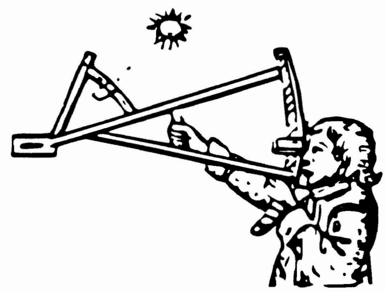
THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-TWO, WINTER 1998-99

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Celestial Navigation Instruction at the Naval Academy

The U.S. Naval Academy is considering a wide range of recommendations from the 1997 Special Committee to its Board of Visitors and from a 1998 special curriculum review committee, referred to as Curriculum 21. The Curriculum 21 review committee, chaired by Vice Admiral Doug Katz, U.S. Navy (Retired), consisted of senior officers and civilians, including representatives of the Academy and the Navy and Marine Corps outside of Annapolis.

Two recommendations of both review committees were to reduce the amount of class time spent on teaching classic celestial navigation and to increase emphasis on emerging electronic navigation technology. These recommendations had inputs from commanding officers and flag officers from the operational fleets.

Vice Admiral John R. Ryan, U.S. Navy, Superintendent, U.S. Naval Academy, in commenting on press reports on potential modifications to the navigation curriculum at the U.S. Naval Academy, said that, in his opinion, "some of the newspaper articles have overstated the effects of our intentions to update the navigation course."

Admiral Ryan said that there is no plan to cancel the Navigation and Piloting course that is taught during the sophomore (third class) year. He also said that the Curriculum 21 recommendations do not advocate the elimination of all celestial navigation instruction. Instruction in the principles and theory of celestial navigation should be retained.

In the spring of their freshman (fourth class) year, Naval Academy midshipmen take Fundamentals of Naval Science (which include piloting and coastal navigation). In the summer the new sophomores, or third classmen, practice navigation (including sextant instruction) during cruises along the East Coast in yard patrol (YP) craft. In the fall they take Navigation (including celestial and electronic systems). Admiral Ryan advises that this triad will continue to form the framework for navigation instruction for future years.

In response to the recommendations, the Naval Academy intends to decrease class time in reducing sights by tables and to introduce midshipmen to the computer software capabilities that are used on board ships to reduce the amount of time spent on celestial navigation computations.

Apology

In keeping with our policy of providing interesting, challenging and provocative articles in The Navigator's Newsletter, we were delayed in printing issue #61 by technical problems. The many technical symbols required for an article was beyond the capability of the software program being used. We apologize for the excessive delay in mailing issue #61.

Ordering Books, Publications or Charts

A sampling of some of the books and charts is included in this issue of the newsletter. The prices listed are the ones currently being published but are subject to change. Other books of interest to you, and not listed, may be available. Let us know, our publishers may have them in print.

DO YOU KNOW . . .?

By Ernest Brown

Who devised the transparent station-pointer three-arm protractor?

(The answer appears at the back of this issue.)

When ordering books, publications or charts, please fax, call, e-mail or write your order separate from your renewal. We may miss your order if it is written on the renewal card. Please DO NOT SEND PAYMENT with your order. Publishers and the government are continually changing prices and the postage now varies with your Zone. We will send you an invoice or statement after we are sure that your order has been filled. You may not get the invoice or statement immediately, but do not be concerned as we may be on travel and will send them when we return. Your order is the most important item. Payment can come at any time.

READERS FORUM

John Ward and Dr. Margaret Folkard wrote from Australia on 29 December 1998:

"We are two retired physicists with a small hobby business of gnomonics. We have been designing, making, installing and restoring sundials of many types for about 25 years.

"We have written a book called 'Sundials Australia' which proved to be surprisingly popular within Australia and overseas. We enclose a complimentary copy.

"In addition to sundials, we have designed and made many replicas of ancient navigation instruments which have been used on re-enactment voyages of discovery around the world. We have made astrolabes, quadrants, altitude boards, Chinese jade star finders, stick charts, spoon compasses, sun compasses, etc. The list is a long one. We enclose a copy of one of our papers which describes sun compasses as possibly used by the Vikings whilst enroute to America via Greenland.

"Recently we attempted to make a solstein (or sunstone) to be used aboard a replica, Viking long boat which was to be rowed from Bergen in Norway via Greenland to America. Leif Ericsson did this journey about 1000 years ago.

"To our limited knowledge, solstein is the mineral iolite or cordierite. See the attached article. We also enclose a poor copy of a report which appeared in TIME MAGAZINE July 14, 1967.

"As physicists (specializing in optics), we are aware of some of the many properties of polarized light and we have a limited knowledge of crystalline pleochroism. We still failed to totally understand if and how solstein works.

"Can you help us by giving us some more information about navigation using solstein? We enclose a part copy of an article from the *New Scientist* magazine which discusses polarization of the daylight sky."

— Regards from gnomonists and physicists John Ward and Dr. Margaret Folkard.

Editor's note: Director John M. Luykx provided several references to the use of the solstein in navigation. The articles were in German and Norwegian.

Member Frederic C. Kapp wrote from St. Simons Island, Georgia on January 1, 1999:

"In October I had the unique experience of making a passage from Bermuda to Tortolla, B.V.I. aboard the replica HM Bark *Endeavor*, the replica of the ship that Lt. James Cook sailed on his voyage of discovery in 1768.

"She is in every way, from the mess deck to the weather deck exactly as was the original. She does however have a full complement of electronic gear (weather, fax, radar, GPS etc.) It was my pleasure to do the celestial work and thus this letter.

"I took stars the first morning out, and while I was working them below with the tables (NA and HO 229), the first officer suggested I try to learn how to use his Merlin Celestial Calculator. I was leery, thinking how could I teach myself to use it, while doing a full days work (AM stars, AM sun, RF at noon, RF in the afternoon and PM stars.) Well, that evening after I had worked our position (which agreed very nicely with the GPS) I began to play with the calculator, Well, I must say, it changed my life.

"In the morning, I took four observations of four stars, sixteen in all, went below, entered them all in the Merlin, and in about ten minutes had a perfect fix, all LOPs advanced to a common time (sights at 0530 with a fix time requested for 0600). For plotting purposes the solution is very nice since it is based on the DR - no need to plot from four different APs. For the rest of the voyage, nine days, I used the calculator and found many more nice features. I had the moon during daylight for several days, and working UL sights of that body were a cinch with excellent results.

"When I returned home, I tried to purchase one, only to find that they had been out of business for about two years. However, Celestaire suggested that I purchase the Celesticomp V, which I am now using. It has some very nice features.

"It will give DR SR, SS and best time to observe.

"It has a star list and will compute what stars are available. This is slow, but another nice feature is that it will give LHA Aries for sight time, and you can then very quickly set up your Rude Star Finder. Using a Rude for planets though is cumbersome, but the calculator will tell you which of the four planets will be available. Takes about five minutes. Gives the alt and az of each body. You can also shoot an unknown body, and it will figure it out.

"It has a nice program for computing dev from a shadow on the compass pin. No need for SR or SS amplitudes.

"There are many more features too numerous to go into here. Suffice it to say, that you do not find a glitch using the tables until the end of the computation when you get to ZN and HC. With the calculator, an erroneous solution is very apparent, and you just re-enter your figures.

"When using the tables, which I like to do to keep in practice, I now use a scientific calculator. This makes adding all those degrees, minutes, and seconds (i.e. GHA and LHA of a star) much quicker and less subject to math errors.

"I still enjoy working a sight with Ageton HO 211 and a calculator removes most all of the possible math errors there. The calculator will give you the suns az any time of the day, but in the absence of one, HO 211 gives you the az without interpolation from your DR position.

"I must say, after all of the above, that a beginning student should learn by using the tabular methods so he will be well grounded in what is going on, and will learn how to plot, keep a DR etc. After all, gadgets can get wet, run out of power or break. Keeping a DR is the most important basis of good navigation and the student must be well grounded in this.

"I still work sights a few times a month so as to keep acquainted with the tabular methods. I must say, that the calculator can relieve a lot of stress, particularly on a small sailing vessel and under racing condition."

— *With kind regards, Frederic C. Kapp*

Captain Keith Sternberg wrote from Lopez Island, Washington on January 10, 1999:

"Dear Navigators: I acquired one of your newsletters a while back (#54) and would like to become a subscriber. Please advise me concerning the fee. I read that you have an E-mail address but I have not yet entered the computer age.

"My interest in navigation takes several forms: everything relating to magnetic compass adjustment, azimuth devices in their various forms including sundials, chronometers and their makers, longitude methods before tables of calculated altitude and azimuth, and early instruments.

"Recently I made a backstaff with a mortised Port Orford cedar frame. I find it easy to use so long as there is not too much wind and found the latitude within five miles of correct. I divided it with dividers, wishing for the 17th century experience, but I may divide the next one on the rotary table!

"In my work I adjust every type and size of vessel and find the work very interesting. Restoring the Earth's magnetic field, as well as it can be, is half the job and the other half is finding the magnetic meridian. I have bearings worked out all around the Puget Sound area. In hazy weather or a place with no distinctive landmarks visible I find the bearing of the best object to be seen in the same manner that variation is found at sea. I never take variation for granted, as marked on the chart, and always try to find the value of variation myself.

"In clear weather I have two ways of finding the sun's azimuth. I like the Globe-Hilsenrath Azimuth Computer, a slide rule actually, when using an azimuth ring or shadow pin. I also have a pelorus which was called the 'London Polaris', made during the last half of the 19th century, which is an equinoctial sundial and gives the azimuth without need to calculate it. I adjust it for Latitude and for Local Apparent Time every two minutes. I enclose a cut of it and would like to know if anyone has seen one."

—*Sincerely, Keith Sternberg*

Editor's note: In addition to compass adjusting, Captain Keith Sternberg does nautical instrument repair.

Member Richard Sayer wrote from Colorado Springs, CO:

"... Lastly, I just acquired a sextant that I know nothing about. On front it says '1894 Stanley Sextant London.' Enclosed are several picture including the bottom of the case. If you have any information that can enlighten me about this little sextant (and you have time) let me know."

—Thanks, Richard Sayer

Editor's note: Director John M. Luykx responded, in part, as follows:

"Based on the photographs enclosed in your letter, it is my opinion that your sextant is probably a modern reproduction of a mid 19th century English made miniature sextant. It was designed for decorative purposes and not for actual use at sea.

"This opinion is based only on what I can see in the photographs regarding 1) workmanship (b) details that can be discerned concerning the mirrors, filters and telescope and c) features that can be identified on the graduated arc and the vernier.

"If I had the instrument in hand, I could give a more informed opinion. In fact, I believe you should obtain a second opinion by contacting experts such as museum curators and offering them your sextant for evaluation.

"Suggestions:

The Mariner's Museum, Newport News, VA
804-595-0365
The Peabody Museum, Salem, MA 508-745-1876
Mystic Museum, Mystic CT 203-572-0711

"Keeping in mind that the *Stanley* firm is well known for the fine workmanship employed in the manufacture of its instruments, you should be able to determine from an examination of your sextant whether it was designed for actual use at sea or whether, as I believe, it was designed strictly for decoration.

"If we can be of any further assistance to you, please contact me at 301-420-2468."

—*Sincerely, John M. Luykx*

Member Captain Donald B. Millar wrote from Annapolis, Maryland on 30 December, 1998:

"Recently upon researching articles on navigation published in back copies of the *Naval Institute Proceedings*, I found the attached copy of an article in the January 1918 edition with the title 'Diagram for Graphical Correction to be applied to Ex-Meridian Altitudes' by Commander E. B. Fenner, USN.

"I gave the diagram a field test by taking several double altitude noon sights using an artificial horizon. My findings in latitude accuracy were within 5 minutes of arc. The accuracy of the correction is dependent on the size of the meridian angle, the smaller the better. It is indeed a quick and easy solution to the Ex-Meridian problem.

"If you deem the article as having interest to the membership and merits inclusion in the Newsletter, the Naval Institute Proceedings has given written permission to reprint the article. Copy of letter is enclosed."

—Very respectfully, Donald B. Millar

Editor's note: A member, identity not known at this time, submitted the following question for the membership:

"A question for the membership: Would any be willing to share tricks, tips on using a minimum of formal instruments? I have read much of what is available on limitations of a variety of techniques including:

1) A.M. radio direction finding.
2) Use of a polarized filter for the determination of solar azimuth when the sun is below the horizon (solarstein method).
3) Solar azimuth at sunrise or sunset if a suitable horizon is available.
4) Shadow tip methods.
5) Use of the Astrocompass.
6) Rising-angle of known celestial bodies (a la Burch).
7) Kamal for altitude measurement."

Editor's note: See issues 51, 52, 53, 55, 56 and 57 for member Eric B. Forsyth's seven newsletters for Fiona's 1995-97 circumnavigation. The following is his first newsletter for his 1998 cruise:

Member Eric Forsyth wrote from Puerto Montt, Chile, in October, 1998:

"Dear Friends, It seemed like *Fiona's* 1998 cruise would never start —we had to yank the engine out only weeks before departure and boatyard people were still working on the new deck two days before we left. The deck replaced the teak, which was finally going after 23 years (yes, Virginia *Fiona* is getting old, like her skipper) work was hampered by a rainy spring. Mike Demont flew in from South Africa a couple of weeks before departure to join Walter and I as the crew. We left on July 9, three days later than planned, and, in fact, we have been running behind schedule for this whole phase of the cruise. In each port I felt a little like the White Rabbit - 'I'm late, I'm late!' Sticking to the timetable is important so that we get a good weather window at Cape Horn. We skipped our traditional one night layover in Block Island, heading straight to Bermuda. For the first two days the winds were light and variable but then we picked up good NE winds and romped to Bermuda in a little over five days after leaving Fire Island Inlet. The shock I encountered on this leg was not caused by the weather or some problem with the boat. Sitting comfortably in the cockpit at happy hour with a run in our hands the day before landfall Walter announced, out of the blue, that he was getting off in Bermuda and flying home. He felt he just was not ready for the trip. I must say this was a blow. Walter was a veteran of *Fiona's* 1995-97 circumnavigation and had become a very competent sailor. Mike had only a month or two of blue water experience under his belt and we were heading for some of the roughest sailing grounds in the world. Once in Bermuda, Mike called friends in Africa who might want to join the cruise and Brenda posted 'crew wanted' messages on Internet notice boards. Finally we left (late as usual, the search for crew was the delaying factor) with a Bermudian crew member who had sailed across the Atlantic and had several good references from yacht skippers. We had wonderful winds and made the 900 mile passage to St. Martin in a little over six days. We had a very near miss with a freighter one night when a couple of hundred miles from St. Martin. Despite prolonged discussion about collision avoidance with the captain on the VHF radio the clown put his helm over when just yards away and barely cleared our stern. When we got to the French side of St. Martin the immigration officials refused to admit Mike as S. Africans needed a visa, so we puttered round to the Dutch side and cleared in there. As there is no border between the French and Dutch parts of the island this is a perfect example of mindless bureaucracy. It was in St. Martin we parted company with our Bermudian crew; he just wasn't working out, considering what lay ahead and I got him a ticket home. After stocking up with duty-free rum Mike and I sailed the boat to Bequia, the start of a charming cruise of the Grenadine Islands. Wandering about the small island of Mayreau we came across the gravestone of Margaret Alexander, who died on the 31st of January, 1950, aged 113! It is staggering to think that this lady, who died well after WWII, as a child probably saw British men-of-war that could have been at the Battle of Trafalgar. Her parents were probably slaves, but she was born just as the British Empire renounced slavery. Later on we talked to a local who was her great-great grandson. We dived on a sunken gunboat on a reef west of Mayreau, but that was from a later era; it had a boiler.

"At each island I bombarded Brenda with phone calls concerning possible crew replacement. She had flushed out on the Internet a Frenchman called Bruno who was very interested and I finally managed to talk to him myself—a not inconsiderable feat considering the phones on most West Indian islands. He seemed OK and we agreed to rendezvous at Curacao, our next stopover with decent air connections. We made it to an inner lagoon by means of a winding channel with a rock-bound narrow entrance. It was quite hair-raising in the dark and we went very slowly. Unfortunately Bruno had not contacted Brenda to give her a flight number and date and after waiting a few days we gave up on him. However, the island did hold a pleasant surprise; through my vintage auto rallies I had come to know a Danish couple who owned a hotel. I gave them a call and they insisted Mike and I should stay with them for a couple of days. The hotel was very luxurious and for two nights we enjoyed a sybaritic existence, particularly so after the semi-Spartan life on a cruising sailboat. Ultimately we tore ourselves away and sailed for the San Blas Islands, a beautiful archipelago of tropical islands off the Darien coast of Panama. They are inhabited by the Kuna Indians, who have a good deal of autonomy and have prevented any development of tourist facilities, so they make a wonderful cruising ground. The Indian ladies come alongside in dugout canoes to sell embroidered cloth squares called molas, which unfortunately for them they have over produced, as the prices were less than when *Fiona* visited the same islands in 1996. The crew situation was now getting really worrisome. The Panama Canal was less than 100 miles away, once through it we were committed to some very long distance sailing that would not be too enjoyable for a crew of only two. There was a solitary phone booth outside the customs house on Porvenir Island, a rare symbol of civilization in these islands and I thanked my lucky stars I could raise the ATT operator on it, so calling home was not a problem. I got Brenda to call several of my old sailing chums in a vague hope they might have a few months to spare that they could spend getting cold and wet off Tierra del Fuego. Mike recalled an old colleague of his from Zimbabwe, Bruce, who was presently on a walk-about in England. The only point of contact was a secretary at his old firm in South Africa who, we hoped, would have a number for him in London. With this slim lead Brenda managed to track him down and he agreed to join us in Panama!

"When we tied up at the Panama Canal YC in Colon I found the city had improved considerably since our last visit in 1996. Many decrepit buildings had been knocked down and people on the street seemed happier and better dressed. Most importantly, nobody mugged me this time! We stayed a few days in order to complete the formalities of transiting the canal and made final arrangements to meet Bruce when we got to Balboa, on the Pacific side. I had to hire three Panamanian youths as line handlers. The commission rules require four people on board as well as the skipper and commission pilot. We stopped for the night in the Gatun Lake, between the Atlantic and Pacific locks. We were definitely discouraged from swimming when we noticed an alligator casing the boat. Bruce arrived on schedule at the Panama City Airport. We left within a couple days and anchored for the night at an island in the Las Perlas group, so Bruce was not thrust immediately into an ocean passage — he had no deep water experience. The next day we left for the Galapagos Islands. On my previous two trips there, we encountered light and variable winds and we motored a lot. This time we had a steady head wind. Although we did not have to use the engine, we had to tack and tack, the 900 mile trip took eleven and half days and we logged just over 1400 miles.

"We spent a few days at Santa Cruz Island. Mike and Bruce went on a tour of the unique wildlife — I had seen them before. We left Santa Cruz just at nightfall so we could motor over to Santa Maria and anchor for the night - what was left of it; we arrived at midnight. Santa Maria is famous among sailors as it was here the old whalers left letters for homeward-bound ships to collect. A barrel was attached to a pole at what became known as Post Office Bay. As the outward-bound ships were often away for several years this was their last chance to send mail home for some time. Strictly speaking, yachts are no longer allowed to cruise to individual islands in the Galapagos but I felt tradition demanded that we stop at Post Office Bay. When we dinghied to the beach early in the morning we were met by a National park ranger who was escorting a gaggle of tourists. We had seen the barrel through binoculars from *Fiona*, so we pleaded to be allowed to walk over to it, but we were firmly ejected. I wonder if the tourists appreciated the irony that we were about to leave on a 4,000 mile cruise to Chile via Easter Island. We were just the sort of sailors the barrel was originally set up for.

"The trip to Easter Island was a delight. We had strong SE trade winds on the beam the whole way. We reeled off 170 miles a day and made the 1,900 mile leg in just under twelve days. At one stage the boisterous winds tore the mainsail, which we removed and repaired using the old Read sewing machine. We approached the island just at sunrise with some trepidation as there is no proper harbor and many sailors tell of difficulty getting ashore in their dinghy through the pounding surf. We anchored well clear of the surf line and saw local boats using a gap between the breaking waves. We inflated the 10 ft rubber dinghy and attached the 8 hp outboard. Without it we would not have been able to get ashore. Just inside the surf was a small breakwater with a thick hawser hanging 6 ft above the water. The idea was to tie the stern of the dinghy to this line and then fasten the bow to the dock wall. Once ashore we went through the arrival formalities at the port captain's office and then treated ourselves to a good lunch at one of the restaurants in the small village of Hanga Roa. The owner was a very helpful Frenchman, Through him we arranged to rent a jeep the next day so we could tour the island.

"The island has a fascinating history. Polynesians from the islands to the west (the Australs or Gambiers) arrived by ocean-going catamarans about the 7th century A.D. It must have been a shock after the lush islands they left; although Easter Island is just sub-tropical (it lies near 27°S) only the occasional palm tree on the shore reminds you of this. The interior is fairly desolate and windswept, you could be in Labrador or the highlands of Scotland. The early settlers soon cut down most of the trees and ate most of the native birds and animals. A long period of hardship began, which they dealt with by carving huge statues of former chiefs (Moai, pronounced Mo-eyes) who were associated with the Good Times. When the statue was erected and mother of pearl and obsidian eyes inserted, its spirit (Mana) guarded the land. The statues always had their backs to the sea. As times got tougher the Moais got bigger, finally achieving over 30 ft in height. (more Moais the answer?) Ultimately the Polynesians descended into cannibalism and fierce fighting between factions led to the destruction of many Moais. This period began just as Europeans discovered Easter Island and their diseases and slaving raids completed the annihilation of the Rapa Nui culture. There are hundreds of the big statues, some have been restored like the ones we saw on the NE coast at Anakena. Further south is the quarry where most were made from the soft pumice-like rock. It lies on the side of a huge volcanic crater; many half-finished statues abound. Finally we drove to the huge crater on the SE corner called Rano Kau. At a high point, right on the precipitous cliff, is an amazing collection of stone dwellings, made from flat basalt rock. Each hut has one small opening for ingress, perhaps 2 ft square. Why on earth people chose to live at this exposed spot, with winds howling in, I don't know. Perhaps it was where they kept the lepers. Immediately south of this small community are a couple of very small rocky islands about three quarters of a mile offshore. Legend has it that in the heyday of the Rapa Nui civilization a young man was chosen each year as the bird king. To achieve this honor the youths climbed down the cliff, swam to the larger island (Moto Nui), found a bird's egg and returned with it unbroken. The winner was crowned and received many honors for the year. I don't know what happened to him after that. Frequently a sacrifice was called for, I suspect.

"When we left we sailed in a big arc round the permanent high pressure zone centered on 30°S. Apart from the first couple of days, when we used the engine, we had good winds on the stern and we ran day after day for the South American coast with the jib set wing and wing, a leg of about 2,000 miles. As we drove south the temperature fell, our t-shirts gave way to pullovers. Our only companions on this lonely stretch of ocean were the sea birds, including the graceful albatross. Some evenings we showed a video using the camcorder as a VCR; we have a small B&W TV set. Perhaps it is a sign of the generation gap that when I screened the Astair/Rogers comedy "The Gay Divorcee", I had to explain to the crew that nobody was getting divorced because they were gay, in 1934 that meant Ginger was happy and carefree. Then I had to explain what a co-respondent was (a common way of divorce in England in the 20's through the 50's was to use a professional co-respondent to imply infidelity — the basis of the plot). I guess some films don't age well, but the dancing was wonderful.

"We anchored south of the lighthouse at Punta Corona 14 days out of Easter Island. The canals (Spanish for channels) have fierce currents and we waited for the flood to take us in - it ran over 8 knots! We have tied up at an excellent marina in Puerto Montt, having logged 8,637 nautical miles since leaving Long Island. I am going to take a lot of broken bits to Long Island to get them repaired and then, on my return, we will cruise the scenic canals that lead down Chile's west coast to Puerto Williams, a scant 90 miles from Cape Horn. We hope to spend Christmas there."

—Best wishes until the next time, Eric

NAVIGATION NOTES

Spherical Trigonometry in a Gale

By Richard S. Preston

Some fundamental relationships of geometry and trigonometry were certainly known experimentally before being demonstrated mathematically from basic axioms. Among them are the facts that the ratio π of the circumference of a circle to its diameter is the same for all circles, and that the ratio of the lengths of two sides of a given triangle is the same as the ratio for the corresponding sides of any triangle having the same angles. Such fact would become obvious to practical craftsmen and artisans engaged in their everyday occupations. Even today there are craftsmen who know that triangles whose sides are in the ratio 3:4:5 or 5:12:13 are right triangles, but care nothing for the fact that these ratios conform to Pythagoras's theorem.

One such discovery occurred fairly late in the development of the theory of celestial navigation. Unlike the discoveries just mentioned, this one was not made in the relative calm of a workshop, or on a construction site, nor even in a scholar's study, but on a sailing ship in the midst of heavy gales in the Celtic Sea, and it resulted in a totally new method of computing latitude and longitude from sextant readings on celestial bodies.

On December 17, 1837, an American merchant ship captain, Thomas H. Sumner, had been prevented for several days from making any sextant observations because of cloud cover. By dead-reckoning his position at midnight was west of the coast of South Wales and south of the Irish coast (see Sumner's chart in Figure 1), but his actual position was sufficiently uncertain that proceeding farther in any direction would put his ship in danger of running aground or on shore. During the night he tacked back and forth hoping to keep his position, but when daylight came he could see no land and his dead reckoning position had become even more uncertain.

At about two hours before noon a brief break in the clouds gave him an opportunity to take an altitude of the sun. The altitude of a star (or sun, moon, or planet) is measured with a sextant. The altitude is the angle, at the observer, between the star and the horizontal as shown in Figure 2. Sumner recorded his sextant reading along with the Greenwich time by his chronometer, which was a very reliable one.

