	253 48.6	37.4	63 12.4	11.4	22 13.9	2.7	54.2
	06	268 48.5	N22 37.1	77 42.8	11.4	S22 11.2	2.8	54.2
	07	283 48.4	36.9	92 13.2	11.4	22 08.4	2.9	54.2
	08	298 48.3	36.6	106 43.6	11.4	22 05.5	3.1	54.2
	09	313 48.2	·· 36.3	121 14.0	11.4	22 02.4	3.1	54.2
	10	328 48.1	36.1	135 44.4	11.4	21 59.3	3.2	54.2
	11	343 48.0	35.8	150 14.8	11.5	21 56.1	3.3	54.2
	12	358 47.9	N22 35.5	164 45.3	11.4	S21 52.8	3.4	54.2
	13	13 47.8	35.3	179 15.7	11.5	21 49.4	3.6	54.3
	14	28 47.7	35.0	193 46.2	11.5	21 45.8	3.6	54.3
	15	43 47.6	·· 34.7	208 16.7	11.5	21 42.2	3.7	54.3
	16	58 47.5	34.5	222 47.2	11.6	21 38.5	3.9	54.3
	17	73 47.4	34.2	237 17.8	11.5	21 34.6	3.9	54.3
	18	88 47.3	N22 33.9	251 48.3	11.6	S21 30.7	4.1	54.3
	19	103 47.2	33.7	266 18.9	11.6	21 26.6	4.1	54.3
	20	118 47.1	33.4	280 49.5	11.6	21 22.5	4.3	54.3
	21	133 47.0	·· 33.1	295 20.1	11.6	21 18.2	4.3	54.3
	22	148 46.9	32.8	309 50.7	11.7	21 13.9	4.5	54.3
	23	163 46.8	32.6	324 21.4	11.7	21 09.4	4.5	54.4
8 THURSDAY	00	178 46.7	N22 32.3	338 52.1	11.7	S21 04.9	4.7	54.4
	01	193 46.6	32.0	353 22.8	11.7	21 00.2	4.7	54.4
	02	208 46.5	31.7	7 53.5	11.7	20 55.5	4.9	54.4
	03	223 46.4	·· 31.5	22 24.2	11.8	20 50.6	4.9	54.4
	04	238 46.3	31.2	36 55.0	11.8	20 45.7	5.1	54.4
	05	253 46.2	30.9	51 25.8	11.8	20 40.6	5.1	54.4
	06	268 46.1	N22 30.6	65 56.6	11.8	S20 35.5	5.3	54.4
	07	283 46.0	30.4	80 27.4	11.9	20 30.2	5.3	54.4
	08	298 45.9	30.1	94 58.3	11.9	20 24.9	5.5	54.5
	09	313 45.8	·· 29.8	109 29.2	11.9	20 19.4	5.5	54.5
	10	328 45.7	29.5	124 00.1	11.9	20 13.9	5.6	54.5
	11	343 45.6	29.2	138 31.0	12.0	20 08.3	5.8	54.5
	12	358 45.5	N22 28.9	153 02.0	12.0	S20 02.5	5.8	54.5
	13	13 45.4	28.7	167 33.0	12.0	19 56.7	5.9	54.5
	14	28 45.4	28.4	182 04.0	12.0	19 50.8	6.0	54.5
	15	43 45.3	·· 28.1	196 35.0	12.1	19 44.8	6.1	54.5
	16	58 45.2	27.8	211 06.1	12.1	19 38.7	6.2	54.6
	17	73 45.1	27.5	225 37.2	12.1	19 32.5	6.3	54.6
	18	88 45.0	N22 27.2	240 08.3	12.2	S19 26.2	6.4	54.6
	19	103 44.9	27.0	254 39.5	12.1	19 19.8	6.5	54.6
	20	118 44.8	26.7	269 10.6	12.3	19 13.3	6.5	54.6
	21	133 44.7	·· 26.4	283 41.9	12.2	19 06.8	6.7	54.6
	22	148 44.6	26.1	298 13.1	12.3	19 00.1	6.8	54.6
	23	163 44.5	25.8	312 44.4	12.2	18 53.3	6.8	54.7
		S.D. 15.8	d 0.3	S.D. 14.7		14.8		14.9