It is an elementary fact of celestial navigation that *two* such readings of altitude and time are necessary to determine latitude and longitude. In those days, everyone thought that in ideal circumstances the two readings would be:

A measurement of the sun's altitude at high noon.

The altitude and the Greenwich time for any celestial body (the sun, if possible) when that body was nearly due east or due west of the observer.

Using the noon altitude of the sun along with information contained in the *Nautical Almanac,* the latitude could be obtained by a simple calculation. Using the latitude thus determined from the noon reading along with the latitude and Greenwich time of the second reading plus data from the *Nautical Almanac,* the longitude could then be computed using the law of cosines for spherical triangles.

Sumner's reading was only two hours before noon, so the sun was only a little to the east, which would not have been ideal; but in fact he was unable to make any second observation at noon or any other time that day. Lacking a measured latitude and perhaps attempting to make some kind of educated guess as to his location, he used his dead-reckoning (estimated) latitude and his single observation to calculate a longitude. He was gratified to see that this calculated longitude put him only 9 miles east of his dead- reckoning longitude. This was an interesting exercise but, since it was based on a doubtful value of the latitude, he calculated the longitude again using a different latitude which was 10' (ten nautical miles) north of his dead-reckoning latitude, obtaining a new calculated longitude which was closer than before to Small's Light and a rocky area off the coast of Wales. In an effort, it seems, to assess further the possible consequences of any error in his dead-reckoning latitude, he made a third calculation of his longitude using a latitude 20' north of his dead-reckoning latitude.

It was at this point that he made his discovery. He had plotted all three calculated positions on his navigation chart and found to his surprise that they lay on a straight line! (This is the solid line running from southwest to northeast drawn by Sumner on his chart, Fig. 1). Although he had not anticipated such a result, he immediately drew the correct conclusion *anyone* who might have measured the altitude of the sun at the same time he did and had got the same measured altitude he had would have to have been somewhere on the line he had drawn. As Sumner described it in his *New and Accurate Method of Finding a Ship's Position at Sea.*

These three positions were then seen to lie in the direction of Small's Light. It then at once appeared, that the observed altitude must have happened at all the three points and at Small's Light, and at the ship, at the same instant of time; and it followed that Small's Light must bear E.N.E. if the chronometer was right. Having been convinced of this truth, the ship was kept on her course, E.N.E., the wind still bearing S.E., and in less than an hour Small's Light was made, bearing E.N.E. 1/2E., and close aboard.

Excellent agreement with his prediction! Sumner had discovered the existence of what are now known as position lines, and in his book he explained the nature of these lines and *why* they exist. At that moment the immediate importance of this discovery was that he now knew the proper course to steer to come in sight of Small's Light. Before long, however, Sumner came to realize a more important consequence of it: if he had been able to make a second observation of altitude and Greenwich time for *any* celestial body he would have been able to go through a similar procedure to generate a new position line on his chart which would necessarily be different from the first. If he had somehow held his ship in the same position during the whole time he would then know that since this position must be somewhere on the first position line as well as somewhere on the second position line, he had to be at the point where the two lines intersected. He could then have determined this position simply by looking at the chart where he would have drawn the two position lines. Almost all modern celestial navigation uses a variation of this graphical method of determining latitude and longitude from two observations.

The existence of lines of position can be described in the following way, using terminology somewhat different from that employed by Sumner in his own explanation.

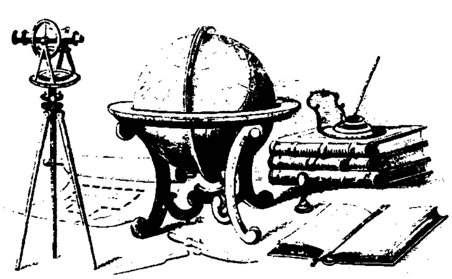
At any instant of time any celestial body — take a particular star as an example — is directly overhead at only one point on earth. This point is called the *geographical position* of the star (Figure 3). For a person located at the geographical position of the star the altitude of the star is obviously 90° because the star is directly overhead. Now consider a second observer at some other location on earth who also, at the same instant, measures the altitude of the same star. The farther the second observer is from the geographical position, the lower the star will be in the sky, and therefore the lower its altitude. Suppose that for the second observer the altitude of the star is 80°. Any other observer who also found the altitude of that star to be 80° at that instant would have to be at the same distance from the geographical position of the star as the second observer. Therefore all observers for whom the altitude of the star is 80° at the same instant must be at points on the circumference of a circle characterized by the fact that all such points are at the same distance from the geographical position, and this distance depends uniquely on the 80° value of the altitude.

Similarly, for any other altitude that might have been measured at that instant, there is a different, unique circle of equal altitudes (Figure 4). One can visualize that as the star moves across the sky the geographical position of the star moves across the face of the earth carrying with it this system of circles of equal altitude.

Every celestial body has its own geographical position which follows its own path around the earth, and èach has a family of circles of equal altitude that move along with the geographical position. For the sun, moon, planets, and a number of stars, the *Nautical Almanac* has tables which allow an observer to determine the latitude and longitude of the geographical position of any of those bodies at any instant. The instant must be specified in terms of the date and Greenwich time. When the geographical position of a celestial body has been determined for the instant at which its altitude was measured, the value of the altitude narrows down the observer's possible location on earth to points on the circumference of a particular circle centered on the geographical position. Thus this circle of equal altitudes has become a *circle of position or position circle.*

If the observer stays at the same location and makes an altitude measurement on some other body (or on the same body after it has moved far enough across the sky), he can then, by the same process, identify another position circle associated with the new geographical position and the new altitude (Figure 5). Since he must be on both position circles simultaneously, he must be at one of the two points of intersection of the two circles. The points of intersection are usually thousands of miles apart, but the navigator knows which one to choose because he already knows approximately where he is, and is already working with a chart that contains his dead-reckoning position. As Sumner explained, a position line is not actually a straight line, but a small arc of a position circle; and, of course, a small arc of any circle looks very much like a straight line. Thus, on a chart extending over just a few degrees of latitude and longitude, like Sumner's in Figure 1, the arc of each circle of position looks like a straight line and the intersecting arcs of two position circles look like two intersecting straight lines.

Sumner's book, published in 1843, had an immediate and revolutionary effect on navigational methods. According to the new terminology of position lines, the noon altitude measurement can now be viewed as enabling the navigator to draw an east-west line on his chart, a position line which turns out to be just the parallel of latitude on which the ship lies. Similarly, the sun's altitude measured six hours earlier or later gives the navigator a position line that runs nearly north and south (and if the sun happens to be exactly east or west of the ship, this line of position runs *due* north and south and is the meridian of longitude on which the ship lies). Prior to Sumner's discovery, of course, no one thought of things this way, and no one drew such position lines.



It was now apparent that altitude measurements no longer had to be made at any special times, although a careful choice of observation times would optimize the reliability of the computed position. The important point was to choose observation times that would give position lines which intersected nearly at right angles. For two readings on the sun this means only that they should be taken about six hours apart. This eliminates the requirement that for one measurement the sun should be far to the east or west and therefore low on the horizon where, unfortunately, atmospheric refraction produces erratic effects on the measured altitude.

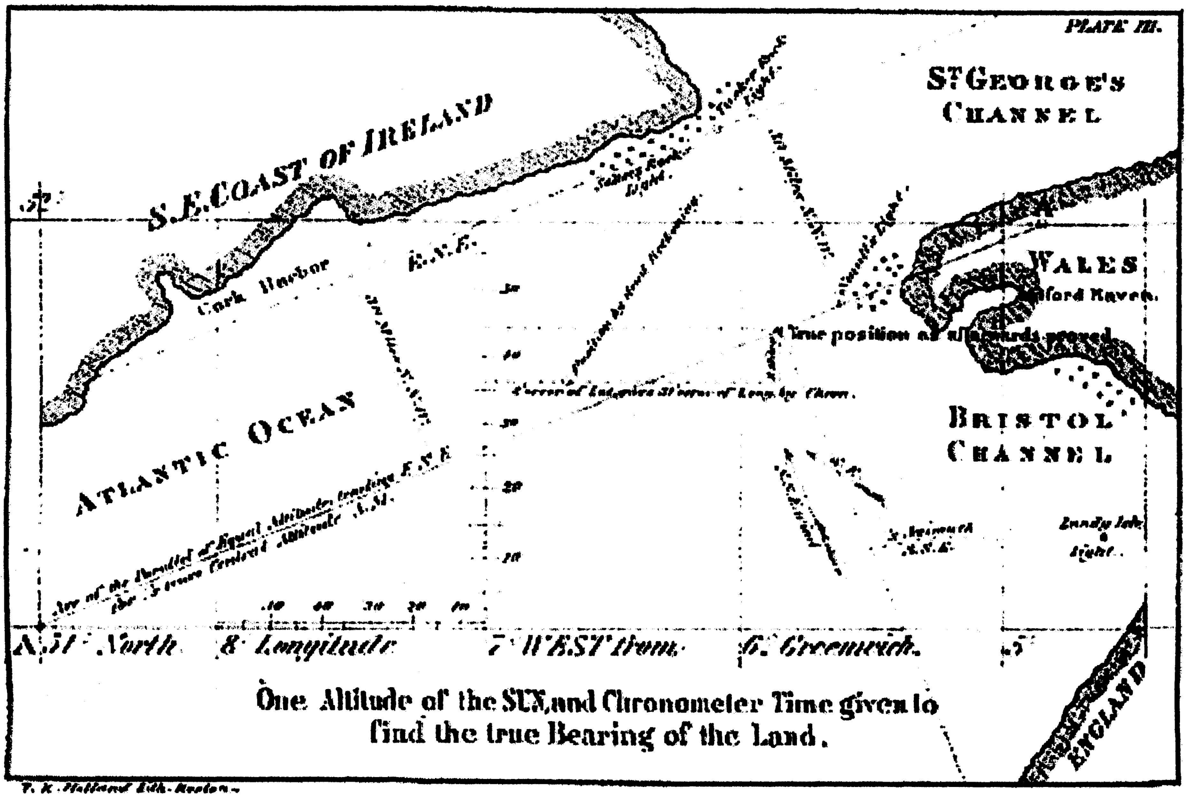
Every ship in the U.S. Navy was immediately supplied with a copy of sumner's book.

Within a few years a variation of Sumner's original position-line method was developed. Sumner's own method came to be called the *chord method* because the straight line drawn between the calculated positions for the two assumed latitudes was a chord, approximating a true arc, of the circle of equal altitudes. The new version was called the *tangent method*. For this method only one position was computed from just one assumed latitude and this was then marked on the chart. Using the assumed latitude, the computed longitude, the Greenwich time, and information from the *Nautical Almanac*, the azimuth angle of the sun (the direction of the sun relative to true north) was calculated. On the chart an azimuth line was laid off in thrÎ direction starting from the calculated position. Then a second line perpendicular to the azimuth line was drawn through the calculated position. The second line was then used as a position line, but instead of being a chord of the true circle of position, this line was tangent to the true circle of position (figure 6). A tangent and a chord, are not exactly the same, but either is a good approximation to a small arc of the circle of equal altitudes if the equal-altitudes circle has a large radius (altitude not too high).

To the modern navigator the chord method seems simpler. It has the apparent advantage of using the same equation twice for locating each position line, with only two numbers changed — the sine and the cosine of the assumed latitude. Calculations for the tangent method use two different equations for locating each position line, one for latitude and one for azimuth, and would seem to require more work. However, with the development of specialized tables to assist in the calculations, the tangent method became popular.

In 1875 Captain A. Marcq-St. Hilaire of the French navy published another way of plotting a position line called the *intercept method*. Instead of calculating two longitudes corresponding to two estimated latitudes (the chord method) or one longitude and one azimuth

Figure 1
This chart is reproduced from Sumner's book. His dead-reckoning position turned out to be quite different from his true position, but on this memorable occasion he made his great discovery, as described in the text. On the chart he has drawn the line AA'. The latitude of point A is 51°N and the longitude is the value he calculated using 51°N and the data from his 10 AM measurement. The latitude of point A' is 52°N and the longitude is the value he calculated using 52°N and the same data. He used these two latitudes because they bracketed his dead-reckoning latitude. His discovery was that his true position must be somewhere on this line.



corresponding to one estimated latitude (the tangent method), he calculated an azimuth and an altitude of the sun using the latitude and longitude of an estimated position at or near the dead-reckoning position. After laying off this azimuth line through the chosen position, as marked on his chart, he found the point on this line where the calculated altitude agreed with the measured altitude. He then created a line of position by drawing a perpendicular to the azimuth line at this point. With each of the three methods the intersection of two such lines of position gives an approximate position that is very close to the exact value, but in general the Marcq-St. Hilaire approximation is the most close to the exact value, but in general the Marcq-St. Hilaire approximation is the most reliable.

The Marcq-St. Hilaire version has been universally adopted, and with good reason. But, if the name of any person is associated nowadays with position lines it is usually Marcq-St. Hilaire's. Sumner's original work, on the other hand, has been nearly forgotten, along with the fact that for many years lines of position were called Sumner lines. This is regrettable because Sumner's discovery was so brilliant and its basic principle is, in the words of Benjamin Pierce (a respected Harvard professor of mathematics and astronomy and a contemporary of Sumner) "so simple and obvious, that it can easily be made intelligible to any man of good sense." Go figure!

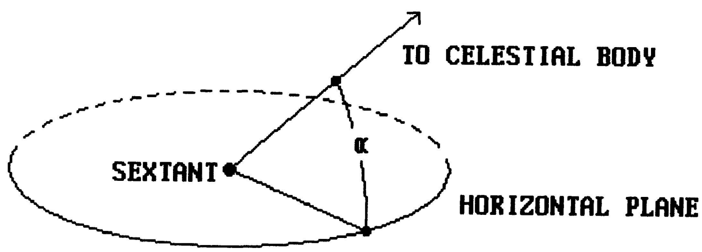


Figure 2
The horizontal plane containing the sextant is depicted here. The altitude α of a celestial body is defined as the angle between this plane and the direction of the celestial body.
An observer at sea actually measures the angle between the horizon and the direction of the celestial body. To obtain α this measured angle has to be corrected for the fact that the horizon is slightly below the horizontal, depending on how high the sextant is above the water.

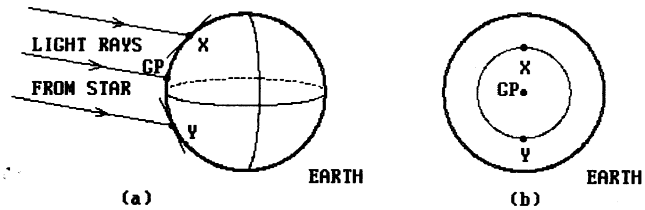


Figure 3
Two views of light rays arriving at three points on earth from a star. GP is the geographical position of the star, the point on earth where the star is directly overhead. The points X and Y have been chosen to be equally distant from GP, but on opposite sides of it. All light rays reaching earth from a distant star are almost exactly parallel, as shown in (a).
(a) At GP the star is overhead so its altitude is obviously 90°. At X and Y the light rays make smaller, but identical, angles with their respective horizontals (the tangents at X and Y), as can be seen. That is, at X and Y the altitude of the star is less than 90° but is the same at both places.
(b) A view from directly above GP. The circle drawn about GP contains X and Y and all other points on earth that are at the same distance from GP as X and Y. Thus the star's altitude is the same at all points on the circle.

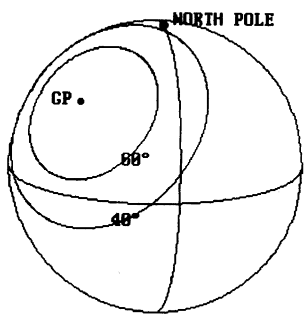


Figure 4
At any point on earth the altitude of a celestial body is uniquely determined by the distance of that point from the geographical position GP. All observers who, at the same instant, find the altitude to be 60° must be at the same distance from GP, and are therefore somewhere on the circle labeled 60°. There is a corresponding circle for any other altitude that might be observed at that same instant. An example is the 40° circle shown, where for all observers the altitude is 40°.

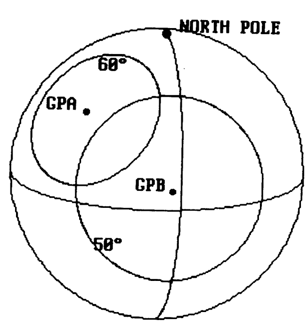


Figure 5
GPA is the geographical position of celestial body A. GPB is the geographical position of celestial body B. An observer who has measured the altitude of celestial object A to be 60° must be somewhere on the 60° equal-altitude circle about GPA. The same observer, at the same location but not necessarily at the same time, who has measured the altitude of celestial object B to be 50° must be somewhere on the 50° equal-altitude circle about GPB. Thus the observer's actual location on earth must be at one of the two points of intersection of the two circles.

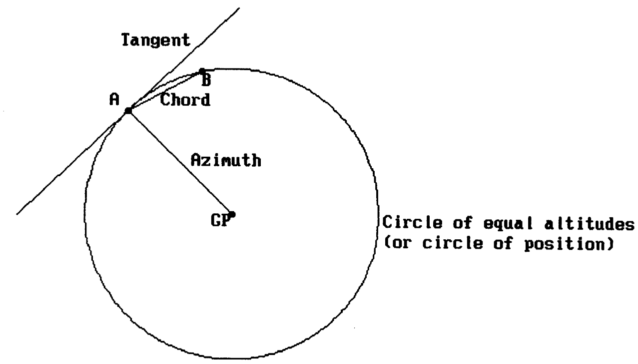


Figure 6
Two possible lines of position at A: (1) the chord AB and (2) the tangent drawn at A. Each is an approximation to the arc AB, which is sandwiched between the chord and the tangent. As the length of the chord is decreased by moving B toward A, the angle between the chord and the tangent becomes smaller until, for practical purposes, they are collinear. Simultaneously, the arc AB becomes indistinguishable from a straight line, but is still betweem the chord and the tangent. Thus either a very short chord originating at A or a very short length of the tangent at A is a good approximation to a very short length of arc at A.

Diagram for Graphical Correction to be Applied to Ex-Meridian Altitudes

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Commander E. B. Fenner, U.S. Navy

(See page 55, January, 1918, Proceedings

The construction of the accompanying diagram is based on the geometrical principle that a perpendicular dropped from the rectangular vertex of a right triangle upon the hypothenuse is a mean proportional between the segments of the hypothenuse so formed.

In example 1 on the accompanying diagram it is evident that $(OD')^2=OB'xOX$, or $OB'=(OD')^2/OX=(OD')^2x1/OX$, which is of the form,—

Correction to observed altitude $=t^2xa$ of the reduction to meridian sight.

OX = the reciprocal of "*a*" (from Bowd., Table 26) expressed in minutes of arc.

OD'= *t* in minutes of time.

OB'= Correction in minutes of arc.

One-tenth of an inch equals one minute of time on the vertical or one minute of arc on the horizontal. This scale could be increased if desired. In the diagram as printed the scale is reduced.

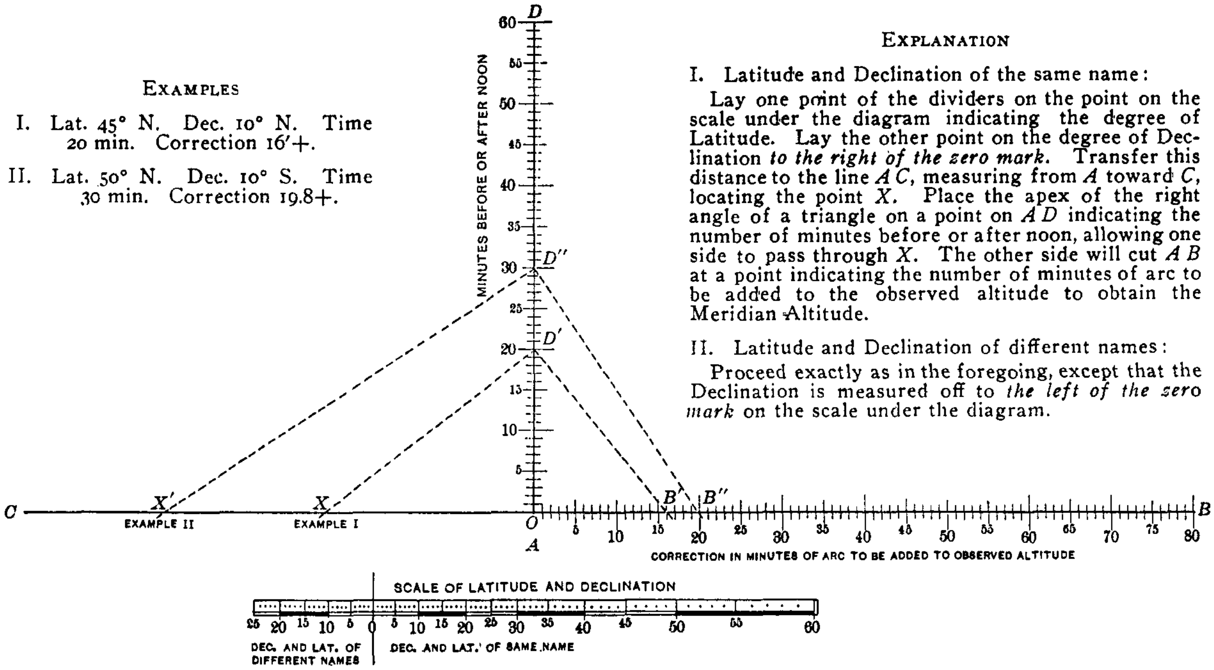
Construct the scale at the bottom of the blue print as follows:

From Table 26 take the value of "*a*" for 0° Lat and 10° Dec.

This is 11.1" or 11.1/60 of one minute.

The reciprocal = 60/11.1=5.4'

DIAGRAM FOR OBTAINING GRAPHICALLY THE CORRECTION TO BE APPLIED TO EX-MERIDIAN ALTITUDES



EXAMPLES

I. Lat. 45° N. Dec. 10° N. Time 20 min. Correction 16′+.

II. Lat. 50° N. Dec. 10° S. Time 30 min. Correction 19.8+.

EXPLANATION

I. Latitude and Declination of the same name:

Lay one point of the dividers on the point on the scale under the diagram indicating the degree of Latitude. Lay the other point on the degree of Declination *to the right of the zero mark.* Transfer this distance to the line *A C*, measuring from *A* toward *C*, locating the point *X*. Place the apex of the right angle of a triangle on a point on *A D* indicating the number of minutes before or after noon, allowing one side to pass through *X*. The other side will cut *A B* at a point indicating the number of minutes of arc to be added to the observed altitude to obtain the Meridian Altitude.

II. Latitude and Declination of different names:

Proceed exactly as in the foregoing, except that the Declination is measured off to *the left of the zero mark* on the scale under the diagram.

DIAGRAM FOR GRAPHICAL CORRECTION

This value of 5.4' measured on the scale of the main diagram, or .54 of an inch, is the distance from 0 to 10 on the lower scale, the distances from 0 to 20, 30, 40, etc., being found similarly.

The results obtained are very accurate and the operation is simplicity itself, while unfavorable conditions for the sight become evident as soon as the triangle is placed on the diagram.

Morrison Polaris

Editor's note: With his letter in Readers Forum of this issue, Captain Keith Sternberg submitted the illustration of the Morrison Polaris with the instructions for its use. Captain Sternberg added a note.

INSTRUCTIONS

To use the Instrument with the SUN AND KNOW LOCAL TIME.

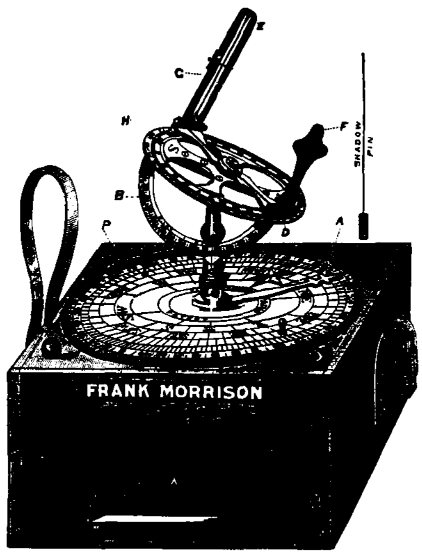
1. Place the Instrument in a line with the Ship's Keel, "Ship's Head" to "Ship's Head"; allowing it to swing free in its Gimbols.

2. Set and clamp the arrow pointer A to the variation E or W, as marked on the compass dial of the Instrument.

3. Set and clamp the latitude half-circle B to the known latitude of the place where the ship is adjusting, using the white line C on the center upright as the pointer.

4. Note the apparent time to within four minutes, and set the sight vane pointer D to it (the time dial is divided

THE MORRISON POLARIS



FRANK MORRISON & SONS

Compass Adjustors and Manufacturers of Nautical Instruments

West Eleventh St., Cleveland, Ohio

to four minutes).

5. Then move the compass dial by the two projections on the plate placed at the E and W points, until the

shadow of the wire line E falls upon the slit F in the sight vane.

6. DECLINATION. When necessary to take this into consideration (for instance when using the instrument early A.M. or late P.M. in equatorial waters), set the cross wire G to the degrees marked on the wire line sight E, according to the SUN'S DECLINATION: follow previous directions until the shadow shown by the cross wires coincides with the cross cuts in the sight vane.

To use the Instrument with a STAR

1. Clamp the time circle horizontally.

2. Place the pointer A to "Ship's Head."

3. Sight the star, using the time circle divided to 180' to determine the position in usual manner.

To use the instrument WITHOUT THE SUN, BY A DISTANT OBJECT, the bearings of which are known.

1. Clamp the upper circle horizontally and place the sight vane pointer to XII or O.

2. Set and clamp the Compass dial Arrow pointer to the known bearing of the distant object.

3. Move the Compass dial by the projections, until you can sight the distant object through the sight vane.

The difference between the Compass dial of the instrument, and the compass on the Ship, is the deviation.

NOTE—The time circle H being divided also to 180', it can be used with the aid of the sights to determine the correct or magnetic course, according to Burdwood's or other Tables, apart from the lower dial.

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of Nautical Instruments
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Morrison was a dealer in Cleveland. The "Polaris" was made in London. Mine is signed "D. MacGregor, Glasgow", a "Nautical Optician", as dealers in navigation instruments and chronometers were called then, for whom it was made. I acquired it from a Great Lakes steamboat captain who was acquainted with Morrison.

HISTORY OF NAVIGATION

The Brown-Nassau Spherical computer

By John M. Luykx

GENERAL

The Brown-Nassau Spherical Computer is a plastic lightweight 12"x13" graphic device which weighs only 14 oz. It was designed in 1944 at the Case Institute of Technology, Cleveland, Ohio primarily for use in the rapid sight reduction of celestial observations for line of position (LOP). Its shape and handiness permits its use in lieu of sight reduction tables in small cramped areas such as the cockpit of a fighter aircraft. The computer solves the navigation triangle as well as other spherical trigonometric navigation problems in much the same way that a "coordinate converter" or "coordinate transformer" solves problems of spherical trigonometry through the relationship that exists between the Celestial Equator coordinate system and the Horizon coordinate system.

The celestial equator and horizon coordinate systems are described in great detail in the 1995 edition of Bowditch, pages 245-255. A description of how the navigation triangle is formed from elements of both the celestial equator and horizon coordinate systems is included on pages 254 and 255 of Bowditch and shown by diagram in figure 15309 on page 254.

CONSTRUCTION OF THE COMPUTER

The computer is constructed of laminated plastic sheets consisting of a rectangular opaque base plate and two transparent rotating quarter circles or "rotors", one against each side of the base plate. The main feature of each face of the base plate is a grid of curves enclosed in a quadrant of a circle 10" in diameter. The horizontal curves on each "rotor" represent parallels of latitude and the vertical curves represent hour angles. A circular declination scale is marked along the circumference of the quadrant on each face. (Figure 1) The two "rotors" are printed with curves matching the latitude curves of the base plate. The two rotors are pivoted at the lower left corner of each face of the base plate. (Figure 2)

OPERATION OF THE COMPUTER

The principal purpose of the computer is to determine computed altitude (Hc) and azimuth angle (Z) from values of latitude (L), meridian angle (t) and declination (d). The computer may also be used to compute initial Great Circle course (C) and Great Circle distance (D) between two points on the earth's surface and to identify stars from values of observed azimuth (ZN) and altitude (H).

Instructions printed on each side of the base plate direct the user to the exact sequence of operations in solving problems which may vary in accordance with the:

Declination (d) and Latitude(L) which may be "same name" or "contrary name"

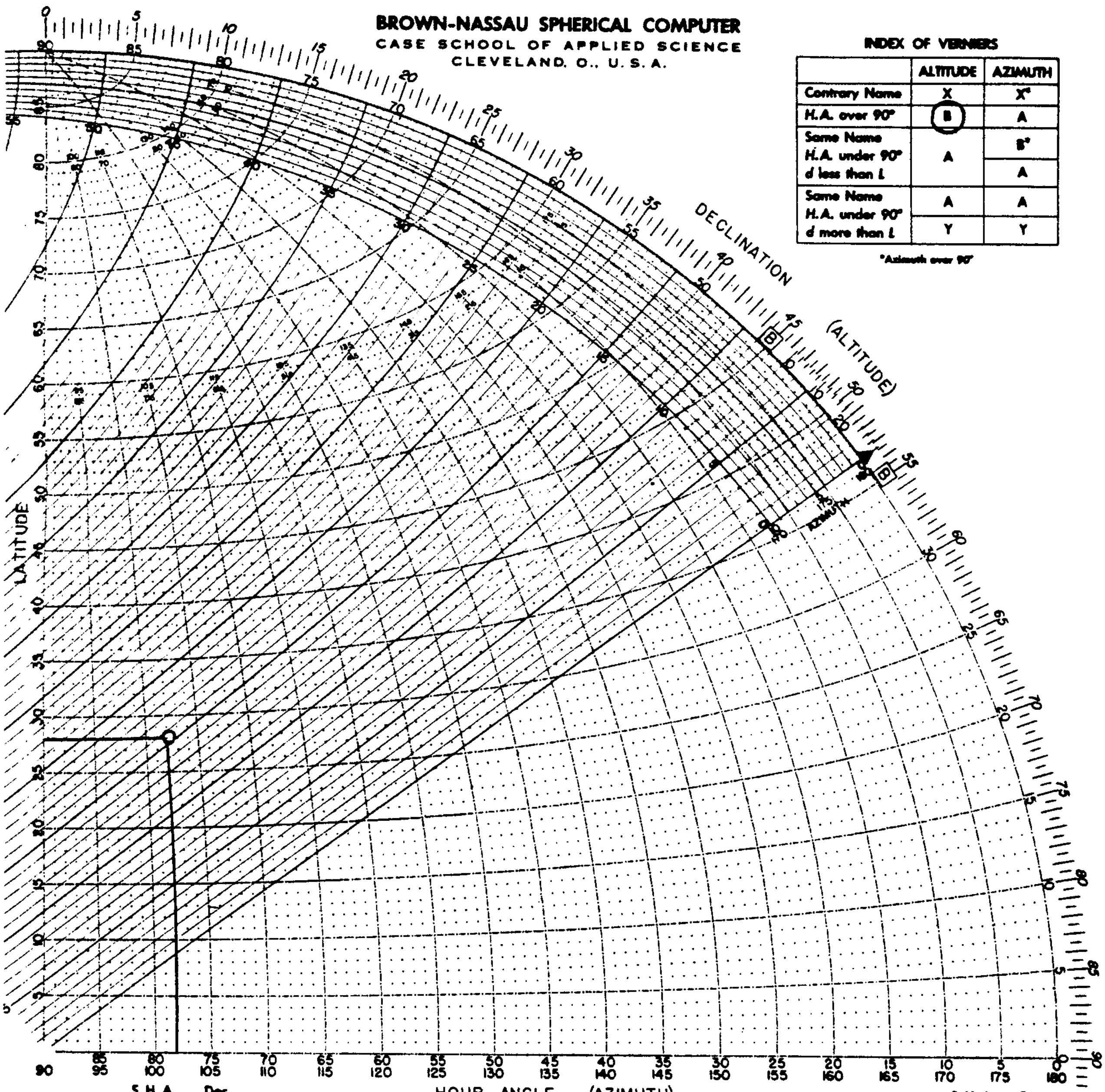
Meridian Angle (t) - which may be greater or less than 90°

Declination (d) - which may be greater or less than Latitude (L)

For sight reduction the computed altitude (Hc) is obtained first from values of L, t and d. Once Hc is obtained, then, azimuth angle (Z) is computed from values of Hc, d and L.

Based on whether a) d and L are "same" or "contrary" name, b) t is greater or less than 90° and c) whether d is greater or less than L, one side or the other of the base

INDEX	B	A
ROTOR SETTING	$d = 53^\circ\ 22'$	$H_c = 15^\circ\ 30'$
ROTOR CURVE	$H_c = 15^\circ\ 30'$	$d = 53^\circ\ 22'$
GRID LAT. SCALE	$L = 28^\circ$	$L = 28^\circ$
GRID LHA SCALE	$LHA = 102^\circ$	$Z = 37^\circ$



INDEX OF VERNIERS

	ALTITUDE	AZIMUTH
Contrary Name	X	X*
H.A. over 90°	B	A
Same Name H.A. under 90° d less than L	A	B* / A
Same Name H.A. under 90° d more than L	A / Y	A / Y

*Azimuth over 90°

(1945)

	S.H.A.	Dec.		S.H.A.	Dec.		S.H.A.	Dec.		S.H.A.	Dec.		S.H.A.	Dec.
Achernar	**336 05**	**S57 31**	**Antares**	**113 29**	**S26 19**	Caph	358 26	N58 51	Kochab	137 17	N74 23	**Rigel**	**282 02**	**S8 16**
Acrux	**174 07**	**S62 48**	**Arcturus**	**146 43**	**N19 28**	θ Centouri	149 08	S36 06	Peacock	54 40	S56 55	**Rigil Kent**	**141 02**	**S60 37**
Aldebaran	**291 48**	**N16 24**	**Betelgeux**	**271 57**	**N7 24**	**Deneb**	**50 07**	**N45 05**	**Pollux**	**244 31**	**N28 10**	**Sirius**	**259 19**	**S16 38**
Alpheratz	358 37	N28 47	**Canopus**	**264 19**	**S52 40**	Dubhe	194 55	N62 03	**Procyon**	**245 54**	**N5 22**	**Spica**	**159 26**	**S10 52**
Altair	**62 58**	**N8 43**	**Capella**	**281 51**	**N45 57**	**Fomalhaut**	**16 21**	**S29 55**	**Regulus**	**208 38**	**N12 14**	**Vega**	**81 14**	**N38 44**

plate is selected for the sight reduction calculations.

Step One: A mark is placed on the intersection of the L and t curves on the base plate. This establishes the DR or the assumed position.

Step Two: The rotor is then set to the value of d.

Step Three: Hc is determined by the position of the selected mark (Step One) among the altitude curves on the rotor.

Step Four: The rotor is then set to the altitude (Hc) determined in Step Three.

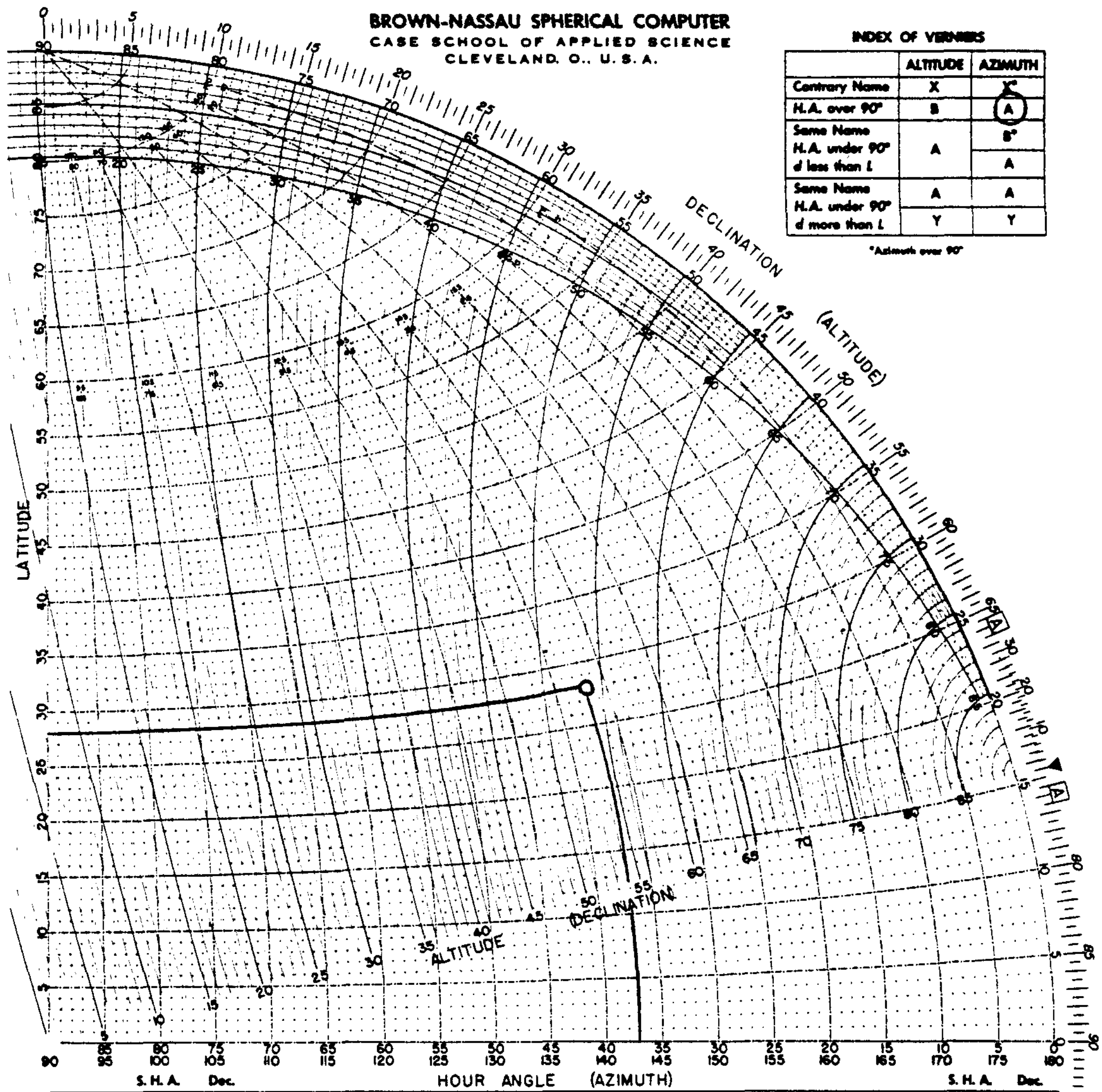
Step Five: The point of intersection of the Declination (d) curve on the rotor and the Latitude (L) curve on the base plate is now determined. This point when extended to the Latitude scale on the left side of the rotor is the azimuth angle (Z).

Note: When solving for initial Great Circle Course and Great Circle Distance (D) follow the same procedure as above, substituting difference of Longitude (Dlo) between two places on the earth's surface for meridian angle t. Latitude (L) of the point of arrival is substituted for C and Great Circle Distance (D) is substituted for 90°-Hc. Initial Great Circle Course is equal to Z corrected to true azimuth (ZN).

ACCURACY OF THE COMPUTER

Although tests of the Brown-Nassau computer conducted by the Aeronautical Instruments Laboratory at the Naval Air Experimental Station at the Navy Yard, Philadelphia from January to June 1944 indicate that general accuracy ranges from 5 to 10 arc minutes, the writer has found that with careful handling and proper setting of the rotors, accuracy of within 2 to 3 arc minutes is possible in altitude and within 0°.3 in azimuth.

Results of accuracy tests conducted by the author



INDEX OF VERNIERS

	ALTITUDE	AZIMUTH
Contrary Name	X	X*
H.A. over 90°	B	A
Same Name H.A. under 90° d less than L	A	B*
		A
Same Name H.A. under 90° d more than L	A	A
	Y	Y

*Azimuth over 90°

	S. H. A.	Dec.												S. H. A.	Dec.
Achernar	336 05	S57 31	Antares	113 29	S26 19	Caph	358 26	N58 51	Kochab	137 17	N74 23	Rigel	282 02	S8 16
Acrux	174 07	S62 48	Arcturus	146 43	N19 28	θ Centauri	149 08	S36 06	Peacock	54 40	S56 55	Rigil Kent	141 02	S60 37
Aldebaran	291 48	N16 24	Betelgeux	271 57	N7 24	Deneb	50 07	N45 05	Pollux	244 31	N28 10	Sirius	259 19	S16 38
Alpheratz	358 37	N28 47	Canopus	264 19	S52 40	Dubhe	194 55	N62 03	Procyon	245 54	N5 22	Spica	159 26	S10 52
Altair	62 58	N8 43	Capella	281 51	N45 57	Fomalhaut	16 21	S29 55	Regulus	208 38	N12 14	Vega	81 14	N38 44

TABLE I
RESULTS OF THE ACCURACY TESTS

GIVEN VALUES			COMPUTED VALUES	
	1		2	3
L	d	t	Hc	ZN
N 35°04'	S 10°23'	E 55°36'	20°35'	120.°0+
			(20°34)′	(119.°5+)
			+1'	+0.°5
N 22°49'	N 35°17'	W 75°20'	24°30'	299°.9+
			(24°29)′	(299.°9+)
			+1	0.°0
N 55°36'	N 40°29'	E 115°45'	20°20'	047°.1+
			(20°26)′	(046°6.+)
			+3'	+0.°5
N 27°15'	S 17°47	W 45°18'	27°04'	229.°7+
			(27°06)′	(229°3+)
			-2'	+0°.4
S 11°29'	N 10°19'	W 40°56'	43°54'	296°.4+
			(43°51)′	(296°.4+)
			+3'	0°.0
S 44°56'	S 50°41'	E 100°16'	27°51'	135°.2+
			(27°48)′	(135°.1+)
			+3'	+0°.1
S 63°32'	S 40°29'	E 65°39'	46°12'	089°.8+
			(46°08)′	(090°.4+)
			+4'	-0°.6
S 27°21'	N 25°11'	W 40°22'	24°35'	319°.5+
			(24°39)′	319°.9+
			-4'	-0°.4
Arithmetic Mean Value of Error			Hc	ZN
			2.′6	0°.3

give the following results:

Column 1 of the table provides the input data for each problem and columns 2 and 3 indicate the solution for the Hc and Z respectively by the Brown-Nassau Computer. Column values in parenthesis indicate the solution by electronic computer for comparison purposes.

SUMMARY

In 1944, at the height of air operations against Japan during World War II, one of the major problems in air navigation was the development of a computer or celestial navigation method suitable for use in small aircraft, such as fighters and attack bombers. The Navy requirements at that time were that:

The computer should be compact and light.

The computer should be simple to operate and unambiguous.

The computer should be sturdy and easy to use under cramped and adverse conditions.

Computer solutions should be rapid and accurate.

The Brown-Nassau computer fulfilled most of these requirements.

The last sentence in the NAES(AIL) report of 29 August 1944 mentioned in Paragraph IV above states:

"Considered as a whole the Brown-Nassau Computer is the first device tested warranting very extensive and complete service testing in small airplanes."

CORRECTION:

Closed Form of Lat. and Long. With Two Sights

James O. Muirhead

On page 10 of Issue Sixty-one (Fall 1998), change equation (15) to make the sign in front of the radical + rather than -.

ANSWER TO DO YOU KNOW . . .? (from pg. 1) The following is from the biographical sketch of Admiral Sir H. E. Purey-Cust, K.B.E., C.B. Hydrographer 1909-1914:

In *Rambler* he had a roving commission, his surveys, ranging from the West Indies and the Straits of Belle Isle to the west and east coasts of Africa and the Red Sea, ended in 1901 at Malta. In 1900 he had been promoted to captain, Wharton having said in his recommendation that he had "shown his talent by devising various contrivances to expedite and improve the surveying operations", a talent that was shown in the development of the Field-Cust automatic tide-gauge and also of the transparent station-pointer, still in use.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-THREE, SPRING 1999

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Ordering Books, Publications or Charts

A sampling of some of the books and charts is included in this issue of the newsletter on page 2. The prices listed are the ones currently being published and are subject to change. Other books of interest to you, and not listed, may be available. Let us know; our publishers may have them in print.

When ordering books, publications or charts, please fax, call, e-mail or write your order separate from your renewal. We may miss your order if it is written on the renewal card. Please DO NOT SEND PAYMENT with your order. Publishers and the government are continually changing prices and the postage now varies with your Zone. We will send you an invoice or statement after we are sure that your order has been filled. You may not get the invoice or statement immediately, but do not be concerned as we may be on travel and will send them when we return. Your order is the most important item. Payment can come at any time.

DO YOU KNOW . . .?

Who developed the hemispherium sundial used by Eratosthenese to measure the circumference of the earth?

(The answer appears on the last page of this issue.)

READERS FORUM

Edited by Ernest Brown

Member Richard S. Preston wrote from DeKalb, IL on 23 February 1999:

"I am beginning to realize, from the material you have sent me, that you have had a very close connection with past editions of Bowditch, possibly as editor. I had not been aware of this. This, with previous Newsletter notes concerning Sumner, certainly puts you in a good position to evaluate notes such as mine.

"I was very pleased to learn yesterday that an article I wrote on the accuracy of the astronomical observations of Lewis and Clark is to be published in the *Proceedings of the American Philosophical Society*. I have calculated the L&C positions from a number of their recorded observations and compared them with the modern values of latitude and longitude of the known locations where their measurements were made. The agreement is very good, although I think their sextant and octant index errors were slightly off.

"These calculations have never been made previously, I believe, and the maps made from their necessarily crude dead reckoning were never adjusted for the latitudes and longitudes that could have been calculated. I think the problem was the following.

"Lewis and Clark had a sextant and an octant; a pretty good watch, a reflecting artificial horizon, and copies of the Nautical Almanac. Their instructions were to use the artificial horizon and an octant in back observation mode to get the noon altitude of the sun; to take equal-altitudes measurements of the sun using a sextant, the artificial horizon, and a pretty good watch; and to get a lunar distance measurement on the same day using the sextant and the watch.

"They calculated the latitude themselves using the noon altitude of the sun, an estimated Greenwich time, and the Nautical Almanac. They were to leave the longitude for experts to work out upon their return because they would be too busy to do the calculations themselves while enroute.

The Readers Forum continues on page 3.

THE NAVIGATION FOUNDATION BOOKS AND CHARTS

SIGHT REDUCTION METHODS & DATA

Air Almanac $54.00
Compact Sight Reduction Tables, Bayless(CMP) $6.00
Nautical Almanac, 1996 (GPO) $27.00
Nautical Almanac,(Commercial Ed.)(Paradise Cay) $17.95
Reed's Nautical Almanacs
North American, East Coast, 1999 .... $29.95
North American, West Coast, 1999 .... $29.95
Caribbean, 1999 .... $29.95
Sailing Directions(Specify area) (NIMA/NOAA) $21.25
Sight Reduction Tables(NIMA/NOAA) Pub229, 6 Vols $12.50
Sight Reduction(NIMA/NOAA) Pub249, 3 Vols $12.50

INSTRUCTIONAL BOOKS ON NAVIGATION

Boaters Bowditch, Hubbard (IM) $34.95
Celestial for the Crusing Navigator, Turner(CMP) $14.95
Celestial Navigation, Wright(CMP) $12.00
Celestial Navigation With the S-Table,
Pepperday(PC) $9.95
Celestial Navigation by H.O. 249, Milligan(CMP) $7.50
Complete On-Board Celestial Navigator, Bennet (IM) $39.95
Dutton's Navigation & Piloting, 14th Ed.
Maloney (Naval Institute) $75.00
Marine Navigation, Piloting, celestial, and
Electronic, Hobbs (NI) $49.95
Marine Navigation Workbook, 4rd Ed. Hobbs (NI) $24.95
The Dutton Workbook Package, Contains both Dutton's
Navigation & Piloting, Marine Navigation Workbook,
Hobbs(NI) $65.00
The Practical Pilot, Eyges(IM) $22.95
The Sextant Handbook, Bauer(IM) $14.95
Emergency Navigation, Burch(IM) $14.95
Real Time Method of Radar Plotting, Waldo(CMP) $15.00
Piloting & Dead Reckoning, 3rd. Ed., Shufeldt
(Naval Institute) $29.95
Problems & Answers in Navigation and Piloting 2nd.
Ed., Maloney(NI) $6.95
Formulae forthe Mariner, 2nd. Ed., Plant(CMP) $12.50
How to Navigate Today, 6th. Ed., Gray(CMP) $6.95
Learn to Navigate, By Tutorial, Wright(CMP) $24.95
An Ocean Navigation Exercise, Stout(CMP) $17.50
A Star to Steer Her By, Bergin(CMP) $18.50
World Cruising Routes, Cornell (IM) $39.95
The Cruising Woman's Advisor, Jessie (IM) $16.95
Sailing/ A Woman's Guide, Colgate (IM) $14.95

HANDBOOKS, COMPUTER & REFERENCE

American Practical Navigator(Bowditch), (N)AA) $23.70
Starpath Radar Trainer, IBM(Windows) Burch $79.00
Starpath Radar Trainer, Macintosh (6.0.5 or Newer) $89.00
Star Finder Book, Burch (PC) $12.95
International Marine's Weather Simplified (IM) $25.95
Navigation Rules of the Road, Burch (PC) $8.95
Emergency Navigation Card, Burch (PC) $12.95
Storm Tactics Handbook, Toss (PC) $19.95

CHARTS

All NOAA/NIMA charts are available through the Navigation Foundation. If you are unsure of the chart number or scale and area coverage for your area of interest, please call, write or send an E-Mail to the telephone number, address or E-Mail address listed below. If you call, leave your name, area code and telephone number and the best time of the day to reach you. Some one will return your call within 24 hours or the Foundation's recorded message will state otherwise. A FAX is available for you to FAX your orders 24 hours a day.

Harbor, Approach and Coastal Charts(Includes all bays, harbors and inland waters of the United States, and Possessions, except the Mississippi River). (NOAA) $16.00

Charts of Foreign Harbors, Approaches and Coastal Charts (NIMA) $16.00

ORDERING INFORMATION

The Foundation can acquire any chart, publication or book, that is in print, from Cornell Maritime Press, U. S. Naval Institute Press, Paradise Cay Maritime Publications, International Marine Publications, Government Printing Office, The NIMA, and NOS/NOAA. If you have questions about any book, chart or publication, please inquire by any one of the three methods listed above. Price lists are available for the organizations listed above, upon request.

PLEASE NOTE: ALL PRICES ARE LIST

Prices change without notice.

DISCOUNTS

Members receive a 20% discount on all books and publications and on all chart orders up to $50.00. Chart orders only, over $50.00 receive a 25% discount. This does not include postage, UPS or other shipping costs. These costs will be added on to the discounted amount of your orders. You will be billed for items ordered.