Lat. °	Twilight Naut. h m	Twilight Civil h m	Sunrise h m	Moonrise 6 h m	Moonrise 7 h m	Moonrise 8 h m	Moonrise 9 h m
N 72	□	□	□	■	■	■	■
N 70	□	□	□	■	■	■	00 49
68	□	□	□	■	■	00 18	{00 02 / 23 53}
66	////	////	00 56	23 11	23 26	23 32	23 33
64	////	////	01 53	22 28	22 54	23 09	23 17
62	////	////	02 25	21 59	22 30	22 50	23 04
60	////	01 18	02 49	21 37	22 11	22 35	22 52
N 58	////	01 58	03 08	21 19	21 55	22 22	22 43
56	////	02 24	03 24	21 04	21 42	22 11	22 34
54	01 12	02 45	03 37	20 51	21 30	22 01	22 26
52	01 48	03 01	03 49	20 40	21 20	21 52	22 19
50	02 13	03 16	03 59	20 30	21 10	21 44	22 13
45	02 55	03 44	04 21	20 08	20 51	21 28	21 59
N 40	03 24	04 05	04 38	19 51	20 35	21 14	21 48
35	03 47	04 23	04 52	19 37	20 21	21 02	21 39
30	04 05	04 38	05 05	19 24	20 10	20 52	21 30
20	04 33	05 02	05 26	19 03	19 50	20 34	21 16
N 10	04 54	05 21	05 44	18 44	19 32	20 18	21 03
0	05 13	05 39	06 01	18 27	19 16	20 04	20 51
S 10	05 29	05 55	06 18	18 09	18 59	19 49	20 39
20	05 45	06 12	06 36	17 51	18 42	19 34	20 26
30	06 00	06 30	06 56	17 29	18 21	19 16	20 11
35	06 09	06 40	07 08	17 17	18 10	19 05	20 03
40	06 18	06 51	07 22	17 02	17 56	18 53	19 53
45	06 27	07 04	07 38	16 45	17 40	18 39	19 41
S 50	06 38	07 19	07 57	16 24	17 20	18 22	19 27
52	06 43	07 27	08 07	16 13	17 10	18 13	19 20
54	06 49	07 34	08 17	16 02	17 00	18 04	19 13
56	06 54	07 43	08 29	15 49	16 48	17 54	19 05
58	07 01	07 52	08 43	15 34	16 34	17 42	18 56
S 60	07 08	08 03	08 59	15 16	16 17	17 28	18 45

Lat. °	Sunset h m	Twilight Civil h m	Twilight Naut. h m	Moonset 6 h m	Moonset 7 h m	Moonset 8 h m	Moonset 9 h m
N 72	□	□	□	■	■	■	■
N 70	□	□	□	■	■	■	03 54
68	□	□	□	■	■	02 44	04 40
66	23 10	////	////	01 07	02 09	03 36	05 09
64	22 15	////	////	01 54	02 52	04 07	05 32
62	21 43	////	////	02 25	03 21	04 31	05 49
60	21 19	22 49	////	02 48	03 43	04 49	06 04
N 58	21 01	22 10	////	03 06	04 00	05 05	06 16
56	20 45	21 44	////	03 22	04 15	05 18	06 27
54	20 32	21 24	22 55	03 35	04 28	05 30	06 37
52	20 20	21 08	22 20	03 46	04 39	05 40	06 45
50	20 10	20 53	21 56	03 57	04 49	05 49	06 53
45	19 49	20 25	21 14	04 18	05 10	06 08	07 08
N 40	19 32	20 04	20 45	04 36	05 27	06 23	07 22
35	19 17	19 46	20 23	04 50	05 42	06 36	07 33
30	19 05	19 32	20 05	05 03	05 54	06 47	07 42
20	18 44	19 08	19 37	05 25	06 15	07 07	07 59
N 10	18 25	18 48	19 15	05 44	06 33	07 23	08 13
0	18 08	18 31	18 57	06 01	06 50	07 39	08 27
S 10	17 52	18 14	18 41	06 19	07 07	07 55	08 40
20	17 34	17 58	18 25	06 38	07 26	08 11	08 54
30	17 14	17 40	18 09	06 59	07 46	08 30	09 10
35	17 02	17 30	18 01	07 12	07 59	08 41	09 20
40	16 48	17 18	17 52	07 26	08 13	08 54	09 30
45	16 32	17 06	17 43	07 44	08 29	09 09	09 43
S 50	16 12	16 50	17 31	08 05	08 49	09 27	09 58
52	16 03	16 43	17 27	08 15	08 59	09 35	10 05
54	15 53	16 36	17 21	08 27	09 10	09 45	10 13
56	15 41	16 27	17 16	08 40	09 22	09 56	10 21
58	15 27	16 17	17 09	08 55	09 37	10 08	10 31
S 60	15 11	16 07	17 02	09 13	09 53	10 22	10 42