ADDRESS, TELEPHONE, E-MAIL

ADDRESS:
The Navigation Foundation
P.O. Box 1126
Rockville, MD 20850

TELEPHONE: 301-622-6448

E-MAIL:
Compuserve - 76476,1165
Internet - 76476.1165@compuserve.com
navigate@ix.netcom.com

WEB PAGE:
http://www.olyc.com
http://www.netcom.com/~navigate/celestial/nav.html

FAX: Dial 301-622-6448, if your fax is manual start send after the tone. If your fax is automatic, dial the number and select send. The machines should commence the fax. If the office is closed because of travel, the fax will be disconnected and the voice answering machine will provide a date when the office is open and a fax machine available.

BILLING: Members will be billed for government chart and publication orders when the orders are filled and the member has received the items. With books from publishers, the member will be billed at a reasonable time after the order is placed. If you receive a bill for your order and have not received the order do not pay the bill but please call immediately. The problem will be rectified.

The Readers Forum, continued from page 1.

"The experts would use the equal altitude measurements to establish the watch time of noon. The Greenwich time of the lunar distance measurement, as determined from the Almanac, would be used with the elapsed watch time between noon and the lunar distance measurement to get the Greenwich time of noon, and from that, the longitude. The rate of the watch was to be established by comparing the elapsed time between successive noons or between successive lunar distance measurements with values determined from the Almanac.

"The problem was that according to conventional ideas of the time (1803-1806) one had to measure the altitude of the moon and the other body at the instant of the lunar distance measurement so that the lunar distance could be corrected for refraction of the other body and refraction and parallax of the moon. For instance, Bowditch, in the early editions, said that if three observers and three sextants are not available, one could measure the required altitudes just before and just after the lunar distance measurement, and then interpolate to get the altitudes at the instant of the lunar distance measurement.

"The fact is that Lewis and Clark *never* made these two 'required' altitude measurements. And they didn't need to! At that time a number of people knew that these altitudes could be *calculated*, as is evident from some private journals and correspondence. But I have not found any detailed explanations of the method in publications of the time. In fact, at least one person recognized that even if the noon altitude of the sun were unavailable, both latitude and longitude could be determined from just the equal altitudes and lunar distance measurements (Andrew Ellicott in a letter to President Jefferson; he doesn't explain).

"Lewis and Clark knew that the 'required' altitudes at the instant of the lunar distance measurement actually did not have to be measured, but the expert who was supposed to make the calculations did not. I make a case that the reason for this was a combination of scientific rivalry and the scramble for jobs and recognition.

"Since I have been subscribing to the Navigator's Newsletter I have seen several articles on lunars by Luykx and by Stark, but no mention of calculating the required altitudes instead of measuring them. Do you think a note on this subject would be of interest?"

— *Sincerely, Dick Preston*

Member Peter W. Ifland sent by e-mail on 9 March 1999:

"I am indeed honored to receive so much favorable coverage for *Taking the Stars* and for my donation of navigation instruments to The Mariners' Museum in Issue Sixty-One of the Newsletter. Thank you very much.

"I particularly value the observations in the Editor's note at the end of the book review on the last page. Errors do creep in! I would most appreciate Ernest Brown's help in correcting the errors he found on p. 188. I'd also like to know of any other errors, corrections or suggestions you may hear about. I'd especially like to have the correction information, whether or not we ever do a second edition. E-mail to pwifland@lynxus.com; snail mail to 8560 Wyoming Club Drive, Cincinnati, OH 45215; or telephone or FAX to (513)761-0952."

— *Thanks again and best regards, Peter Ifland*

Member Jeremy C. Allen sent by e-mail on 10 March 1999:

"I would like to thank you for directing me to CelestAire for Bruce Stark's Tables for Clearing the Lunar Distance. They were out of stock when I called, which means that there was at least some interest in the book. I did receive my copy in late December however.

"In early January I set sail aboard the TS *Empire State VI* rated as 3rd Assistant Engineer. I did, however, bring my sextant and celestial navigation tables to keep up my skills in Navigation. I also brought my Lunar Tables with me.

"During one evening twilight, while all of the deck cadets were taking their evening round of stars, I decided to find GMT by Lunar Distance. The quizzical looks I earned while finding the angular distance between the Moon and Jupiter were quite humorous. After taking my sights, I retired to my stateroom and waded through the 30 minutes of calculations to determine GMT. I am pleased to report that my error was only 13 seconds slow. I thought that my results were quite good for a first sight.

"I do have one suggestion for anyone who is going to try to shoot lunars: I found it advantageous to shoot a quick round of 'pre-sights' to get the approximate altitudes of the bodies and the lunar distance before taking the actual measurements. I discovered that when I started shooting the actual sights, the time between shooting the two altitudes and then the lunar distance was greatly reduced when I could quickly adjust my sextant arm to the correct whole degree and then just spin the micrometer drum to fine tune the sight.

"One last note. I am happy to report that the Maritime Cadets at the various Maritime Academies are maintaining a rigorous celestial navigation program, even in the age of GPS. There were several days during the voyage, which the cadets were required to navigate solely by Celestial means. Also, the celestial navigation projects that the upper class had to complete were both comprehensive and challenging. As a product of such an education, I can assure you that celestial navigation is far from dying out in today's US Merchant Marine. Thank you again for your always informative newsletter."

— *Sincerely yours, Jeremy C. Allen 3/M*

Member Bruce Stark sent by e-mail on 7 March 1999:

"Week after week of overcast sky has gotten me to thinking about he importance of dead reckoning. I'd like to see more about it in the Newsletter. It's as much an art as celestial navigation, and celestial isn't worth much unless paired with it.

"Maybe some members have advice, experiences, or cautionary tales the rest of us could learn from.

"My own view of dead reckoning is that it covers everything from keeping a reckoning by plotting tools or traverse tables to keeping one in the back of your head. The problems may be somewhat different, but I believe it's essentially the same thing whether practiced at sea, on land, or in the air. And I'm sure there are times when it includes enough uncertainty, puzzlement, and danger to hold the attention of even the most experienced navigators."

— *Sincerely, Bruce*

The Executive Director responded to member Bruce Stark:

"Thank you for your e-mail. I agree that dead reckoning is most important to everyone on the sea and in the air. As a'nugget' in Naval Aviation my first deployment was on a 'Jeep' Carrier, the *USS Bairoko(CVE115)*. The only electronic navigation was a YEZB. It was kind of like a radio range but had coded sectors. The problem, it was supposed to keep its north orientation with the gyro but would stick and rotate with the ship's course. We were one of the first all weather squadrons and flew in all weather. The only reason I could find the ship was to keep a course and time plot on my knee pad and retrace the course and time or draw a line back to the PIM and guess on the wind. Sooner or later I would get within radar range and get home. I swear by DR plots and I am still here to prove their worth."

— *Best regards, Terry Carraway*

Member Steve Olson sent by e-mail from Dar es Salaam, Tanzania:

"I always appreciate getting the newsletter, as maps and navigation have been a lifelong interest for me. I taught myself celestial navigation when I was 13 and growing up in Duluth, Minnesota. A few years later I figured that celestial was on the way out, so I went into geology instead, which was one of the few professions left where people actually went out in the field and 'made maps'. Twenty years later, whilst sitting out in a gold mine in Mali, West Africa, I read the article in National Geographic on Peary's trip to the pole which showed how he used the artificial horizon with the sun, and which gave me the first reference to the Foundation. That was enough to re-kindle my interest in navigation. I quickly became obsessed with determining my position to a gnat's eyelash with a sextant in the bush. John Luykx kindly pointed out that I should try a theodolite for greater precision. While living in the Philippines, I discover a nasty little thing called deflection of the vertical can throw your astronomical position off by over a kilometer.

"Four theodolites later, my precision is down to about that of GPS with selective availability turned on. I am now working on getting to within +/- 0.5 arcsecond with a vintage Wild T-4 theodolite and a variety of home-made electronic timing devices.

"I currently reside in Dar es Salaam, Tanzania with my wife and children. We are learning to enjoy sailing on the Indian Ocean. It is certainly warmer than Lake Superior and you do not have to worry about hitting ice."

— *Thanks and best regards, Steve Olson*

Member William M. Gruber sent by e-mail on 9 March 1999:

"Thanks....I received the Nautical Almanacs today from California by Book Rate....I had to purchase two Saturday morning from BOAT-US before driving up to Lake Lanier for the 10 AM start of my first class; otherwise I would not have had enough on hand for the students. But that's OK....I can still utilize the ones you had sent in the course of the year....I'm expecting the HO229 vols any day now. Regarding the Star Finder and/or Aries disk-dialer, I can get the first from Celestaire and have USPS working on a source of the second. By the way, I just received a copy of Stark's 'Lunar Distances'....I intend to show it around in Chattanooga when I get installed as vice-president of The Dixie 'N' Club (a group of USPS 'N's' from several southern states formed to further the science of celestial navigation."

— *Regards, Bill G.*

The Executive Director responded to Member William M. Gruber:

"You should have your commercial Nautical Almanacs by now. If not let me know. I mailed you volumes of 229 today and you should have them in a few days. We do not handle the Aries disk-dialer or the Star Finder Set. You should procure them from any source available. We are sorry that we cannot help you with these.

"I will send you a statement in a day or two. Do not be concerned. I have also sent you another renewal notice since I did not receive an answer to my e-mail."

— *Best regards, Terry Carraway*

Colin Maclean sent by e-mail on 17 March 1999:

"I write in the hope you can help me obtain a copy of a wonderful paperback on navigation which has been out of print for some time: 'Finding Your Way on Land or Sea, Reading Nature's Maps' by Harold Gatty, most recently published by The Stephen Greene Press, Fessenden Road, Brattleboro, Vermont 05301. First published around 1959 under a slightly different name. Copyright 1983. ISBN 0-8289-0502-9.

"I have tried rare book services without success, and now write to you because its practical advice on navigation by personal observation is very closely attuned to the principles your Foundation promotes. I believe it deserves a place in our library and I hope you can help me obtain a copy." — *Yours faithfully, Colin Maclean*

The Executive Director responded to Colin Maclean:

"Please contact Mr. John Luykx (pronounced Likes) at InfoCenter. His telephone is 800-852-0649 and e-mail navtrak@us.hsanet.net. If there is a copy available he will know. All the old, rare and out of print books that we have accumulated over the years reside at the U.S. Naval Observatory Library. We donated them to the library so everyone would have the opportunity to research these documents. If Mr. Luykx is unable to help, contact Mrs. Corbin, Librarian at the U.S.N.O. at bgc@sicon.usno.navy.mil or call 202-762-1463."

— *Best regards, Terry F. Carraway*

Henry Cordova sent by e-mail from Tamarac, Florida on 15 March 1999:

"Thanks for the quick response. I have developed celestial navigation software for the HP28/48 pocket calculators, designed to be used with either the Nautical Almanac or Compact Data for Nav. & Astro. (Yallop & Hohenkerk). The software will determine GHA & Dec. correct for index, dip, refraction, parallax, S.D. errors and running fixes; and generate sight reductions (Azimuths and Intercepts) AND lat/long fixes. The software also has a resight capability, allowing least-squares evaluation and rejection of individual LOPs by comparison with the mean positions of all sights. Please send a stamped, self-addressed, 8_x11 envelope and a clean HP48-RAM card and I will return the software and 24 pages of hardcopy documentation. This is strictly a vanity publication for me, and I require no payment, although if you find the software useful and you should decide to favor me with a small donation, I will not insult you by rejecting it..."

— *Thanks, Henry Cordova*

James Jones sent by e-mail from Dallas, Texas on 21 March 1999:

"Could you mail me some more information on your group? I am particularly interested in celestial navigation as used in aviation, history, current usage, etc.

"I am looking for copies of H.O. 218. This set of sight reduction tables was used extensively in WWII by naval aviators. It was developed by the RAF. The tables did not see extensive civilian use after the war, because they were classified and were apparently not declassified until some time after the war was over. I have a few volumes, covering about 20 degrees of latitude. They are very good tables and a comparison of these with H.O. 249 suggests that 249 may have to some extent been developed from 218.

"Current usage: Celestial navigation is still used in the aviation context more than most realize. Last time I asked, Air Force navigators were still being trained in its use. It is extensively practiced in Africa, where avionics are not considered to be of the highest reliability.

"Perhaps the best argument I can think of for the preservation of the art of celestial navigation can be summarized in two words: SOLAR FLARES. GPS navigation satellites, and the GPS navigation systems that depend on them, can easily and quickly be rendered inoperable by a strong solar flare. Imagine you are on that long cruise to Australia and your GPS goes PPPFFT!!!! I know people here in Texas that cruise yachts off the Texas coast and like to sail them to the Caribbean on occasion. None that I have queried know ANY celestial navigation, even how to take a noon sight. Their usual reply is 'What do I need a sextant for? I have GPS.'

"Anyone interested in celestial air navigation or its history, PLEASE REPLY. My postal address is 4216 Larchmont, Dallas, Texas 75205."

The Executive Director responded to an inquiry as to the availability of certain back issues from a non member:

"My e-mail implied that we only provide back issues to members. Our tax exempt corporate charter only allows us to sell charts, books, publications and other items to members. If we supplied back issues to anyone, then a person could wait one issue and order back issues. That would be unfair to our members who contribute to keep the art of celestial navigation alive. The Newsletter is one method that allows members to come in contact with others with like interests. Your contribution of $35.00 to become a member, is tax deductible. If you order charts or publications shortly you will have regained your $35.00 and will also be allowed to order all of 61 back issues.

"If you would like to join we would be delighted to send you the back issues you desire. Sorry.

— *Best regards, Terry F. Carraway*

The Executive Director wrote to a new member, Byron D. Ruppel on 17 March 1999:

"Thank you for your interest in the Navigation Foundation. We are always delighted to have new members join our small unique group. I am sure that you will find that your membership benefits you, particularly if you order charts, books and publications.

"As you probably know, the Foundation has no paid directors, employees or officials. We all are volunteers and keep the Foundation moving as our major hobby. All of our membership fees go to independent typist, lay-out artists, printers, office supplies and, of course, the Post Office.

"I will mail you the issues you wanted this week. Thank you again for joining our group.

— *Best regards, Terry F. Carraway*

Member Tim Prass sent by e-mail on 5 April 1999:

"First let me say, it gives me great pleasure to be a part of this organization. Navigation has for me been a hobby of ever growing proportion over the last 5 years. By training I'm a mechanical engineer so things mathematical come fairly easy. My fascination with navigation started in earnest in 1994 as a result of my association with a fine group of men who enjoy wilderness horse pack trips. These trips involve about a week or so on horseback (carrying just the essentials) traveling as far away from civilization as possible given the time. Each member of the group has had to hone a skill for the team, mine was navigation. I acquainted myself with topo maps and compass readings, and before each trip I became as familiar with the terrain as possible. Basically my job was to know where we were at all times. Needless to say, that was just the start. Late last year while surfing the net I stumbled on a homestudy course on celestial navigation from Starpath and took it. I've been practicing ever since whenever possible (using my recently acquired Astra IIIb sextant) in my front yard with an artificial horizon, winter weather permitting, and have gotten good results duplicating my known position. I'm looking forward to summer when I can take a little more time to sharpen my sextant reading and sight reduction skills.

"There is something awe inspiring about practicing a skill that is hundreds of years old and which relies on no modern technology of any kind. All my life I've looked up at the stars and have been familiar with the most common constellations, but this new skill has brought the nighttime sky alive. I see so much more now when I look up. I know stars by their names. I can differentiate between planets and stars by their movement. I got to watch Venus and Jupiter cross paths.

"Unfortunately, living in Indianapolis doesn't provide much access even to small bodies of water so I'm basically landlocked. That being the case, I'm committed to learning as much as I can about using my sextant for lunar distances and using it with an artificial horizon. Maybe someday I'll have a chance to cross an ocean on a ship rather than in an airplane.

"I really would appreciate information on the following: —Lunar distance methods for Lat, lon and GMT. (I have a book on the calculation methods) or any other means by which a sextant can be used to determine position without an horizon. —Any study/practice material and or certification related to celestial navigation I can pursue, considering my circumstances.

"One more thing, I'd like to hear from any other members, if any, with circumstances similar to mine." —*Thanks again, Tim Prass.*

Member Tim Prass sent by e-mail on 8 April 1999:

"...On the plane I finally found time to read #61 (it came with my membership). I can tell that the arrival of the newsletter is going to rearrange my use of time from now on. I've got #62 and haven't been able to even look at it.

"Were any of Ambassador Huguenin's desert crossing activities published either in the form of logs or letters?

"Several references were made to the Starpath home study course in #61. This is the course that I took with absolutely no other exposure to the subject. Granted, I take to math but as I recall I only had to call Starpath 3 times to complete the course. (The staff at Starpath was most helpful). Since, I have completed Leonard Gray's '100 Problems in Celestial Navigation' and I'm looking for more.

"As for my e-mail address, (tim.prass@carrier.utc.com). Unless I am flooded with e-mails, it won't be a problem. Either my home address or e-mail is okay." *Thanks for the response.*

NAVIGATION NOTES

Editor's Note: The following is a March 3, 1999 press release from the U.S. Naval Observatory:

March 3, 1999 marks the 150th anniversary of the establishment of the U.S. Nautical Almanac Office (NAO) by Congress. Since its founding, the NAO and the U.S. Naval Observatory (its modern-day parent organization) have compiled a distinguished record of service to the U.S. Navy, the other armed services, the international scientific community, and the public by providing reliable, practical astronomical data. These data are used for a wide variety of purposes including navigation, surveying, scientific research, mission planning, and everyday activities.

To commemorate this special event, the U.S. Naval Observatory is hosting the Nautical Almanac Office Sesquicentennial Symposium on 3-5 March 1999 in Washington, DC. The symposium will cover a broad spectrum of topics including the history of the office, its mission, the users of its products, the underlying science, and a look toward the future. The attendees, all invited, will come from diverse backgrounds, both military and civilian, and will be international in scope. In addition to papers presented by the Nautical Almanac Office staff, invited speakers include scientists and historians from a variety of institutions. Program information for the symposium may be found on the Astronomical Applications Department web site at URL:

http://as.usno.navy.mil/NAO150/

In 1849, Congress established the Nautical Almanac Office to prepare and publish an official national almanac. Up to that time American scientists and seamen relied on foreign almanacs — particularly those of Great Britain — for astronomical and navigational data. Privately published almanacs, such as Benjamin Franklin's *Poor Richard's Almanac* were generally not adequate for scientific use.

The Office was placed under the direction of Lieutenant Charles Henry Davis, an experienced naval officer with a scientific background and personal associations with prominent American scientists. Davis established the Office in Cambridge, Massachusetts, independent of the U.S. Naval Observatory in Washington. In Cambridge the Office had access to Harvard University and Professor Benjamin Peirce, the leading American mathematician of the time. The Office would remain in Cambridge until 1866, when it was moved to Washington, DC. In 1893, the Nautical Almanac Office moved into office space at the U.S. Naval Observatory's new home north of Georgetown.

In 1852, the Office published its first volume, *The American Ephemeris and Nautical Almanac* for 1855. An extract of this, *The American Nautical Almanac* for 1855, was issued for mariners. *The American Ephemeris and Nautical Almanac* provided data needed by astronomers and surveyors. In addition to its practical purpose, it served as a source of national pride. The volume was regarded as an important demonstration of the developing scientific prowess in the United States. *The American Ephemeris and Nautical Almanac* and its successors, *The Astronomical Almanac* and *The Nautical Almanac*, have been published continuously ever since. *The Air Almanac*, a publication geared towards aviation navigation, has been published continuously since 1941.

Over the years, the Nautical Almanac Office has employed several of the nation's most able astronomers and mathematicians, including Simon Newcomb and G. W. Hill, whose 19th Century theories on the motions of the planets remained in use until the 1980's. In the 1940's, the first mechanical computers dramatically improved the accuracy and streamlined the production of the Almanacs. In the 1960's, the Office established a close and lasting relationship with Her Majesty's Nautical Almanac Office in Great Britain and with scientists at the Jet Propulsion Laboratory. *The Astronomical Almanac* (a new, joint publication of the British and American Offices) was introduced in 1984.

Today, the Nautical Almanac Office is a part of the USNO's Astronomical Applications Department. It continues to provide annual printed almanacs for air and marine navigation, and for use by astronomers worldwide. In addition, it continues to develop and refine computer-based almanacs, such as the **M**ultiyear **I**nteractive **C**omputer **A**lmanac (MICA), and to provide a wide range of free, interactive almanac data via the USNO's World Wide Web site, http://www.usno.navy.mil.

In addition to providing critical astronomical data, the Astronomical Applications Department also carries out a modest research program in diverse ares, including celestial mechanics, positional astronomy, and navigation to enable it to meet future needs.

The Development of Sight Reduction Tables for Air Navigation

By Ernest Brown

Inspection type sight reduction tables quickly replaced the earlier tables which were arranged to facilitate mathematical solutions, usually involving logarithms or auxiliary functions or both. The inspection tables provided direct tabulations of altitude and azimuth angle (in some tables true azimuth). Except for interpolation of the tabular values, the tables enabled the air navigator to avoid tedious, time consuming mathematical calculations which often resulted in mistakes. The tables provided the speed in sight reduction essential to safe air navigation not previously provided by the earlier tables.

H.O.Pub. No. 214 (popularly known as H.O. 214), *Tables of Computed Altitude and Azimuth*, published by the U.S. Navy Hydrographic Office between 1936 and 1946 in nine volumes, was the first modern inspection table which could meet the needs of air navigation to some reasonable degree (see figure 1). But its design fell far short of what was actually needed at the time.

Volume I	0°	to	9°	1939
Volume II	10°	to	19°	1939
Volume III	20°	to	29°	1939
Volume IV	30°	to	39°	1936
Volume IV	30°	to	39°	1937
(Altitude correction for DR Latitude)				
Volume V	40°	to	49°	1940
Volume VI	50°	to	59°	1940
Volume VII	60°	to	69°	1940
Volume VIII	70°	to	79°	1941
Volume IX	80°	to	89°	1946

One feature of H.O. 214 which the air navigators did not like was the tabulation of altitude to the nearest tenth of a minute of arc and azimuth angle to the nearest tenth of a degree. Their objective was speed with reasonable accuracy. The *Air Almanac*, continuously published by the U.S. Naval Observatory since 1941, met the Air navigators needs as to both tabulations and the precision of such tabulations (see Figure 2).

Between 1938 and 1944 the British Admiralty published Air Pub. 1618, *Astronomical Navigation Tables*, in 15 volumes (lat. 0°-79°). Responding to the complaint with respect to H.O. 214 above, the U.S. Navy Hydrographic Office in 1941 republished the first 14 volumes (lat. 0°-69°) of A.P. 1618 as H.O. Pub.No. 218 or H.O. 218. The Hydrographic Office, particularly with respect to its support of the merchant marine, did not want to change H.O. 214 to satisfy the needs of air navigation.

In basic design, A.P. 1618 (H.O. 218) is similar to H.O. 214. This similarity is for both parts of the table. One part of the table is the general solution of the astronomical triangle, using as entering arguments latitude, declina-

DECLINATION CONTRARY NAME TO LATITUDE

Lat. 30°

H.A.	24° 00′ Alt.	Δd	Δt	Az.	24° 30′ Alt.	Δd	Δt	Az.	25° 00′ Alt.	Δd	Δt	Az.	25° 30′ Alt.	Δd	Δt	Az.
°	° ′			°	° ′			°	° ′			°	° ′			°
00	36 00.0	1.0	01	180.0	35 30.0	1.0	01	180.0	35 00.0	1.0	01	180.0	34 30.0	1.0	01	180.0
1	35 59.5	1.0	02	178.9	35 29.5	1.0	03	178.9	34 59.5	1.0	02	178.9	34 29.5	1.0	02	178.9
2	35 58.0	1.0	04	177.7	35 28.0	1.0	04	177.8	34 58.0	1.0	04	177.8	34 28.0	1.0	04	177.8
3	35 55.4	1.0	06	176.6	35 25.4	1.0	06	176.6	34 55.5	1.0	06	176.7	34 25.5	1.0	06	176.7
4	35 51.8	1.0	08	175.5	35 21.9	1.0	08	175.5	34 52.0	1.0	08	175.6	34 22.1	1.0	07	175.6
05	35 47.2	1.0	09	174.4	35 17.4	1.0	09	174.4	34 47.5	1.0	09	174.5	34 17.6	1.0	09	174.5
6	35 41.6	99	11	173.2	35 11.8	99	11	173.3	34 42.0	99	11	173.4	34 12.2	99	11	173.4
7	35 35.0	99	13	172.1	35 05.3	99	13	172.2	34 35.5	99	12	172.3	34 05.8	99	12	172.4
8	35 27.4	99	14	171.0	34 57.7	99	14	171.1	34 28.0	99	14	171.2	33 58.4	99	14	171.3
9	35 18.8	99	16	169.9	34 49.2	99	16	170.0	34 19.6	99	16	170.1	33 50.0	99	16	170.2
10	35 09.2	98	18	168.8	34 39.7	98	17	168.9	34 10.2	98	17	169.0	33 40.7	98	17	169.1
1	34 58.6	98	19	167.7	34 29.2	98	19	167.8	33 59.8	98	19	168.0	33 30.4	98	19	168.1
2	34 47.1	98	21	166.6	34 17.8	98	21	166.8	33 48.5	98	20	166.9	33 19.2	98	20	167.0
3	34 34.6	97	22	165.5	34 05.4	97	22	165.7	33 36.3	97	22	165.8	33 07.1	97	22	166.0
4	34 21.2	97	24	164.5	33 52.1	97	24	164.6	33 23.1	97	24	164.8	32 54.1	97	23	164.9
15	34 06.8	96	26	163.4	33 37.9	96	25	163.6	33 09.0	96	25	163.7	32 40.1	96	25	163.9
6	33 51.5	96	27	162.3	33 22.7	96	27	162.5	32 54.0	96	26	162.7	32 25.2	96	26	162.9
7	33 35.3	95	28	161.3	33 06.7	95	28	161.5	32 38.1	95	28	161.7	32 09.5	95	28	161.8
8	33 18.2	95	30	160.3	32 49.7	95	30	160.4	32 21.3	95	30	160.6	31 52.8	95	29	160.8
9	33 00.2	94	32	159.2	32 31.9	94	31	159.4	32 03.6	94	31	159.6	31 35.3	94	31	159.8
20	32 41.3	94	33	158.2	32 13.2	94	33	158.4	31 45.1	94	32	158.6	31 17.0	94	32	158.8
1	32 21.6	93	34	157.2	31 53.7	93	34	157.4	31 25.8	93	34	157.6	30 57.8	93	33	157.8
2	32 01.0	92	36	156.2	31 33.3	92	35	156.4	31 05.6	93	35	156.6	30 37.8	93	35	156.9
3	31 39.7	92	37	155.2	31 12.1	92	37	155.4	30 44.6	92	36	155.7	30 17.0	92	36	155.9
4	31 17.5	91	38	154.2	30 50.1	91	38	154.5	30 22.7	91	38	154.7	29 55.3	91	37	154.9
25	30 54.5	90	40	153.3	30 27.3	91	39	153.5	30 00.2	91	39	153.8	29 33.0	91	39	154.0
6	30 30.7	90	41	152.3	30 03.8	90	41	152.6	29 36.8	90	40	152.8	29 09.8	90	40	153.1
7	30 06.2	89	42	151.4	29 39.4	89	42	151.6	29 12.7	89	42	151.9	28 45.9	89	41	152.1
8	29 40.9	88	43	150.4	29 14.4	88	43	150.7	28 47.8	89	43	151.0	28 21.2	89	42	151.2
9	29 14.9	88	44	149.5	28 48.6	88	44	149.8	28 22.2	88	44	150.0	27 55.8	88	43	150.3
30	28 48.1	87	46	148.6	28 22.0	87	45	148.9	27 55.9	87	45	149.1	27 29.7	87	45	149.4
1	28 20.7	86	47	147.7	27 54.8	86	46	148.0	27 28.9	86	46	148.3	27 03.0	87	46	148.5
2	27 52.6	85	48	146.8	27 26.9	86	48	147.1	27 01.2	86	47	147.4	26 35.5	86	47	147.7
3	27 23.8	85	49	145.9	26 58.4	85	49	146.2	26 32.9	85	48	146.5	26 07.4	85	48	146.8
4	26 54.4	84	50	145.1	26 29.1	84	50	145.4	26 03.9	84	49	145.7	25 38.6	84	49	146.0
35	26 24.3	83	51	144.2	25 59.3	83	51	144.5	25 34.3	83	50	144.8	25 09.2	84	50	145.1
6	25 53.6	82	52	143.4	25 28.8	83	52	143.7	25 04.0	83	52	144.0	24 39.2	83	51	144.3
7	25 22.2	82	53	142.5	24 57.7	82	53	142.8	24 33.2	82	52	143.2	24 08.5	82	52	143.5
8	24 50.3	81	54	141.7	24 26.0	81	54	142.0	24 01.7	81	53	142.3	23 37.3	81	53	142.7
9	24 17.8	80	55	140.9	23 53.8	80	55	141.2	23 29.7	80	54	141.5	23 05.5	81	54	141.9

26° 00′ Alt.	Δd	Δt	Az.	26° 30′ Alt.	Δd	Δt	Az.	27° 00′ Alt.	Δd	Δt	Az.	27° 30′ Alt.	Δd	Δt	Az.	H.A.
° ′			°	° ′			°	° ′			°	° ′			°	°
34 00.0	1.0	01	180.0	33 30.0	1.0	01	180.0	33 00.0	1.0	01	180.0	32 30.0	1.0	01	180.0	00
33 59.5	1.0	02	178.9	33 29.5	1.0	02	178.9	32 59.5	1.0	02	178.9	32 29.5	1.0	02	178.9	1
33 58.0	1.0	04	177.8	33 28.1	1.0	04	177.9	32 58.1	1.0	04	177.9	32 28.1	1.0	04	177.9	2
33 55.6	1.0	06	176.8	33 25.6	1.0	06	176.8	32 55.7	1.0	06	176.8	32 25.7	1.0	06	176.8	3
33 52.1	1.0	07	175.7	33 22.2	1.0	07	175.7	32 52.3	1.0	07	175.8	32 22.4	1.0	07	175.8	4
33 47.7	1.0	09	174.6	33 17.9	1.0	09	174.6	32 48.0	1.0	09	174.7	32 18.1	1.0	09	174.8	05
33 42.3	99	10	173.5	33 12.5	99	10	173.6	32 42.7	99	10	173.6	32 12.9	99	10	173.7	6
33 36.0	99	12	172.4	33 06.2	99	12	172.5	32 36.5	99	12	172.6	32 06.7	99	12	172.7	7
33 28.7	99	14	171.4	32 59.0	99	14	171.5	32 29.3	99	14	171.5	31 59.6	99	13	171.6	8
33 20.4	99	15	170.3	32 50.8	99	15	170.4	32 21.2	99	15	170.5	31 51.6	99	15	170.6	9
33 11.2	98	17	169.3	32 41.7	98	17	169.4	32 12.2	98	17	169.5	31 42.6	98	16	169.6	10
33 01.0	98	18	168.2	32 31.6	98	18	168.3	32 02.2	98	18	168.4	31 32.8	98	18	168.5	1
32 49.9	98	20	167.2	32 20.6	98	20	167.3	31 51.3	98	20	167.4	31 22.0	98	19	167.5	2
32 37.9	97	22	166.1	32 08.7	97	21	166.2	31 39.5	97	21	166.4	31 10.3	97	21	166.5	3
32 25.0	97	23	165.1	31 55.9	97	23	165.2	31 26.9	97	23	165.4	30 57.8	97	22	165.5	4
32 11.2	96	25	164.0	31 42.2	96	24	164.2	31 13.3	97	24	164.4	30 44.3	97	24	164.5	15
31 56.4	96	26	163.0	31 27.6	96	26	163.2	30 58.8	96	26	163.4	30 39.0	96	25	163.5	6
31 40.8	95	28	162.0	31 12.2	96	27	162.2	30 43.5	96	27	162.4	30 14.8	96	27	162.5	7
31 24.3	95	29	161.0	30 55.9	95	29	161.2	30 27.3	95	28	161.4	29 58.8	96	28	161.6	8
31 07.0	94	30	160.0	30 38.7	94	30	160.2	30 10.3	95	30	160.4	29 42.0	96	30	160.6	9
30 48.8	94	32	159.0	30 20.7	94	31	159.2	29 52.5	94	31	159.4	29 24.3	94	31	159.6	20
30 29.8	93	33	158.0	30 01.8	93	33	158.3	29 33.8	93	32	158.5	29 05.8	93	32	158.7	1
30 10.0	93	34	157.1	29 42.2	93	34	157.3	29 14.3	93	34	157.5	28 46.5	93	33	157.7	2
29 49.4	92	36	156.1	29 21.7	92	35	156.3	28 54.1	92	35	156.6	28 26.4	92	35	156.8	3
29 27.9	91	37	155.2	29 00.5	92	37	155.4	28 33.0	92	36	155.6	28 05.5	92	36	155.9	4
29 05.7	91	38	154.2	28 38.5	91	38	154.5	28 11.2	91	38	154.7	27 43.9	91	37	154.9	25
28 42.8	90	40	153.3	28 15.7	90	39	153.6	27 48.6	90	39	153.8	27 21.5	90	39	154.0	6
28 19.0	89	41	152.4	27 52.2	90	40	152.6	27 25.3	90	40	152.9	26 58.4	90	40	153.1	7
27 54.6	89	42	151.5	27 27.9	89	42	151.7	27 01.3	89	41	152.0	26 34.6	89	41	152.2	8
27 29.4	88	43	150.6	27 03.0	88	43	150.8	26 36.5	88	42	151.1	26 10.0	88	42	151.4	9
27 03.5	87	44	149.7	26 37.3	87	44	150.0	26 11.1	88	44	150.2	25 44.8	88	43	150.5	30
26 37.0	87	45	148.8	26 11.0	87	45	149.1	25 44.9	87	45	149.4	25 18.8	87	44	149.6	1
26 09.7	86	46	148.0	25 43.9	86	46	148.2	25 18.1	86	46	148.5	24 52.3	86	45	148.8	2
25 41.8	85	48	147.1	25 16.3	85	47	147.4	24 50.6	85	47	147.7	24 25.0	86	46	148.0	3
25 13.3	84	49	146.3	24 47.9	85	48	146.5	24 22.5	85	48	146.8	23 57.1	85	48	147.1	4
24 44.1	84	50	145.4	24 19.0	84	49	145.7	23 53.8	84	49	146.0	23 28.6	84	49	146.3	35
24 14.3	83	51	144.6	23 49.4	83	50	144.9	23 24.5	83	50	145.2	22 59.5	83	50	145.5	6
23 43.9	82	52	143.8	23 19.2	82	51	144.1	22 54.5	82	51	144.4	22 29.8	83	51	144.7	7
23 12.9	81	53	143.0	22 48.5	82	52	143.3	22 24.0	82	52	143.6	21 59.4	82	51	143.9	8
22 41.3	81	54	142.2	22 17.1	81	53	142.5	21 52.8	81	53	142.8	21 28.6	81	52	143.1	9

Figure 1. H.O. Pub. No. 214, Tables of Computed Altitude and Azimuth, *Extract*

LAT.	30°			31°			32°			33°			34°			LAT.
H.A.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	H.A.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	33 43	−8	180	32 43	−8	180	31 43	−8	180	30 43	−8	180	29 43	−8	180	360
1	33 43	8	179	32 43	8	179	31 43	8	179	30 43	8	179	29 43	8	179	359
2	33 41	8	178	32 41	8	178	31 41	8	178	30 41	8	178	29 42	8	178	358
3	33 39	8	177	32 39	8	177	31 39	8	177	30 39	8	177	29 39	8	177	357
4	33 35	8	176	32 36	8	176	31 36	8	176	30 36	8	176	29 36	8	176	356
5	33 31	−8	175	32 31	−8	175	31 32	−8	175	30 32	−8	175	29 32	−8	175	355
6	33 26	8	174	32 26	8	174	31 26	8	174	30 27	8	174	29 27	8	174	354
7	33 19	8	172	32 20	8	173	31 20	8	173	30 21	8	173	29 21	8	173	353
8	33 12	8	171	32 13	8	172	31 13	8	172	30 14	8	172	29 15	8	172	352
9	33 04	8	170	32 05	8	170	31 06	8	171	30 06	8	171	29 07	8	171	351
10	32 55	−8	169	31 56	−8	169	30 57	−8	170	29 58	−8	170	28 59	−8	170	350
11	32 45	8	168	31 46	8	168	30 47	8	169	29 48	8	169	28 50	8	169	349
12	32 34	8	167	31 35	8	167	30 37	8	167	29 38	8	168	28 39	8	168	348
13	32 22	8	166	31 23	8	166	30 25	8	166	29 27	8	167	28 28	8	167	347
14	32 09	8	165	31 11	8	165	30 13	8	165	29 15	8	166	28 17	8	166	346
15	31 55	−8	164	30 57	−8	164	30 00	−8	164	29 02	−8	165	28 04	−8	165	345
16	31 40	8	163	30 43	8	163	29 46	8	163	28 48	8	164	27 51	8	164	344
17	31 25	8	162	30 28	8	162	29 31	8	162	28 33	8	163	27 36	8	163	343
18	31 09	7	161	30 12	8	161	29 15	8	161	28 18	8	162	27 21	8	162	342
19	30 51	7	160	29 55	7	160	28 58	7	161	28 02	7	161	27 05	8	161	341
20	30 33	−7	159	29 37	−7	159	28 41	−7	160	27 45	−7	160	26 49	−7	160	340
21	30 14	7	158	29 19	7	158	28 23	7	159	27 27	7	159	26 31	7	159	339
22	29 55	7	157	28 59	7	157	28 04	7	158	27 08	7	158	26 13	7	158	338
23	29 34	7	156	28 39	7	156	27 44	7	157	26 49	7	157	25 54	7	157	337
24	29 13	7	155	28 18	7	156	27 24	7	156	26 29	7	156	25 34	7	156	336
25	28 51	−7	154	27 57	−7	155	27 02	−7	155	26 08	−7	155	25 14	−7	155	335
26	28 28	7	153	27 34	7	154	26 40	7	154	25 47	7	154	24 53	7	154	334
27	28 04	7	153	27 11	7	153	26 18	7	153	25 24	7	153	24 31	7	153	333
28	27 40	7	152	26 47	7	152	25 54	7	152	25 01	7	152	24 08	7	153	332
29	27 15	7	151	26 23	7	151	25 30	7	151	24 38	7	151	23 45	7	152	331
30	26 49	−7	150	25 57	−7	150	25 05	−7	150	24 13	−7	151	23 21	−7	151	330
31	26 23	7	149	25 32	7	149	24 40	7	149	23 48	7	150	22 57	7	150	329
32	25 56	7	148	25 05	7	148	24 14	7	149	23 23	7	149	22 31	7	149	328
33	25 28	7	147	24 38	7	148	23 47	7	148	22 56	7	148	22 05	7	148	327
34	25 00	7	146	24 10	7	147	23 20	7	147	22 29	7	147	21 39	7	147	326
35	24 31	−7	146	23 41	−7	146	22 52	−7	146	22 02	−7	146	21 12	−7	147	325
36	24 01	7	145	23 12	7	145	22 23	7	145	21 34	7	146	20 44	7	146	324
37	23 31	6	144	22 42	7	144	21 54	7	144	21 05	7	145	20 16	7	145	323
38	23 00	6	143	22 12	6	143	21 24	7	144	20 36	7	144	19 47	7	144	322
39	22 29	6	142	21 41	6	143	20 54	6	143	20 06	7	143	19 18	7	143	321
40	21 57	−6	142	21 10	−6	142	20 23	−6	142	19 35	−6	142	18 48	−7	143	320
41	21 24	6	141	20 38	6	141	19 51	6	141	19 04	6	142	18 17	6	142	319
42	20 51	6	140	20 05	6	140	19 19	6	141	18 33	6	141	17 46	6	141	318
43	20 18	6	139	19 32	6	140	18 47	6	140	18 01	6	140	17 15	6	140	317
44	19 44	6	139	18 59	6	139	18 14	6	139	17 28	6	139	16 43	6	139	316
45	19 09	−6	138	18 25	−6	138	17 40	−6	138	16 55	−6	139	16 10	−6	139	315

{For argument H.A. on the left, True Azimuth = 360° − Tabulated Azimuth.
{For argument H.A. on the right, True Azimuth = Tabulated Azimuth.
No correction for date is necessary until 1948.

Figure 3. H.O. Pub. No. 218, Astronomical Navigation Tables, *Extract*

AIR ALMANAC

GREENWICH P. M. 1943 JANUARY 1 (FRIDAY)

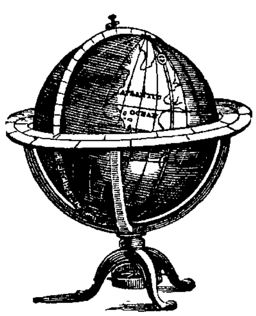
GCT	☉ SUN GHA	SUN Dec.	♈ GHA	MARS 1.7 GHA	MARS Dec.	JUPITER −2.2 GHA	JUPITER Dec.	SATURN 0.0 GHA	SATURN Dec.	◐ MOON GHA	MOON Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
12 00	359 10	S23 03	280 16	29 57	S22 19	166 59	N21 59	215 02	N19 36	69 27	S 7 32
10	1 40		282 46	32 28		169 29		217 33		71 51	34
20	4 10		285 17	34 58		172 00		220 03		74 16	36
30	6 40	• •	287 47	37 28	• •	174 30	• •	222 33	• •	76 41	• 38
40	9 10		290 18	39 58		177 01		225 04		79 06	39
50	11 40		292 48	42 28		179 31		227 34		81 31	41
13 00	14 10	S23 03	295 18	44 58	S22 19	182 02	N21 59	230 05	N19 36	83 56	S 7 43
10	16 40		297 49	47 28		184 32		232 35		86 21	45
20	19 10		300 19	49 58		187 03		235 06		88 46	46
30	21 40	• •	302 50	52 28	• •	189 33	• •	237 36	• •	91 11	• 48
40	24 10		305 20	54 58		192 04		240 06		93 36	50
50	26 40		307 50	57 28		194 34		242 37		96 01	52
14 00	29 09	S23 03	310 21	59 59	S22 20	197 04	N21 59	245 07	N19 36	98 26	S 7 53
10	31 39		312 51	62 29		199 35		247 38		100 51	55
20	34 09		315 22	64 59		202 05		250 08		103 16	57
30	36 39	• •	317 52	67 29	• •	204 36	• •	252 39	• •	105 41	• 7 59
40	39 09		320 23	69 59		207 06		255 09		108 06	8 00
50	41 39		322 53	72 29		209 37		257 39		110 30	02

Lat.	Sun-rise	Twlt.	Moon-rise	Diff.
N °	h m	m	h m	m
60	9 03	57	1 43	83
58	8 46	51	39	81
56	32	47	36	79
54	19	43	34	76
52	8 08	40	31	75
50	7 59	38	29	73
45	38	34	24	70
40	22	31	21	66
35	7 08	28	17	64
30	6 56	26	14	61
20	35	24	09	57
10	6 17	23	05	53

Figure 2. Air Almanac Extract

tion and hour angle to obtain respondents altitude and azimuth angle. In the star part of the table, the named star is really no more than an exact declination entering argument (no interpolation required) for one of the 22 stars used in the table. There are major differences between the two tables.

At this stage of development there are three incremental advancements beyond H.O. 214: (1) desired tabular precision, (2) avoiding interpolation for declination, and (3) providing for refraction at 5,000 feet. (To Be Continued)



CORRECTION

Closed Form of Lat. and Long. With Two Sights

James O. Muirhead

On page 10 of Issue Sixty-one (Fall 1998), change equation (15) to make the sign in front of the radical + rather than -.

MARINE INFORMATION NOTES

The Nautical Almanac

The Nautical Almanac is provided jointly by Her Majesty's Nautical Almanac Office, London, and the Nautical Almanac Office of the Astronomical Applications Department of the U.S. Naval Observatory, Washington, DC to meet the general requirements of the Royal Navy and the United States Navy. The source of this product in the United Kingdom is The Stationery Office Limited, St. Crispins, Duke Street, Norwich NR3 1 PD. The source in the United States is Superintendent of Documents, U.S. Government Printing Office, Washington, DC.

Except for minor modifications, such as for language, this product is used in the Brazilian, Chilean, Danish, Greek, Indian, Indonesian, Italian, Korean, Mexican and Norwegian Almanacs. There are also commercial issues: One of these issues is the commercial edition published jointly by:

Paradise Cay Publication	Celestaire, Inc.
Post Office Box 29	416 S. Pershing
Arcata, CA 95521	Wichita, KS 67218

This edition has an expanded coverage of 14 months.

NIMA's Marine Navigation Department Home Page

The NIMA Marine Navigation Department's website **www.nima.mil** has recently added a "Customer Photograph Gallery" page. This page enables the user to send and review photos of pertinent navigation features, aids and navigational information for compilation into NIMA publications and for use by other navigators. The gallery has been partially populated and is soliciting your input during this midpoint stage. Please send your comments and suggestions about this page via the "E-mail Your Comments" button at its website.

Global Maritime Distress and Safety System (GMDSS)

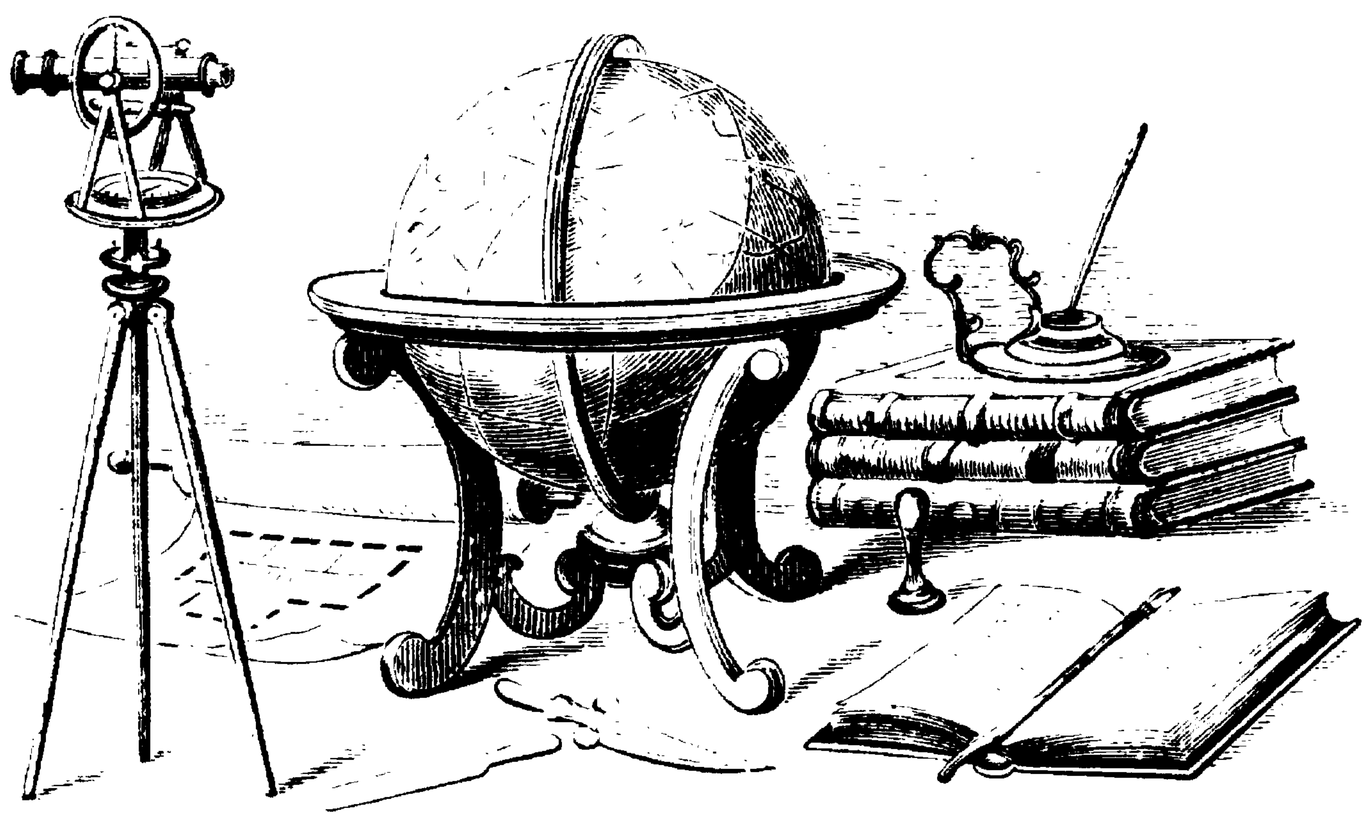
The Federal Communications Commission announced that the Global Maritime Distress and Safety System (GMDSS) has become fully implemented in the United States effective February 1, 1999. All cargo ships of 300 gross tons and upwards, all large passenger vessels operated in the open sea and all small passenger vessels operating on international voyages now must comply fully with the GMDSS requirements unless exempted by the FCC. The GMDSS is a ship-to-shore distress and safety communications system that requires two separate means of sending a distress alert. It relies on geostationary communications satellites and terrestrial digital communications systems that enable ship radio operators to send and receive distress and safety communications worldwide. The GMDSS also uses radar transponders and distress beacons that pinpoint the location of a ship or survival craft in distress. It replaces the manual Morse Code radiotelegraph system. Full implementation of this automated communication system vastly improves the ability of ships at sea to notify the maritime community of events which may threaten loss of life.

The GMDSS was first adopted by the International Maritime Organization (IMO) in 1988. In 1992, the FCC adopted new rules phasing in GMDSS compliance, with full implementation scheduled for February 1, 1999. Prior to the GMDSS, passenger and large cargo ships were required to be equipped with manual Morse Code radiotelegraph installations manned by skilled radiotelegraph operators when sailing in the open sea or on international voyages.

Electronic SAFETYNET Manual

The new address for accessing Electronic SAFETYNET Manual is:

http://www.inmarsat.org/support/index.html.



NEWSLETTER INDEX

Index 92 (1-35) published with issue Thirty-five (Spring 1991), is an index covering Issue One through Thirty-five.
Index to Navigation Problems (4-33), published in Issue Thirty-three (Fall 1991), covers navigation problems in Issues Four through thirty-three.
Index to Navigation Personalities (12-53), published in Issue Fifty-three (Fall 1996), covers personalities in Issues Twelve through Fifty-three.
Index to Book Reviews (36-53), published in Issue Fifty-three (Fall 1996), covers reviews in Issues Thirty-six through Fifty-three.
Index to History of Navigation (3-54), published in Issue Fifty-four (Winter 1996-97), covers history articles in Issues Three through Fifty-four. This includes articles under the heading Navigation Notes in Issues Three through Seven.
Index to Navigation Notes (1-56), published in Issue Fifty-six (Summer 1997), does not include the navigation problems and history articles previously published in the Navigation Notes section.
Index to Navigation Basics Review (13-58), published in Issue Fifty-eight (Winter 1997-98), covers those articles written as reviews of the basics of navigation in Issues thirteen through Fifty-eight.
Index to Navigation Foundation Peary Project (23-42), published in Issue Fifty-eight (Winter 1997-98), covers articles and comments on the analysis of the data of Robert E. Peary's expedition to the North Pole in 1909 in Issues Twenty-three through Forty-two.
Index to Marine Information Notes (3-60), published in Issue Sixty (Summer 1998), covers only those notes of more lasting interest in Issues Three through Sixty.
Index to Navigation Problems (34-60), published in Issue Sixty, covers navigation problems in Issues Thirty-four through Sixty.
Index to DO YOU KNOW . . .? (36-63), published in Issue Sixty-three (Spring 1999) covers questions in Issues Thirty-six through Sixty-three.