Day	SUN Eqn. of Time 00^h m s	SUN Eqn. of Time 12^h m s	SUN Mer. Pass. h m	MOON Mer. Pass. Upper h m	MOON Mer. Pass. Lower h m	MOON Age d	MOON Phase
6	04 33	04 38	12 05	24 39	12 14	15	○
7	04 43	04 48	12 05	00 39	13 03	16	
8	04 53	04 58	12 05	01 27	13 51	17	

Problem 7 – July 9th, 21:44:32, 36° 56.5'N, 132° 32'W



Body	Mag	Hc	Zn
21: POLLUX	1.2	002°09.4'	304.1°
26: REGULUS	1.2	019°30.3'	270.6°
27: DUBHE	2	045°34.8'	324.0°
28: DENEBOLA	2.2	040°59.1'	256.5°
32: ALIOTH	1.7	060°45.1'	321.4°
33: SPICA	1.2	036°24.8'	211.4°
34: ALKAID	1.8	071°05.6'	317.4°
36: MENKENT	2.2	015°28.0'	192.5°
37: ARCTURUS	0.2	069°08.3'	215.6°
40: KOCHAB	2.2	052°39.9'	358.3°
41: ALPHECCA	2.2	078°11.5'	147.4°
42: ANTARES	1.2	023°44.4'	159.8°
45: SHAULA	1.7	008°32.7'	151.2°
46: RASALHAGUE	2	048°49.3'	116.5°
47: ELTANIN	2.4	056°44.5'	050.3°
48: KAUS AUSTR	2	005°09.9'	141.0°
49: VEGA	0.1	048°55.9'	070.8°
50: NUNKI	2	007°00.7'	130.6°
51: ALTAIR	0.8	020°22.0'	094.3°
53: DENEB	1.2	029°09.2'	053.3°
58: POLARIS	2	036°08.4'	000.2°
59: Caph	2.4	012°47.3'	021.6°
62: Gamma Casiopeiae	2.2	011°07.2'	015.6°
84: Menkalinan	2	000°41.0'	331.0°
95: Castor	1.6	003°00.4'	308.5°
105: Algeiba	2.2	026°12.0'	276.1°
108: Merak	2.4	045°32.1'	316.3°
121: Mizar	2.2	064°55.0'	324.3°
145: Epsilon Scorpii	2.4	014°50.1'	158.1°
152: Theta Scorpii	2	003°03.1'	153.4°
164: Gamma Cygni	2.2	030°16.9'	060.3°
Mars	-0.1	037°23.9'	219.6°
Jupiter	-2.1	039°43.7'	202.5°
Saturn	0.9	040°03.3'	221.8°

David and Steve on the bow of the world's most advanced warship, the Destroyer USS Spruance (DDG 111). The authors were invited to the commissioning of the ship in Key West, FL as guests of the Commanding Officer, CDR Tate Westbrook, in recognition of the Starpath training in celestial and coastal navigation provided to officers of the ship.

About the authors

David Burch is Director of Starpath School of Navigation. He is fellow of the Institute of Navigation and the Royal Institute of Navigation and received the former's Superior Achievement Award for outstanding performance as a practicing navigator. He has navigated eleven Hawaii races in boats from 36 ft to 73 ft, including an elapsed time record for boats under 38 ft that lasted for 16 years, two division wins, and two Gabriella III Navigator's Trophies for first to finish.

Stephen Miller is the Starpath Lead Instructor in Coastal and Celestial Navigation. He holds a USCG Masters License, and was previously the Dean of Professional Mariner Training at Chapman School of Seamanship in Stuart, FL, where he taught all levels of navigation in the classroom and underway. He is a former Navy Quartermaster, with more than 25 years of sailing experience in his own boat on the East Coast. He is the author of *The Captain's Moon*, a book on moon photography.