ISSUE	QUESTION	AUTHOR
Thirty-six Summer 1992	We all know Harrison was the inventor of the first sufficiently accurate chronometer to find longitude. Larcum Kendall's copy, K1, of Harrison's No. 4 was used by Captain Cook in his later voyages. It is not as widely known that Kendall made a second copy, K2. Who was the famous Captain who used it and what happened to it?	Allan Bayless
Thirty-seven Fall 1992	Most readers know that the bubble sextant was used for air navigation aboard the trans-oceanic clippers in the 1930s and that many World War II air navigators were trained in its use. In effect, it was a sextant with its own artificial horizon in the form of a small bubble level that was observed via a mirror placed at a 45 degree angle above it. Do you know when the bubble sextant first came into use and in what mode of navigation it was used?	Roger Jones

Thirty-eight Winter 1992-93	The cross staff was a forerunner of the backstaff. Do you know when it came into use and how it was used?	Roger Jones
Thirty-nine Spring 1993	Special techniques have been used for years by many celestial navigators. Do you know the "Noon Constant" and how it was used?	Roger Jones
Forty Summer 1993	A number of well known voyagers and navigators have commented in various published articles and reports that in comparing celestial fixes with GPS fixes and GPS fixes with known locations, all as depicted on a chart, significant discrepancies have been noted. Discounting possible celestial observer error and GPS signal data that may be temporarily unreliable, do you know what a map datum is and the magnitude of positioning errors that may occur if a chart is used that is not based upon the mathematical model of the WGS84 horizontal datum?	Roger Jones
Forty-one/two Fall/Winter 1993-94	Who invented the first doubly reflecting octant? When?	Roger Jones
Forty-three Spring 1994	What is the year of the oldest extant isogonic chart?	Ernest Brown
Forty-four Summer 1994	Why mariners were once charged not to eat onions or garlic?	Ernest Brown
Forty-five Fall 1994	When the Mercator chart came into general use among navigators?	Ernest Brown
Forty-six Winter 1994-95	When the North Magnetic Pole was first located?	Ernest Brown
Forty-seven Spring 1995	Who invented the isogram (isoline) used to display on a map or chart a constant value such as a pressure, temperature, magnetic variation, etc.?	Ernest Brown
Forty-eight Summer 1995	Who first introduced English speaking navigators to the sight reduction method of using the pole as the assumed position?	Ernest Brown
Forty-nine Fall 1995	What the base plate and latitude templates of No. 2102-D, Star Finder and Identifier, are?	Ernest Brown

Fifty Winter 1995-96	The phase-out dates for the Loran-C and Omega Radionavigation Systems?	Ernest Brown
Fifty-one Spring 1996	The advantage front-coated sextant mirrors have over the back-coated mirrors in common usage?	John M. Luykx
Fifty-two Summer 1996	The name of the new agency that will subsume the Defense Mapping Agency?	Ernest Brown
Fifty-three Fall 1996	What is wrong with the pole-guy wire analogy which is so useful in explaining the concept of circles of equal altitude?	Ernest Brown
Fifty-four Winter 1996-97	Who were the first two men to reach both poles of the earth together?	Ernest Brown
Fifty-five spring 1997	What "dead reckoning" is and the origin of the term?	Allan E. Bayless
Fifty-six Summer 1997	How Eratosthenese used the pointer and bowl of a sundial at Alexandria and the pointer of another sundial at Syene (Aswan) to measure the circumference of the earth?	Ernest Brown
Fifty-nine Spring 1998	The range at which a small, portable 4-watt jammer can take out GPS civil signals?	Ernest Brown
Sixty Summer 1998	How much shorter is the route from Europe to Japan via the Northern Seaway than via the Suez Canal?	Ernest Brown
Sixty-one Fall 1998	Why the building of junk with more than two masts was a capital offense in China in A.D. 1500?	Ernest Brown
Sixty-two winter 1998-99	Who devised the transparent station pointer (three-arm protractor)?	Ernest Brown
Sixty-three Spring 1999	Who developed the hemispherium sundial used by Eratosthenese to measure the circumference of the earth?	Ernest Brown

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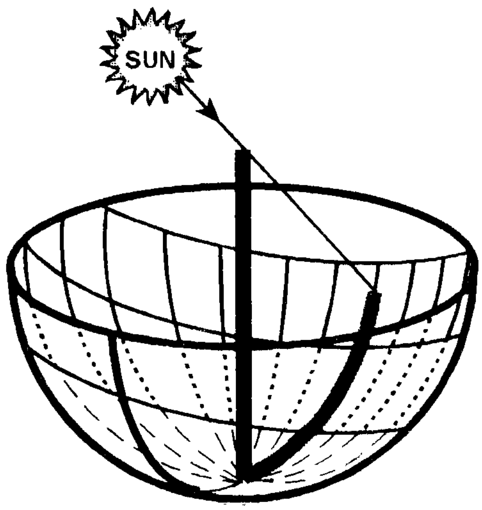
The Foundation for the Promotion
of the Art of Navigation
Box 1126, Rockville, MD 20850

ANSWER TO DO YOU KNOW...?

(from p. 1)

The hemispherium was developed about 340 BC by Berosus, a Chaldean astronomer-priest living in Egypt during the time of Alexander the Great. The illustration on the back page is from the Southern Hemisphere Edition of *Sundials* Australia.



A vertical post was placed centrally inside a hollowed out hemisphere. The inside surface of the hemisphere had vertical lines carved on it to divide the daylight period into 12 hours, and horizontal lines to show the seasons. The shadow cast on the inside surface by the tip of the post marked out the path of the sun as it travelled across the sky.

Schematic hemispherium — the grey curve represents the post's shadow.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-FOUR, SUMMER 1999

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Spring has arrived and we have presented two awards for excellence in navigation: The Benjamin Dutton Award at the U.S. Naval Academy and the Rear Admiral Thomas D. Davies award at Tabor Academy in Marion, Massachusetts.

The U.S. Naval Academy Award was presented to MIDN 3/C Patrick Kane at the Surface Warfare Officers reception on Saturday, 22 May. The Tabor Academy Award was presented to Brendan R. Gotowka. Captain James E. Geil, Chair, Nautical Science Department writes:

"I hope all is well with you and the Navigation Foundation. We have had a very good year at Tabor. The Tabor recipient and I spent the winter in the Virgin Islands running our coral reef ecology program for Tabor students. We had fifty-four participate during three 10-day cruises, plus a three week voyage back to Massachusetts in March.

"The celestial navigation course is also going very well. Several of my current and past students practiced their celestial skills during the passage from the Caribbean to Florida.

"Brendan R. Gotowka is the recipient of the Davies Award this year. His work in celestial navigation has been outstanding. Brendan has also just been appointed to the U.S. Naval Academy. We are very happy for him and will be pleased to have him at Annapolis representing Tabor Academy.

"Awards will be presented at Commencement, which will take place on Saturday, June 5.

"Thank you for your continuing sponsorship of the meaningful award. Tabor remains committed to teaching students the art of celestial navigation." Best regards.

— *James E. Geil, Chair, Nautical Science Department, Tabor Academy.*

We received the following e-mail from F. Edward McCabe at marines@flinet.com:

"I was a U.S. Marine Corps Navigator (Air) during WWII. I went through training at Cherry Point Marine Corps Air Station in North Carolina. I would be interested in regaining long lost knowledge.

"To my knowledge there were only about 50 of us, perhaps less. I would like to know if you have any in your organization." *Thank you.*

— *F. Edward McCabe, Aviation Navigator (Eons Ago).*

The Executive Director responded:

"If there are any members who were in the Marine Corps Air Navigation Program, please send me or McCabe an e-mail. Or let us know and we will send him an e-mail with your response."

READERS FORUM

Edited by Ernest Brown

New Member Carl Herzog, Editor, *Reed's Nautical Almanacs*, wrote to the Executive Director on April 21, 1999:

"Thanks for taking the time Wednesday to talk to me about the Foundation's work, and changing the address on future mailings to Reed's.

"Enclosed is a check for $35. Please consider it a personal membership for me. I'd appreciate it if you could send me the last two years back issues of the Foundation's newsletter, assuming they are available.

DO YOU KNOW...?

Who was the first person to conceive the design of H.O.Pub No. 249, *Sight Reduction Tables for Air Navigation?*

(See final page of this issue)

The only one we seem to have in the office is from the Fall of 1997. Let me know if you need an additional fee to cover mailing of back issues.

"As I mentioned, I've taught celestial and traditional seamanship skills on schooners and tall ships. Although editing Reed's Almanacs is a mostly full-time job now, I'm still doing some teaching on the *Ernestina* and on private boats.

"If there is anything I can do to help out the Foundation, don't hesitate to give me a call."

— *Thanks again. Carl Herzog, Editor, Reed's Nautical Almanacs*

Member Dr. G. G. Bennett wrote from Australia on 23 April 1999:

"I enclose some material relating to the publication of a new book on celestial navigation, a subject which may be of interest to some of our members. The material has been prepared using Microsoft Word for Windows 95 on an IBM machine. If it would be a help in preparing your ms, I can send you a copy on either a floppy disk or by e-mail.

"I would be grateful if you would include it in your next issue of the Newsletter.

— *Yours sincerely, G. G. Bennett*

In response to an e-mail from Joseph N. Portney, the Executive Director wrote on 1 May 1999:

"I remember you. I was with Admiral Davies from 1968 until his death in 1991. Since you knew Gene Rankin, you must know that he married Admiral Davies' widow, Eloise.

"I could give you the details but I suggest you contact the Naval Aviation History Museum at Pensacola. I sent him down in 1978/79 to make a living history of his flight. You would have the information straight from his mouth if you got the information from them. All my knowledge is bits and pieces that make up the entire story, all gained on mid watches while at sea on his staff. When you do get the information from Pensacola, I would be glad to give it a review to see if he told everything including some little tidbits that may not get into official history. One incident was the delivery of a kangaroo in a wooden cage, presented by the mayor of the small town where *Truculent Turtle* was sent because the officials were afraid that it would crash on take-off. When the horrified engineers were told to load the kangaroo into the tail of the plane, they told Davies that the plane could not possibly fly with the additional load. They were even concerned with the already overloaded XP2V1. He told them to load the kangaroo. They did and *Turtle* flew the first 500 NM in ground effect before they had burned enough fuel to climb.

"It is true about the fuel. They all believed the gages which showed less fuel than they calculated. The after thought of the Admiral was that they should have actually dip-sticked the tanks and checked the gage. They took a vote and decided to land in Ohio since they had the distance record.

"Under the new aviation rules, Davies still holds the record for distance in heavy multi-engined aircraft."

— *Best regards, Terry F. Carraway, Captain, U.S. Navy (Retired)*

Joseph N. Portney responded on May 3, 1999:

"You might be interested in viewing this month's Brain Game at http://www.littongcs.com click Portney's Ponderables, then Brain Games. The subject is how the crew of the WWII USAAF B-24D *Lady Be Good* were deceived by a reciprocal bearing from a Banghazi HF/DF station and flew beyond their base to their demise on their first combat mission. How the ambiguous bearing could have been resolved and the tragedy averted is revealed for the first time."

— *Best regards, Joe Portney*

Member John Lewis of Seattle, WA sent by e-mail on May 3, 1999:

"Just returned from a brief vacation in France, and visited for the first time the Musee de la Marine in the Palais de Chaillot (right across the Seine from the Eiffel Tower). Very impressive large maritime museum. They are expanding this year their exhibit on navigation, with several Borda circles, double sextants, interesting mechanical calculators for clearing lunar distances, chronometers, etc. Was not all labelled when I was there but should be by this summer."

— *John Lewis*

James E. Roeber sent by e-mail on 8 May 1999:

"Allow me to introduce myself. I'm Jim Roeber, Assistant National Educational Officer (ANEO) for United States Power Squadrons (USPS). A fellow USPS member sent me a copy of the first page of your Issue #62 - Winter 98-99 Navigator's Newsletter. He was calling to my attention your column on celestial navigation instruction at the Naval Academy.

"As I'm sure you know well, USPS offers its members several courses in celestial navigation - a basic, hands-on, 'how-to' course and an advanced, theory course. We had heard some early reports that the Academy was going to dump celestial navigation instruction and were glad to hear that was a premature and erroneous message. In your Issue #62 column, I took particular note of your comment that USNA plans to decrease class time spent in reducing sights by tables and introduce midshipmen to computer software capabilities for sight reduction. I was pleased to see that step forward, for I often wonder if we don't spend more time teaching arithmetic than we do teaching how to take and use sights.

"Three times each year, as part of my ANEO job, I write a USPS Educational Department newsletter ('Currents') for distribution to our national officers, district commanders and educational officers, and squadron commanders. Copies are also sent to the 50 State Boating Law Administrators. I am right now compiling the issue of 'Currents' to be distributed in early June. I would like permission to quote all or part of your column on 'Celestial Navigation Instruction at the Naval Academy' in this issue of 'Currents.' I would, of course, cite you as the author, and 'The Navigation Newsletter' and the Foundation for the Promotion of the Art of Navigation as the source. I know I could paraphrase the message, but I think it carries much more clout as a direct quotation from such a credible source.

"I would also like to receive information about the Foundation.

"Thanks for your consideration of my request."

— *Regards, Jim*

Member Richard J. Stachurski wrote from Belleview, WA by e-mail on May 3, 1999:

"I am a Foundation member living in Belleview, WA and I have a question that I'm sure one of the other members can help me with. When checking the index error of a sextant how far away must the horizon or other sighted object be in order to avoid parallax problems? I would also appreciate some help in understanding the exact geometry of index error. Thanks very much for considering this question."

— *Richard J. Stachurski*

Andrew T. Young sent by e-mail on 29 April 1999:

"I thought I knew something about green flashes — see my Web site on the subject at

http://mintaka.sdsu.edu/GF/

which contains my bibliography of some 950 references on this subject — but I recently was startled to read, in C. H. Cotter's *A History of Nautical Astronomy* that 'The method of finding longitude from an observation of the Green Flash which occurs in favorable meteorological conditions when the upper limb of the Sun sinks below the visible horizon has been suggested on many occasions during the present century.'

"This was all news to me! Might one of your members be able to steer me to further information on this interesting idea?

"Cotter dismisses it as insufficiently precise, because of variations in the dip of the horizon, as well as in timing. But I think something useful might yet be done with this problem. In any case, I'm eager to learn about those 'many occasions' he refers to!"

— *Andrew T. Young, aty@mintaka.sdsu.edu*

The following was received from russl@frontier.net:

"I am a sixth grader doing a research paper on Ferdinand Magellan. I have been unsuccessful in finding a photograph of a sexton and was hoping you might be able to help me out. If you have a picture or know of a web site, that would help me a lot."

— *Thank you very much, Sincerely, Russ*

The Executive Director responded:

"Dear Russ, Congratulations on your choice of research. Magellan was an interesting explorer.

"First, Magellan did not use a sextant. The sextant was not invented until about 1730. There were several inventions that were similar and combined they became the sextant. Magellan did his exploring in the first half of the 16th century. At this period of time there were two celestial navigation instruments, the astrolabe invented in the 3rd century B.C. by Apollonius of Perga, and the cross-staff. The cross-staff was probably the choice by Magellan. The cross-staff was used up until about 1590 when the backstaff was invented.

"I have attached a photocopy of the cross-staff and the backstaff. It is in the GIF format and should be readable using Microsoft Net Browser. Find the attachment in Windows Explorer and double click on the name 'cross-staff.' It should show the picture."

— *Best regards, Terry F. Carraway*

In response to a request for information on how to learn to sail on the ocean by the stars and the sun, the Executive Director responded:

"Start with the local library and see if you can check out any books on celestial navigation. This will give you a start. If you are close to a U.S. Power Squadron, check with them. They frequently give courses on celestial. Also check with the U.S.C.G. Auxiliary. They also have courses. If all else fails, try The Starpath School of Navigation in Seattle, Washington. Their web page is www.starpath.com. If you want more information, you can e-mail Dr. David Burch at starpath@starpath.com."

— *Best regards, Terry F. Carraway*

The following was received on the Internet:

"I am preparing a report on navigators and navigation for my 6th grade school class. I know about some types of navigators like ship and airplane. What are some others?"

— *Thank you, Daniel*

The Executive Director responded:

"Dear Daniel, You can add tank commanders to your list. In Desert Storm many tank commanders used GPS to find their way around the desert. Also navigators are still used at sea, in yacht races, individuals who sail their yachts around the world and every boatman on the water. Everyone on a boat uses some form of navigation. They use lighthouses, water towers, buildings, buoys, and prominent landmarks when in sight of land. This is called 'piloting' but is still navigation because it tells the sailor his position and keeps him from hitting rocks or running aground. When outside the sight of land they have to use 'Dead Reckoning', celestial navigation, Loran or GPS.

"We had a member who was a desert navigator. He was a Swiss Ambassador who had navigated the Saudi and Sahara deserts by celestial navigation.

"Anyone who flies an airplane, private or commercial, has to navigate continually. If he is not under the control of the FAA and does not have electronic navigational aids he must use landmarks from his chart to get to his designation. If he has electronic aids he still navigates from one electronic site to another.

"When someone drives or walks they use landmarks or maps to find their way. That is also navigation.

"We hope we did not confuse the issue of navigation but instead helped you in your research."

— *Best regards, Terry F. Carraway.*

Member Bruce Stark sent by e-mail on 22 May 1999:

"Dick Preston's letter was especially interesting to me because I've worked a number of the Lewis and Clark observations too, with good results. He's taken on a really tough problem, and clearly knows what he's doing.

"But he errs in supposing it was not generally known in 1803 that a lunar distance could be cleared with calculated altitudes. That approach was explained in the most widely used navigation manuals of the day. In Maskelyne's *Requisite Tables* the method of calculating altitudes, with examples, is given between pages 33 and 36 of the Explanation. In the 1791 edition of *The Practical Navigator*, by Moore, the method and examples are between pages 245 and 248, in the 1821 Bowditch (the earliest edition I have), between pages 164 and 166. In all cases the procedure for calculating altitudes is an integral part of the discussion of lunars."

— *Sincerely, Bruce Stark*

Member Richard S. Preston responded to member Bruce Stark's comments on June 10, 1999:

"I am very grateful for Bruce Stark's comments. I have done some quick research and find that he is quite correct in saying that in 1803 it was widely known that lunar distances could be cleared using calculated altitudes. Fortunately for me I still have time to correct my article for the *Proceedings of the American Philosophical Society* to reflect this fact.

"You may be interested to know how I came to the erroneous conclusion that the method of calculating altitudes was not well known at that time.

"I knew that Lewis and Clark took along a copy of P. Kelly's *Practical Introduction to Spherics and Nautical Astronomy*, and I was able to get photocopies of the relevant pages of this work from the Naval Observatory Library. I found no mention of the possibility of calculating the altitudes.

"I also knew that Lewis & Clark carried copies of the *Nautical Almanac* for several years. In photocopies of relevant pages from the edition of 1805 I saw that the reader was referred to Problem XI of Maskelyne's requisite tables. In the photocopy I received of that particular section of Maskelyne's work (1802 edition) only one sample calculation was given, and only observed altitudes were mentioned.

"I had seen a copy of the 1802 edition of Bowditch and had noticed that he mentioned calculation of the altitudes but then argued against the idea on grounds of the complexity of the calculations and his belief that calculated altitudes were subject to significant errors. I must now admit that I failed to read further to where I would have seen that Bowditch did give instructions for calculating the altitudes.

"It was my failure to find any discussion of calculated altitudes for lunar distances in Kelly, Maskelyne, or Bowditch that led me astray.

"Upon seeing Bruce Stark's note I took advantage of the fact that I was spending the summer in New England to visit two libraries where I could look at some actual navigation texts from that period instead of mere photocopies of selected pages from them. These were the libraries of the Seaport Museum in Mystic, CT and the Peabody-Essex Museum in Salem, MA.

"When I looked again at the 1802 Bowditch, I finally saw that he did describe the calculation of the altitudes, which I had not noticed previously. This was a serious misreading on my part.

"In the 1782 edition of Maskelyne's requisite tables (the latest edition I encountered) I found that in Problem XI of Maskelyne's tables requisite to which the *Nautical Almanac* referred the reader, the author gave several alternative procedures for clearing lunar distances, rather than just the one in my photocopy from the edition of 1802. Again, calculation of the altitudes was not mentioned in this section. But having the whole volume to look at I now found that in Problem VII, which is considerably earlier in the text, he did give instructions for calculating altitudes. He did not explicitly mention lunar distances or his Problem XI at this point, but he did make an additional comment that might suggest to a knowledgeable reader that calculated altitudes can be used for clearing lunar distances.

"In the course of my research on Lewis and Clark I have found custodians of rare books such as these to be very cooperative in providing photocopies of specific pages that I have requested by telephone. But clearly there is no substitute for the real thing.

"As Bruce Stark says, Moore's *New Practical Navigator*, in the 1798 edition edited by Bowditch (and the model for Bowditch's own *New American Practical Navigator*), also contains instructions for calculating the altitudes. Similar instructions were also contained in the 1796 edition of J. Robertson's *Elements of Navigation*. In the 1796 edition of Kelley's *Introduction to Spherics and Nautical Astronomy*, however, there is no mention of calculating the altitudes.

"In none of these works did I find any discussion of the accuracy required for the estimate of the longitude used in calculating the altitudes, except for Bowditch's skeptical comment mentioned above. In all of the worked problems given by any of these authors, the longitude used is the longitude by account and is given as degrees E or W with no minutes or seconds. This might be understood by the reader as an indication that the longitude need not be very exact, which is correct. But it might also be read as an indication that the calculated altitudes are not very reliable so there is no point in being too finicky about the longitude estimate. This would suggest that calculating the altitudes is a last resort, which is directly opposite to the statement by Robert Patterson (one of Lewis's navigation instructors) in his *Astronomical Notebook* that on land he actually prefers calculated altitudes to measured ones.

"I am still mystified as to why the Lewis and Clark longitudes were never calculated. The man appointed to make the calculations, Ferdinand Hassler, was considered an expert in astronomy, navigation and surveying. He was the first superintendent of the Coastal Survey, which became the Coast and Geodetic Survey, and certainly understood the method of lunars. He wrestled with some of the Lewis and Clark observations, complaining in one letter about missing information (the altitudes I think), and eventually gave up 'in despair'"

— *Sincerely, Dick Preston*

Member Dr. George G. Bennett of Sydney, Australia sent by e-mail on March 31, 1999:

"I read with interest the contribution of J. G. Hocking in the 1998 Fall issue on the problem of the inversion of the formula for meridional parts. I have not found a need for this in my work on navigational problems on the spheroid, although it could arise in other contexts.

"There is a direct parallel to the problem which arises in the calculation of rhumb lines on the spheroid where it may be required to invert the formula for meridian distances in order to calculate the latitude directly.

"The formula for meridian distances is:

$$m = \frac{a}{1852}\left(A_0ø - A_2\mathbf{sin}2ø + A_4\mathbf{sin}4ø - A_6\mathbf{sin}6ø \ldots\right)$$

where *a* is the semi-major axis of **the** spheroid, *m* is in international nautical miles,

$$A_0 = 1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256}\ldots\ldots$$

$$A_2 = \frac{3}{8}\left(e^2 + \frac{e^4}{4} + \frac{15e^6}{128}\ldots\ldots\ldots\right)$$

$$A_4 = \frac{15}{256}\left(e^4 + \frac{3e^6}{4}\ldots\ldots\ldots\right)$$

$$A_6 = \frac{35e^6}{3072}\ldots\ldots\ldots$$

and *e* is the eccentricity of the spheroid.

My solution of the problem is

$$ø = \frac{1852m}{aA_0} + \frac{A_2}{A_0}\mathbf{sin}2T + \frac{7A_4}{5A_0}\mathbf{sin}4T + \frac{11A_6}{5A_0}\mathbf{sin}6T\ldots\ldots\ldots$$

where *T* is the first term on the right hand side of the expression and is the solution for a spherical earth.

"One can also use an iterative procedure with an initial value of $ø = m/60$ in the above formula for *m*, For most marine applications three iterations are sufficient for the solution to converge.

"The problem does not arise if a solution is effected using tables. With a tabular solution one can interpolate the argument to find a unique value of the respondent and v.v.. For that reason I have compiled and published a set of tables entitled, *Tables for the Solution of Problems Associated with Rhumb Line Courses and Distance Using the World Geodetic System Spheroid* 1984.

"All of the above and more can be found in my article in the British Journal of Navigation entitled *Practical Rhumb Line Calculations on the Spheroid*, 1996 Vol. 49 No. 1 pp 112-119. I have approached the problem of the inversion of the formula for meridional parts in a similar way to that of meridian distance. My solution is as follows,

"The solution for meridional parts is

$$M = \frac{10800}{\pi}\left(\mathbf{ln\ tan}\left(\frac{\pi}{4} + \frac{ø}{2}\right) - \frac{1}{2}\,e\mathbf{ln}\left(\frac{1+e\mathbf{sin}ø}{1-e\mathbf{sin}ø}\right)\right)$$

When given a value for the meridional parts, *M*, solve for latitude from

$$ø = ø_0 + f\mathbf{sin}2ø_0 + 1/2f^2\mathbf{sin}4ø_0\ldots\ldots\ldots \qquad \text{(A)}$$

where $ø_0$ is calculated from $\mathbf{sin}ø_0 = 1 + \frac{2}{1+e_1^{2M\pi/10800}}$

f is the flattening of the spheroid and e_1 is the base of natural logarithms. This last expression being the solution for a spherical earth.

"A more precise formula may be derived empirically as follows,

$$ø = ø_0 + 0.1923\rho\mathbf{sin}2ø_0 + 0.0004\rho^2\mathbf{sin}4ø_0\ldots\ldots\ldots \qquad \text{(B)}$$

where $\rho = \frac{\pi}{180}$

"A further refinement of the solution can be made by using more terms and increasing the number of decimal places. The results of using formulas (A) and (B) over a range of latitudes is as follows,

At latitude	Formula (A)	Formula (B)
0°	0°	0°
10	9.999 891	0.000 009
20	19.999 808	20.000 012

30	29.999 767	30.000 006
40	39.999 771	39.999 993
50	49.999 808	49.999 977
60	59.999 861	59.999 966
70	69.999 914	69.999 965
80	79.999 961	79.999 978

Which in practical terms means that the maximum error using formula (A) is about 25 metres and using formula (B) is about 4 metres.

"Two minor points in the Newsletter in relation to the original contribution: (l) For readers who are not familiar with the subject there may be some confusion with the use of *e* which was used for the eccentricity of the spheroid and also the base of natural logarithms, and (2) it would be preferable to use the term 'geodetic latitude' rather than 'geodesic latitude' to accord with most geodetic publications."

— *George E. Bennett*

Director Allan E. Bayless wrote from Pompano Beach, Florida on June 4, 1999:

"I note in *The Navigator's Newsletter,* #63, Spring 1999, on page 4, which arrived today, Mr. Gruber's interest in the 'Aries disc dialer.' If this is, as I suppose, the 'USPS LHA _ Finder,' the last I heard (a couple of years ago) USPS had decreed the thing would no longer be produced, so Mr. Gruber may come up empty unless USPS still has a few in stock.

"As it happens, I designed the thing to be produced in plastic while I was the Chairman of the USPS Navigation Committee. It appeared in 1973. It was intended to replace an earlier and less elaborate version printed on a page of the N Course material which demanded the dials be cut out. The paper version wasn't too satisfactory and one scale was printed upside down. The plastic 'slide-rule' version will find LHA _ to about _1_. I have only one of these which I keep in the same case with my HO 2102D Star Finder.

"If Mr. Gruber is unsuccessful in getting one of these instruments, I'd be glad to send him a photocopy together with the explanation and description that accompanies the instrument. It is merely a 'quick and dirty' way of approximating LHA _ and there are certainly other entirely satisfactory methods of finding it."

— *Cordially, Allan*

NAVIGATION NOTES

A simplification of the Method of Lunars

By Richard S. Preston

As readers of *The Navigator's Newsletter* are aware, the method of lunar distances ("lunars") was a means of determining Greenwich time for longitude in the days when reliable chronometers were scarce and expensive. In recent years articles by John M. Luykz and Bruce Stark in the *Newsletter* have gone into considerable detail about the method of lunars. I would like to present an additional sidelight on the subject.

The basis of the method of lunars is that the angular separation of the moon from any other celestial body (the lunar distance of the body) has a predictable value at any instant. This value, however, changes continuously with time because the moon moves across the sky more slowly than the sun, planets or stars. Having measured the angular separation of the moon from some chosen body, it is possible, with information from the *Nautical Almanac,* to calculate what the Greenwich time was at the instant of the measurement. Thus a lunar-distance measurement served the same purpose as a modern radio time check, albeit with much lower accuracy.

Because of refraction and parallax, however, observers at different points on earth who measure the lunar distance to a particular body at the same instant will get slightly differing sextant readings of this angle. But if all these observers make the appropriate corrections for refraction and parallax, they should all agree on a single corrected value of the lunar distance and derive the same Greenwich time from it (assuming, of course, that they have all made accurate measurements).

In order to correct for refraction and parallax it is necessary to know the observed altitudes (corrected for index error and dip but *not* for refraction or parallax) of the moon and the other body at the instant of the lunar-distance measurement (Figure 1a). From the observed lunar distance and the two uncorrected altitudes, the difference in azimuth of the moon and the other body must first be calculated (Figure 1b). Then the altitudes of the moon and the other body are corrected for refraction and parallax. These corrected altitudes, along with the previously calculated difference in azimuth angle, are sufficient for calculating the corrected lunar distance (Figure 2). This is the angle needed for determining Greenwich time using the *Nautical Almanac.*

There are obvious problems with making the three required measurements simultaneously. In the earliest editions of the *New American Practical Navigator* (1802 and following), Nathaniel Bowditch recommended that when there was only one observer, altitude measurements could be made on both bodies immediately before and immediately after the lunar distance measurement, and the results averaged to find the values at the instant of the lunar distance measurement. In later editions he alluded to the possibility of determining the altitudes by calculation instead of by actual measurement, but he advised against using such a procedure and did not even describe it. As late as 1822, P. Kelly, in *A Practical Introduction to Spherics and Nautical Astronomy* (Fifth Edition), made no reference to such a possibility. Charles Cotter, author of the comprehensive *History of Nautical Astronomy* (1968) apparently never encountered any literature on the subject of calculating the altitudes, for he does not mention such a possibility in his book.

But the fact is that it is *not* necessary to measure the altitudes. (This was pointed out to me by Robert Bergantino of Butte, MT.) The observer can actually calculate the altitudes quite accurately if he knows his latitude and has only approximate values of the Greenwich time and his longitude. Ignorance of this fact was responsible for an inexcusable failure by the U.S. government to use any of the astronomical observations made by Lewis and Clark during their famous expedition. The purpose of these observations was to obtain a sequence of geographical positions which could be used, after their return, to correct the maps that were made from their dead-reckoning notes. The corrections were never made because the longitudes were never calculated.

When Lewis and Clark made lunar-distance measurements they never measured either of the required altitudes because *they* knew they could be calculated. But the expert who was supposed to make the necessary longitude calculations after their return gave up "in despair" because, apparently, he did not know that this was possible. This was despite the fact that both of Lewis's instructors in navigation, Robert Patterson and Andrew Ellicott, knew how to calculate the altitudes, and preferred this calculation to actual measurement. Furthermore, Philip Turnor and David Thompson, who explored western Canada before, during and after the Lewis and Clark expedition, routinely calculated the necessary altitudes instead of measuring them. The only measurements for longitude that Lewis and Clark made were (1) morning and afternoon equal-altitudes measurements on the sun to determine the time by watch of noon; (2) the meridian altitude of the sun to determine the latitude (which was needed in the longitude calculation); and (3) lunar-distance measurements with no accompanying altitude measurements. I describe all of this in some detail in a forthcoming article in the *Proceedings of the American Philosophical Society.* Turnor and Thompson used a somewhat different approach but likewise made no altitude measurements along with their lunar-distance measurements. I would now like to show how, despite the seeming absurdity of the idea, it is possible that, even without actual measurements, the required altitudes can be calculated by a navigator who has only approximate ideas of the Greenwich time and his longitude.

To get an idea of the method one may picture an observer at a certain latitude who measures the altitude of a star exactly seven hours after his local noon. A second observer one hour (15_) west of the first observer but at the same latitude will see the same star at almost exactly the same altitude one hour after the first observer does. This will be the same length of time, seven hours, after his own local noon. A third observer at the same latitude but three hours (45_) west of the first will see the same star at nearly the same altitude three hours after the first observer does, which will again be seven hours after his own local noon. The conclusion from this is that at a given latitude the observed altitude of a given star depends more on the elapsed time since noon than on the observer's longitude. Thus when it comes to calculating an altitude, the important quantity is the elapsed time since local noon. Knowledge of this elapsed time and of the latitude, along with a rough guess as to the longitude, permits a highly accurate calculation of the altitude.

But in 1803 the navigator (on land, at least), using the method of Patterson and Ellicott, knew this elapsed time because he had used the well-known equal-altitudes method to determine what his watch was reading at the instant of noon, and he had also recorded the reading of his watch at the instant of his lunar-distance measurement. He also knew his latitude from his noon altitude measurement, which did not require accurate knowledge of the longitude. Of course he had to correct the elapsed time for the rate of his watch. If he remained at the same location for several days he determined the rate by comparing the noon-to-noon time by watch with the noon-to-noon time from the *Nautical Almanac.*

Using his known latitude, the elapsed time since noon and an estimated longitude, the navigator could calculate highly accurate estimates of the required altitudes at the instant of the lunar-distance measurement. An altitude calculated this way is best for a star or planet, intermediate for the sun, and least reliable for the moon. But if the longitude estimate is fairly close, all such calculated altitudes are quite accurate.

These ideas may be made clearer by an examination of the law of cosines for spherical trigonometry, which is used in the following form, to calculate each of the required altitudes:

$$\sin(Alt)=\sin(Dec)\sin(Lat)+\cos(Dec)\cos(Lat)\cos(LHA)$$

where

Alt=altitude of the body,

Dec=declination of the body,

LHA=local hour angle of the body=observer's longitude+GHA of the body.

Lat=observer's latitude

Thus, in order to calculate a missing altitude one must know the latitude, the declination of the body, and its local hour angle. The navigator already knows his latitude from his noon altitude of the sun. I will now show that choosing a value of the longitude fixes the values of the declination and the LHA.

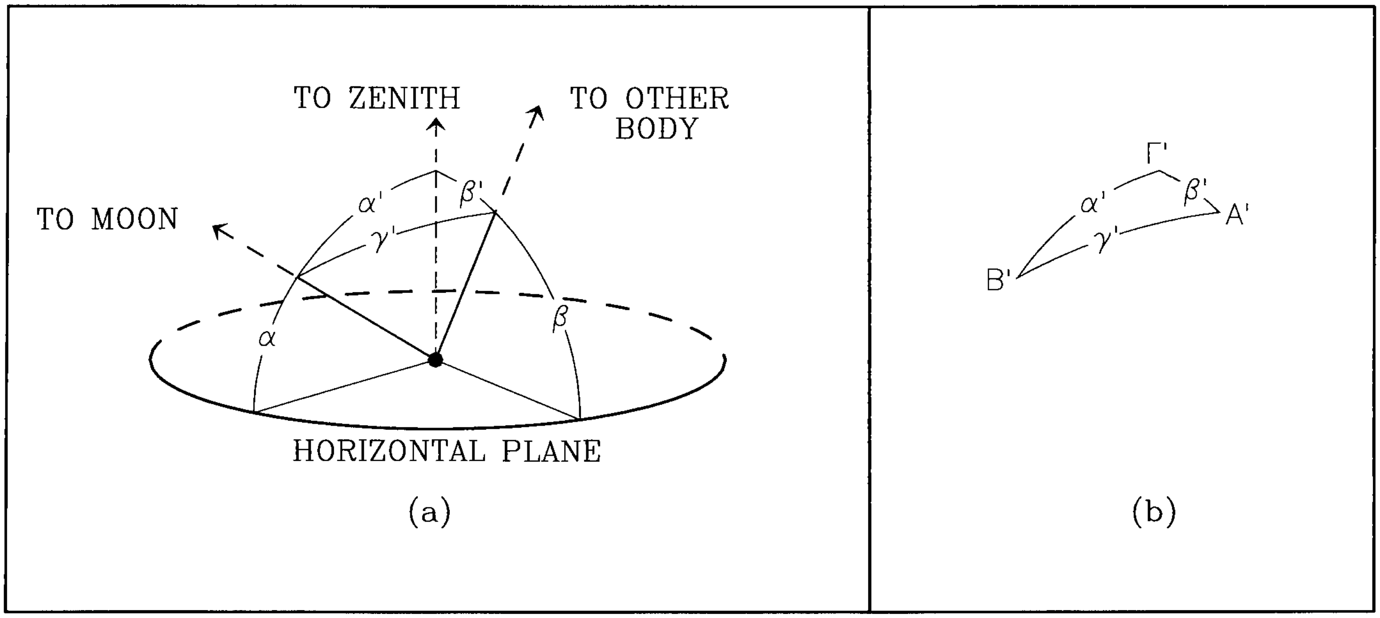


Figure 1 (a): The sextant is used to measure the angle α, which is the altitude of the moon; the angle ß, which is the altitude of the other body; and the angle γ′, which is the angle between the moon and the other body (the uncorrected lunar distance). The zenith angle α′ is 90°-α, and the zenith angle ß′ is 90°-ß.
(b): The arc α′, ß′ and γ′ form a spherical triangle, and their values can be used with the law of cosines for spherical triangles to find the angle Γ′ which is easily seen to be the difference in the azimuths of the moon and the other body.

(1) Declination of the body: This can be obtained from the *Nautical Almanac* when the Greenwich time is given. But, in effect, the Greenwich time to be used is known when the longitude and the elapsed time from noon are known. And because the elapsed time from noon is known from watch readings, the Greenwich time to be used depends only on the longitude. Thus the declination to be used in the formula is fixed when the value of the longitude is chosen.

(2) The LHA: This depends on the choice of longitude and on the choice of the GHA of the body. But the GHA depends on the Greenwich time and, as I have just shown, the Greenwich time itself depends only on the choice of longitude. Thus, the LHA, too, depends only on the choice of longitude.

Next I will show that it is all right simply to *estimate* the longitude because neither the declination nor the LHA depends strongly on the actual value of the estimate.

(1) The declination of the body: The declination of a star is essentially constant. The declination of the sun varies by a few minutes of arc over several hours, and the declination of the moon varies somewhat faster. But since an uncertainty in longitude of a few degrees results in an uncertainty in Greenwich time of less than an hour, the declination of the sun or the moon, as taken from the *Nautical Almanac* for use in the equation, will be only very slightly in error, and that of a star or a plane hardly in error at all.

(2) The LHA: Although the local hour angle needed in the equation depends only on the choice of longitude, this dependency is weak. For example, suppose that the estimated longitude is decreased (moved westward) by 1_. This increases the estimated Greenwich time both at noon and at the instant of the lunar distance measurement by four minutes. But the GHA of the body, which is obtained from the *Almanac*, increases by approximately 1_ in four minutes of time. Thus the *decrease* in longitude is very nearly equal to the *increase* in GHA, so that the local hour angle, which is the sum of the longitude and the GHA, is hardly changed by a change in the estimated longitude.

Thus the navigator can use a reasonable estimate of his longitude (probably his dead-reckoning value) and calculate very good estimates of the altitudes of the moon and the other body at the instant of the lunar-distance measurement.

To complete the calculation the navigator must remember that these calculated altitudes must be interpreted as values after correction for refraction and parallax, and that to determine the difference in azimuth angles (Figure 1), it is the *uncorrected* ("measured") altitudes that are needed. Thus the calculated altitudes must be "de-corrected" by tacking on refraction and parallax, which is the reverse of the more familiar operation of correcting altitudes by removing refraction and parallax from the measured values. From this point the calculation continues in the standard manner (Figures 1 and 2) as prescribed in standard works on navigation in the early 19th century.

When the navigator has determined the Greenwich time of his lunar distance measurement by this procedure, he uses it with the elapsed time between noon and this measurement to find the Greenwich time at noon.

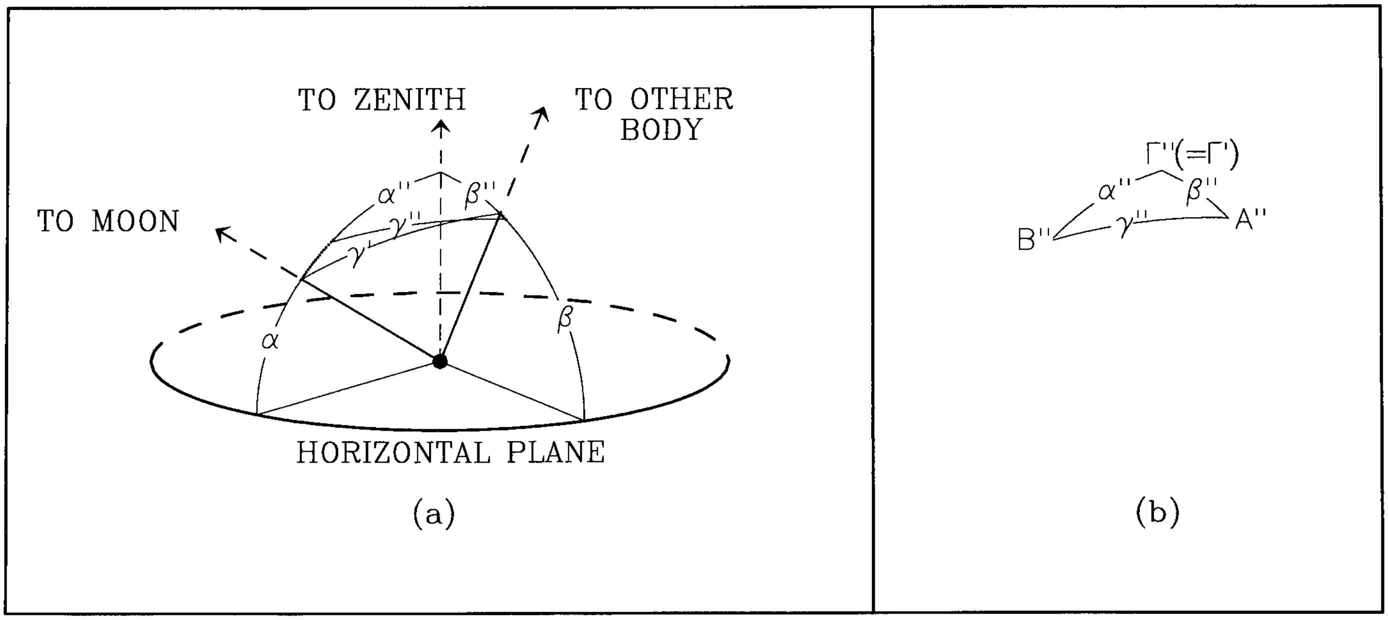


Figure 2 (a): Corrections for refraction and parallax of the moon have adjusted its altitude upward somewhat, thereby changing its zenith angle to a somewhat smaller value, α". For the other body the altitude has been adjusted downward slightly to correct for refraction, thereby increasing its zenith angle slightly to ß". The arc γ" is the corrected lunar distance.
(b): The arcs α", ß", and γ" form a spherical triangle. Since α", ß", and the angle T" are known, the corrected lunar distance γ" can be calculated using the law of cosines for spherical triangles. To determine the Greenwich time of the measurement this lunar distance is then compared with values obtained using data from the Nautical Almanac.

This, of course, he translates quite readily into his longitude. If he is doubtful of the result he can consider this longitude to be a new estimate and repeat the whole calculation. If there is little or no change he can be confident of his result. If the change is significant, he can make a third round of calculations, and so on, in a cycle of successive approximations.

Using actual Lewis and Clark observations and the appropriate editions of the *Nautical Almanac*, I find that for a first estimate of longitude deliberately chosen to be 4_ off (a large error in the dead reckoning) the calculated values of longitude converge quite satisfactorily in three iterations of this procedure. However, the calculated longitude is already within a few minutes of the final value of the longitude at the end of the initial calculation. Considering the much larger uncertainty in the final value of the longitude due to the difficulty of making accurate lunar distance measurements, and the drudgery involved in making the calculations, a longitude error of a few minutes was probably tolerable at the time of Lewis and Clark. Thus, the result of a single iteration would almost always be acceptable. In the usual case the navigator would have a much better initial estimate of his longitude than I used, so no further iterations would even be contemplated.

Lewis and Clark were instructed by President Jefferson not to attempt longitude calculations during their trip because they would not be able to spare the several hours of time needed for working out each longitude. Determinations of latitude from their noon altitude measurements were simple and they routinely did the calculations themselves. The recommendations by Lewis's instructors that they not measure the required altitudes along with their lunar distance measurements was probably intended to save them additional time. This made the measurements simpler and less time consuming, but made the necessary calculations more onerous — to the point where the calculations never got done.

One of Lewis's navigation instructors (Andrew Ellicott) even knew how to find his longitude not only without measuring the required altitudes at the instant of the lunar distance measurement, but also without even measuring the noon altitude of the sun for latitude. He could determine both latitude and longitude from just the two equal-altitudes measurements (morning and afternoon) and the measured lunar distance. This anticipated the later realization that, in principle, a fix requires just two measured altitudes and the Greenwich times of their measurement. But Ellicott was using this method more than thirty years before lines of position were discovered so his calculations must have been extremely time consuming.

Mathematical note:

Figures 1 and 2 represent an outline of the method of determining the corrected lunar distance. They also suggest that the observed lunar distance need not be thought of as an approximation to the correct lunar distance. From a trigonometric point of view it is simply a quantity from which, with the two altitudes, the difference in azimuths of the two bodies can be calculated preliminary to calculating the true lunar distance. There are other instruments that could be used (on terra firma, at least) to measure the difference in azimuths. Measuring the apparent lunar distance with the sextant is simply a clever way to avoid carrying a second instrument, such as a theodolite, to measure the difference in azimuths directly.

Louis M. Sebert of Ottawa, Canada, who read this note in an early form, was prompted to look up moon observations in the Royal Engineers manual *Field Astronomy* published in 1920. He says: "Lunars are dismissed at once with the statement that they can't be read with a theodolite."

To the contrary, both the required altitudes and the difference in azimuth *can* be read with a theodolite, but perhaps not with sufficient accuracy.

The Complete On-Board Celestial Navigator

By George G. Bennett
An International Marine/McGraw Hill Book
Camden, Maine
ISBN 0-07-007110-1. 176 pages $27.95.
www.internationalmarine.com

A navigator who puts to sea these days without some means of fixing position electronically, in my view, would be most imprudent - some might say foolhardy. The safety and lives of the crew are at stake and must be of prime consideration. There can be no reasonable argument for not providing some such facility. The cost of purchasing GPS (Global Positioning System) equipment, expressed as a fraction of the value of even a small ocean-going sailing boat plus its maintenance and running cost, is minute. However, the navigator who relies solely on GPS for position fixing is just as imprudent as the navigator who disdains any 'new-fangled paraphernalia'. The advantages of an all-weather positioning system should be self-evident, but as with all navigation systems a healthy skepticism of the reliability of such devices and the data they provide is essential. It brings to mind a report which stated that the skipper of a high-speed catamaran ferry was relying entirely on GPS to guide him into port in bad weather and ended up running the vessel into a sea wall. To rely totally on GPS positions surely is the height of folly. Plotting one's course and taking heed of other navigational information as well is paramount in the practice of a responsible navigator. An understanding of accuracy standards, particularly the deliberate downgrading of satellite position and/or clock data, and the uncertainties in charted information, particularly when dealing with old and new datums, is most important.

When position fixing out of sight of land from some external source, e.g. hyperbolic or satellite system, is not available to the navigator, then, apart from bearings obtained from shore-based radio stations, which are often sparsely located, signs from the weather and condition of the sea e.g. its color, temperature, movement etc., all that remains are observations to those celestial objects which can be seen when the horizon is also visible during the day, and at morning and evening twilight. There are, of course, exceptions such as sextant observations of lunar distances, but these are rarely if ever, used. The norm will be, weather permitting, observations of the Sun, Moon, bright stars and the four brightest planets. Then equipped with a sextant, watch, radio, almanac, and the means for reducing and plotting those observations, the position of the vessel may be determined.

To undertake celestial navigation will normally require the purchase of a text book, an almanac for the current year, a set of tables for reducing sights and, although not essential but useful, some means of predicting and/or identifying celestial bodies. The second item will normally need to be replaced annually. To this writer's knowledge no one has produced, under one cover, the above requirements. Now we have a publication that covers a period of five years containing all the essential elements required for celestial navigation in about 160 pages. The scope of the work encompasses an explanation of the care and adjustment of equipment and details of practical methods for predicting, observing and reducing observations for fixing position and determining azimuth (true bearing) in particular.

(1) Text books vary in quality, length and price, and to overcome the limitations of time, usually include extracts from old almanacs for illustrative examples. This latter problem is avoided here because all the examples use the current data from the almanac section. The explanations in the text book section of this work embrace the standard and accepted methods of position fixing and compass checking, using celestial observations. Some novel treatments of e.g. multiple sextant observations, noon sun-sights, etc. are included in this work.

(2) The book provides the astronomical coordinates of the Sun, Moon, four navigational planets and 58 stars. This has been achieved by giving all data to the nearest minute of arc (1') and at less frequent intervals than conventional almanacs. Some old salts might throw up their hands in horror at this loss of accuracy, but no data item will be in error by more than about 0.5' and, on average, about 0.25'. This choice of accuracy is in keeping with the requirements of what is essentially a back-up system.

(3) Tables are given for interpolating the above coordinates and for correcting sextant observations. For the latter, the corrections are given in the form of critical tables. These tables require no interpolation and limit the errors to a maximum of half a unit in the quantity extracted.

(4) If a calculator/computer is not available, tables and graphs for sight reduction by the intercept method are provided. Those

who have made a study of this topic may be interested in what follows, otherwise proceed to (5). The history of the last two centuries of the development of aids for reducing celestial observations made to determine position has been chronicled in Bowditch. Although there is no claim to completeness in that account, the highlights in the development of a variety of methods has been set out to give the reader a good understanding of how so many of the best minds have been directed to this important navigational problem. The interest in devising a simple practical solution when only basic calculating devices (mainly mechanical and tabular) were available has receded with the establishment of hyperbolic and, later, satellite navigational systems and the calculator/computer. We look on many of these methods in Bowditch as historical curios, as indeed they are. However, we shall still need to provide some means of sight reduction which is independent of electronic or outside agencies.

Before you jump to the conclusion that what is about to follow is another 'new' set of sight reduction tables, you may be surprised that the basis of the calculation of altitude for the intercept method given here, is by the tried and proven cosine-haversine formula. In 1979 P. F. Pfab of the Honorable Cross-Staff Society of Sweden published his so-called PET Tables (reviewed in the U.S. and British Journals of Navigation) which were based on the cosine-haversine formula but only after a detailed investigation of tabular methods had been made. His analysis took into account such things as accuracy, rules, book openings, DR versus assumed position, etc. The PET Tables have been modified and adopted here. They are extremely simple to use. There is only one rule to understand and that is for forming the algebraic difference between latitude and declination, L ~ D. There are no decimal places and no interpolation is required of the reduced accuracy, referred to before, is acceptable. Headings in the tables correspond directly to the variables latitude, LHA, declination etc. Because the DR position is used in the solution, intercepts are usually short and convenient to plot. The tables have been investigated using a computer program that simulates a human operator selecting, combining and extracting values from the tables. 11,387 tests were made and analyzed over the following ranges of the principle parameters.

Latitude	0° to N80°	LHA	0° to 180°
Declination	N90° to S90°	Altitude	0° to 80°

Input parameters were given to 0.1'. The differences, called errors, between the altitudes calculated accurately and those derived from the computer solution were compiled using two techniques, one with the operator interpolating the tables to 0.1' and the other without interpolation. The results of that investigation are as follows,

Using Interpolation

Altitude Difference (min.)	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2*
Percentage of Errors	79.0	16.5	3.4	0.9	0.1	0.02

No Interpolation

Altitude Difference (min.)	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5*
Percentage of errors	62.4	31.5	5.6	0.5	0.01

**Maximum error*

It can be deduced from these tests that there are no geometrical quirks in the solution when, for some methods, certain combinations of data require special treatment. If the tables are not interpolated, then about 94% of reductions have errors not exceeding 1' and if interpolated about 95% have errors not exceeding 0.4'. These accuracies are quite acceptable. Azimuth calculation must be considered of secondary importance to that of the altitude calculation because it will only be necessary to determine azimuth to a low accuracy for plotting purposes. In practice, errors of a degree or so should be quite adequate, particularly as intercepts are short when the DR, rather than a chosen position, is used. A graphical and a tabular method of solution are given. The former solution is based on the Weir Azimuth Diagram. The original diagram as used by the British Navy (Admiralty Chart No. 5000) has been re-drawn, divided and duplicated to provide a solution that does not require colors and double scales requirements which were necessary in the original diagram to distinguish between celestial and terrestrial hemispheres - a fruitful source of mistake. The second method of solution is the tabular equivalent of the Rust diagram, which was a graphical solution based on the sine formula. No interpolation is required and the four pages of tables can also be used to find amplitudes.

(5) Although not essential, some form of prediction and identification device e.g. A Rude Star Identifier No. 2102-D or Star Finder and Identifier No. NP 323 will be found to be of considerable value in the planning of observations and for identifying unknown or mistaken bodies. Such devices are rendered unnecessary by the inclusion in the book of tables which list (names and magnitudes) the altitudes and azimuths of 58 stars for every 10° of the LHA of Aries at intervals of 10° of latitude, between N60° and S60°. For the Sun, Moon and planets, a separate tabulation for the same range of latitude at every 10° of the LHA of the body for declination at 5° intervals is given. The complete tables occupy only 26 pages.

(6) The times of sunrise and sunset, and morning and evening civil twilight, are given in graphical form on two pages. These will be invaluable for predicting times to observe azimuth by the method of amplitudes and to take conventional morning to evening star sights etc. at twilight.

CONCLUSION

The Complete On-Board Celestial navigator is a practical, convenient and economical solution for the mariner who wants a back-up system to GPS that contains all the essential instruction and data for making and reducing astronomical observations. For navigators who have been used to the Nautical Almanac, the transition to this form of data presentation will require a small adjustment in their technique of interpolating the data. Although the accuracy of the almanac data has been reduced, these errors should be quite acceptable for the circumstances envisaged. Under one cover, in the compass of about 180 pages, one can find, in addition to the five years of almanac data, a description of standard celestial methods of prediction, observation and reduction. Star charts of the northern and southern skies showing constellation outlines and names of the bright stars are included to assist in finding and identifying celestial bodies. Worked examples are provided which illustrate the use of the almanac and associated tables. The book lies open flat (spiral binding), the covers are coated to be weather resistant and the inside pages are on a hardy uncoated paper.

DO YOU KNOW...?

THE DEVELOPMENT OF SIGHT REDUCTION TABLES FOR AIR NAVIGATION

By Ernest Brown

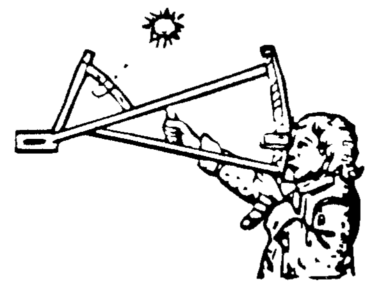
(Continued from Issue Sixty-Three, Spring 1999)

The late D. H. Sadler, a former director of Her Majesty's Nautical Almanac Office, Royal Greenwich Observatory, published a review of the preliminary edition (1947) of H.O. Pub. No. 249, then titled *Star Tables for Air Navigation*. The following brief quote from this review (Volume 1, No. 1, January 1948 the British *Journal of the Institute of Navigation* reveals certain attitudes in the late 1930s and early 1940s which worked against the development of the optimum sight reduction table: "It seems inconceivable that no star tables using sidereal time as argument, and with the stars arranged in order of azimuth, should have been published prior to the last war, but no such tables are known. The idea of sidereal time (or LHA Aries) as the main argument for the stars was, of course, considered in 1937 when the *Astronomical Navigation Tables* were designed; but it was only considered in relation to the tabulation for a single star and, in such case, the disadvantage of twice the amount of tabulation outweighs the other advantages. Oddly enough, the arrangement of several stars on the same page, in order of Azimuth, was used in the Japanese Celestial Air Navigation Tables, volume three of which was published in August 1940; but here the argument used is local hour angle and there would seem to be little, if any, advantage to be gained by the arrangement."

But soon after George G. Hoehne, a Pan American Airways navigation instructor, first inspected H.O. 218 in 1941, he became the first person on record to see the synergism of the combination of multiple star entries on the same page for successive arguments of local hour angle Aries. Part of the synergism was the compatibility of this tabular format with the bubble sextant averaging time during observations. (To be continued).

Editor's note: The quote above is used with permission of the Royal Institute of Navigation, London ©1948.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-FIVE, FALL 1999

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

The Foundation continues to get many e-mails from all over the world asking about various forms of navigation, equipment and for information about us. Each e-mail is answered and when a long explanation is required a page from "Bowditch" is added as an attachment. This procedure has resulted in a number of "Questioners" to join. We are getting many members from outside the country. I hope the trend continues since it adds members. To date the new members have equaled the numbers who have dropped or for other reasons are no longer members. Our numbers are still low but continue to be large enough for us to pay the bills. If any member knows of someone who may be interested in The Navigation Foundation let us know, and we will send them an information packet.

Our web page, http://pw2.netcom.com/~navigate/celestial/nav.html continues to get hits. Before the counter was reset we had almost 8,000 hits since the spring of 1998, when the page was designed. We also have a web page at http://www.olyc.com. At this address we are one of several boating and sailing pages. Give them a look. We get many favorable comments about the design.

> DO YOU KNOW . . .?
> When the first time ball was dropped?
> *(See final page of this issue)*

When you are looking for books, charts and publications on navigation think about The Foundation. We can get many of the books, that are in print, for which you are searching. You also get them at your members discount. Sometimes, if the publication is inexpensive, the member cost is the same as the list price, once the postage is added. Even then it is worth the time to order it from your Foundation.

For anyone trying to contact Dr. David Burch at The Starpath School of Navigation in Seattle, Washington, the address has changed. The new postal mailing address is: Starpath,

6300 - 32nd Avenue NW., Seattle, WA 98107. The 800 order line is 800-955-8328, the internet address is: www.starpath.com.

READERS FORUM

Edited by Ernest Brown

Member Richard S. Preston wrote from South Bristol, Maine, on August 29, 1999:

"I am pleased that my note on lunar distances has appeared. I was somewhat disappointed, however, that there were some typos in my lead-in to the argument for the reliability of calculated altitudes. The actual mathematical argument may be a little tricky to follow, and I had hoped that the lead-in would serve as a plausible, if not rigorous, introduction. The problem is that both of my degree symbols [°] in this part of the paper turned into underscores [_]. Experienced readers can figure out what went wrong, but others may have trouble.

"Would it not be advisable to let authors review proofs of their notes and articles before the final printing?

"Has the Newsletter ever printed anything on the rhyming mnemonics once used for calculating geographic position from astronomical observations? I have a friend who heard one or two of these 'poems' as a boy, but knew nothing about navigation and did not memorize them.

"There are, of course, rhymes for rules of the road. I was puzzled at first by seeing first an old, and later a new, version of one of them.

Old:

When red and green you see ahead,
Port your helm and show your red.

New:

When red and green you see ahead,
Starboard turn and show your red.

"I had to do some reading to find out why 'port your helm' means exactly the same thing as 'starboard turn."

— *Regards, Dick Preston*

Member W. D. Charlwood wrote from Surbiton, Surrey, Great Britain on 30th June 1999:

". . . As an aside, would you ask one of your experts to publish a comprehensive article in the Newsletter with regard to the cleaning, refurbishing and care of the sextant?

"It would be nice if it also included details of the various fluids and oils required, and from whom they are obtainable.

"There is virtually nobody servicing and/or repairing these instruments in Great Britain any more, and even getting mirrors re-silvered is difficult."

—*Best wishes, W. D. Charlwood*

Member Edward I. Matthews sent by e-mail on 26 July 1999:

"Colin Maclean's letter in issue 63 reminded me of Harold Gatty's *The Raft Book,* a survival manual for inexperienced navigators, published in 1943 during World War II. This book describes methods of finding one's position at sea by various celestial and Polynesian methods without relying on navigation instruments other than a watch set to GMT. The book includes a

20"x40" Base Chart Mercator projection of the world from 70° to 50° S with a star chart including 4th magnitude bodies superimposed in red. The reverse side contains the same bodies on a black background as they would appear to an observer. The time that a star on the same latitude(=declination) as the desired destination will be overhead can be easily determined by the date time tape supplied . The star then would act as a beacon at that time ala the biblical Star of Bethlehem for a Great Circle course to that destination from thousands of miles away!

"Gatty also describes the construction of the HARP, a device for measuring altitude, using a scale provided on the Base Chart. This device was tested at the Army Air Force Equipment Laboratory at Wright Field and the accuracy obtained approached 10' of arc.

"Other methods include the duration of the day, sunrise, sunset, and the height of the sun at noon. Tables listing these values in increments of 5 days and 2 deg of latitude are included. The migrating habits of birds and fish can also provide an indication of the proximity of land.

"During WWII I was the navy supercargo on a merchant vessel and enjoyed the complete blackout condition when on a moonless night the sky was ablaze with stars. Many opportunities to try the overhead star method of determining our position was presented."

— *Best regards, Ed Matthews.*

Member Bruce Stark sent by e-mail on 27 August 1999:

"I'd like to expand on a question Richard Preston raises in the Navigation Notes article he wrote for issue sixty-four of the Newsletter. On page nine, in the middle paragraph in the second column, he mentions that Lewis's navigation instructor, Andrew Ellicott, knew how to get a fix from two altitudes of the sun. This is worthy of note because modern navigators tend to think there was no practical way to work such an observation before Sumner discovered the line of position.

"But long before Sumner was born, any competent navigator could get latitude from two altitudes of the sun. He could get his local time too, in case he'd missed his morning time sight. Generally speaking, equal altitudes were not used for this. In fact the navigator didn't care, when he measured the altitudes, which side of the meridian they were on. Opposite sides or both on one side, the method worked the same.

"After explaining how to get altitude from meridian altitudes, the old navigation manuals showed how to get latitude from altitudes taken at other times. I expect the observation Andrew Ellicott used most often for this purpose would have been a 'Double Altitude.'

"The name 'Double Altitude' is confusing, since 'double' implies 'equal.' The "Equal Altitudes' procedure was different, and had a different purpose.

"The most common double altitude method during the period Mr. Preston is researching was the one published by Cornelius Douwes of Amsterdam. It dates from 1740. Later on Maskelyne, Bowditch, and others worked to extend Douwes' tables so as to cover all hour angles and cut down on interpolation.

"Years ago I played around with Douwes' method, altering it slightly so I could use the tables from a WWII era Bowditch and not wear out the old book with its tables of Half Elapsed Time, Middle Time, and Log Rising. I'm inclined to suspect that if any two altitudes of the sun will give a good latitude and/or local hour angle using lines of position, they'll give a good latitude and/or local hour angle using Douwes' method.

"While double altitudes are laborious, they are less so than the original Sumner approach, which calls for working four time sights and plotting the results. Also, in spite of what some writers have assumed, there is no need to adjust elapsed time for the ship's change of longitude. 'Elapsed' means just that. But you do adjust one altitude for the run of the ship.

"A weakness in Douwes' method is that dead reckoning latitude goes into the calculation. To get an accurate result when there's a big discrepancy between D.R. latitude and the latitude found, part of the calculation has to be repeated, using the latitude found. Also, there was a complicated set of rules governing the observation. But the set of rules eventually gave way to an understanding that azimuth is what matters - getting a good cut, as we would say today."

—*Sincerely, Bruce Stark*

Member David F. Burch, Ph.D, Director Starpath School of Navigation, sent by e-mail on 10 August 1999:

"Congratulations on a great issue 64, and thanks much for the plug for our courses.

"Could you please send a copy of issue 64 to:

Dr. Luis Soltero

900 Broad Avenue South, #23

Naples, FL 14102

"He is an experienced sailor (7 years cruising) and developer of innovative celestial nav materials and I am sure will sign up with the nav foundation when he sees this excellent issue.

"I would send him mine, but can't give it up."

— *Thanks much, David*

Member E. B. Forsyth wrote this Newsletter #2 from Cape Town, South Africa in February, 1999:

"Dear Friends, Without a doubt the past three months have provided some of the finest cruising I have ever known. I hope this newsletter will do justice to the experience. Since we left Puerto Montt we have sailed in areas of awesome grandeur and yet, because of the cold climate, sparsely populated. High winds have been fairly common, in the Chilean 'canals'. Securing the boat for the night was often difficult. I am lucky that my crew, Mike and Bruce, are young and enthusiastic and accepted some hardship as part of the fun. In many ways the sense of accomplishment felt on reaching some of the remoter anchorages was augmented by the struggle to get there. We left Puerto Montt with the intention of taking a month to negotiate the labyrinth of islands and narrow channels that form southern Chile's west coast. On our left we had the magnificent snow-covered Andes towering above us. At first, in the vicinity of Chiloé, the countryside was pastoral with farms and small fishing villages. Within a week this changed, even to the west the islands were steep and forbidding. There was almost no habitation. In fact, we found only two isolated small communities after we left Chiloé. Perhaps you can get a feel for the people and places if I tell you about one of them, Puerto Eden. This was obviously named in the same spirit that led Eric the Red to call Greenland-Greenland. It is hardly a Garden of Eden. A community of about three hundred souls live clustered on the side of a steep hill around a small bay. There are no vehicles, there is nowhere else to drive to. A mile or so of boardwalk connects the houses at either end of the village. There are two or three tiny shops. When we dropped anchor opposite the small school it was late afternoon. We rowed ashore, it was rocky and covered with weeds. Some men were repairing a small wooden boat, beached at low tide. With our poor Spanish we asked them if there was a restaurant - they were baffled. Later, when we discovered how poor the village was, we realized the question was ridiculous. Nevertheless somehow we were directed to a small house a few yards away, nothing more than a two-roomed hut really, where a sprightly rather plump middle-aged woman agreed to make us dinner. We sat in the kitchen cum dining-room, a large wood-fired stove kept the place cosy. The planks forming the outside wall were ill-fitting and I could see daylight through the cracks. Cloth tacked over the gaps kept out the draught. Through a curtained doorway I could see into the other room, a sort of living-room, bedroom combination. Despite the basic nature of the house they had a TV, VCR and hifi system. She fed us a good meal of salad (onions and tomatoes), potato and fish and an odd sweet, followed by coffee. We also had a glass of wine. Not bad for $6 each. We arranged with her to buy four loaves of bread in the morning, which she would bake. The first things we had to do in the morning, however, was replenish our fuel. Puerto Eden was our last chance to get diesel before we arrived in Puerto Williams, near Cape Horn. The fuel was kept in drums near a small, run-down jetty. We had to pump it by hand into our jerry jugs. After that we tried to buy fresh vegetables or fruit, but the small shops were shut. When I went to pick up the bread another lady was there with a large purple bag. In it was a selection of new clothes she was peddling. I looked at them in a perfunctory way but I wasn't buying - I had spent all my pesos on diesel fuel. At this she mad a moue' and in voluble Spanish wanted to know how an honest woman could make a living if rich gringos didn't buy her stuff. Guilt-stricken, I offered to pay in US dollars. She rushed off for a consultation with someone in the village about the worth of a dollar. On her return I bought a plaid shirt. Good value, too. After that we all took a walk along the shore and returned to the boat to await the Port Captain, who had promised to bring over the papers authorizing us to proceed to Puerto Williams. It was happy hour when he showed up - he really enjoyed our rum. He wanted to know if he could help us further in any way, so I asked him to get us a few onions and some fruit. As incentive I gave him a bottle of Mount Gay rum from our cache. He returned a couple of hours later with a large plastic bag that heaved and bulged in a funny way - what on earth was inside? The answer was four king crabs, all alive-o, that's what. The seaman he brought with him rapidly dispatched two to crab heaven by ripping their bodies apart. I shuddered and we cooked the legs in our largest pan.

"I shall always remember the first big glacier we sailed to - the Pio XI glacier, about three miles wide. A river of ice snaking down between two mountains whose snowy tops were lost in clouds. As we got close, we had to pick our way through a myriad of floating ice pieces that had broken off the glacier. We put our bowsprit up against one medium-sized berg and chipped some antique ice for our happy hour drinks. As we got further south the days lengthened and got colder. I was amazed at how old the towering rocks on either side looked. They were grey and scarred but smooth, as though they had spent a million years being ground down by ice. Hardy vegetation clung to the lower slopes and in crevasses. The trunks of the small trees were bowed horizontal to stay out of the wind. Our anchorage each night was usually a small, deserted, cove in which we could tuck ourselves out of the wind. Usually, pristine streams emptied onto the sea. Bruce often went fly fishing and once caught several trout. In one narrow pass we were caught by a williwaw, a strong gusty wind, that knocked us over and put the whisker pole in the water, but *Fiona* is a tough old lady and no damage resulted. As we traversed the western reaches of the Magellan Strait the weather was, quite frankly, terrible. Frequent rain, hail and sleet with strong winds and temperatures in the 30's. We wore heavy clothing and our foul weather gear all the time on deck. In the narrow channels we usually hand steered as we could not trust the self-steerer in the gusty winds. The guy at the wheel got frequent infusions of hot drinks and soup passed up from the cabin, where the heater ran most of the time. We had an interesting, if not unique, experience in the Cockburn channel, which runs southwest from the Magellan to the south side of Tierra del Fuego. Afer a rough day, which began very early when we were literally blown out of our anchorage by 45 knot winds (the anchor dragged, so rather than reset it, we just left), we finished with a hard beat against wind and current up to a large bay called Niemann harbor. Once inside the bay, conditions were much more moderate and we searched for a suitable spot to spend the night. To our amazement we found the best little sheltered cove had been annexed by another yacht, which was lying with four lines ashore. It was an American boat and we gave them a call on the radio. A middle-aged couple came out into the cockpit, as amazed as we were to see *Fiona* bobbing a few feet away. They had been there three or for days, waiting for a break in the weather. We found another cove about a mile away and secured ourselves with the anchor and three lines to trees on shore, then we talked to the Americans on the VHF radio. They were in contact with a large yacht they had met further north, which belonged to a wealthy New Zealander. A professional captain, his wife and a crew member were bringing the boat to Ushuaia (near Pto Williams, on the Argentinian side of the Beagle channel) so the owner could board her for a trip to Antarctica. The next day it was arranged that all three of us would meet at an anchorage on the southwest side of Tierra del Fuego. It was a spectacular setting. The anchorage was a huge natural amphitheater forming almost a complete bowl. Vast mountains soared above on three sides. Lakes above the bowl fed sparkling waterfalls. All three yachts rafted together with a dozen lines ashore. That evening we had a pot luck dinner on the luxurious New Zealand boat (70 ft long) and screened a video of Hal Roth and his wife negotiating these same Chilean canals twenty-five years earlier. As it is very rare to see another boat, let alone another yacht, it is hard to imagine three yachts had ever rafted up before in this lonely spot. At the western end of the Beagle channel I noticed the character of the mountains had changed - no longer smooth and scarred they were sharper with a jagged skyline. These mountains, however, protect the eastern end of the channel from the fierce westerlies that sweep across the Pacific Ocean (the Beagle is about 55°S) and the countryside took on a softer appearance - a little grass showed on the shore. Puerto Williams is on Navarino Island, which lies south of Tierra del Fuego. On a nice day it is very pleasant, we took several walks through the woods - beavers were introduced in the 1940's and their dams are everywhere. The port is run by the navy, basic supplies are available. The yacht club must be one of the most exotic in the world - it is an old freighter, sunk in a small creek off the Beagle. There is a wonderful bar in the old wheel house with a roaring fire every night and souvenirs on the bulkheads from the many visiting yachts and expeditions. The port has an interesting museum dedicated to the extinct Yaghan Indians, who inhabited this region for millennia before the arrival of whites. Disease and deliberate extermination finished them off within a century.

"From Puerto Williams we headed south, leaving on Christmas Day. We anchored for the night at a small island in the beagle between Argentina, on the north, and Chile on the south. In the 1970's this island and several nearby were the subject of a territorial dispute over which the two countries nearly went to war. In fact they still have a very chilly relationship in this part of the world. To maintain their hold the Chilean Navy stations a man in a house on shore. We rowed over to show our papers. He was delighted to see us - his wife made tea and gave us home-made cake. The officer had his wife and two children with him, otherwise they were alone. The posting was for a duration of a year - I didn't envy them. The next day we were trapped by a 45 kt gale which blew out after twenty-four hours and then we left to sail past Cape Horn and out into the Drake Passage. As we sailed south the short nights faded entirely, below 60°S it was light all day. My first glimpse of Antarctica was Smith Island, part of the South Shetland group which fringe the western side of the Antarctic Peninsula. It rose vertically out of the sea, the top was shrouded in clouds and the sides were a stark study in black and white. There is no vegetation whatsoever in Antarctica, that I could see. We threaded our way in the strait between the Shetlands and the mainland under powerful easterly winds - a feature of Antarctic summer I hadn't appreciated before. The sea was dotted with icebergs. As we approached Port Lockroy the ice became quite dense in places and we finally dropped the sails and motored slowly through the ice, jinking from side to side to avoid striking any large pieces. Port Lockroy consists of a few huts on a small island in a bay which is part of Wiencke Island. Activity started here in the 1940's when the British started a secret radio station to relay weather information during WWII. After that it became a scientific research base with emphasis on ionospheric investigation. In the 1960's it was abandoned. Following an Antarctic Treaty that required countries to operate or remove the detritus of their activity the Brits restored a couple of huts and made them a live-in museum of 1950's scientific work. During summer (November to March) two men occupy the huts living just as they did 50 years ago - lots of canned food and kerosene lanterns. They operate a small post office and rooms are set up with scientific gear of the era. Lockroy is frequently visited by the small cruise liners that bring the more adventuresome tourists to Antarctica. We arrived on New Year's Eve and were invited ashore by the residents. We took some rum and champagne, it was quite a night in their little hut, eating cottage pie and swigging our Caribbean rum in front of the wood-fired stove. I shall remember the start of 1999 for a long time.

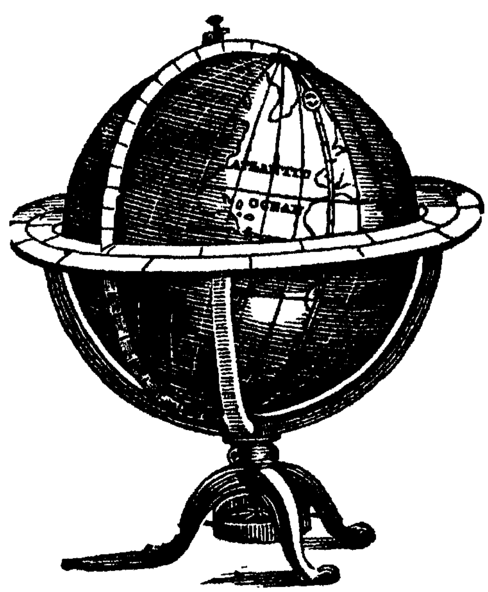
"The Brits share the small island they live on with a penguin rookery. This has its drawbacks, which you will appreciate if you have ever smelt one. Another problem for them is fresh water. When the ice is firm they can walk to Wiencke Island for pieces of ice to melt. But when we arrived the so-called 'fast' ice was melting (in fact lumps of it kept floating by, occasionally bumping into the boat), and uncontaminated ice on their island was hard to find. The resident scientists have no boat, so one afternoon we gave one of them a lift to a nearby island in our inflatable to search for a skua's nest he had roughly located using binoculars. Besides all the nesting penguins, skuas, terns and cormorants there was a complete whale skeleton on the shore, a relic of the old whaling days. Further onshore were dozens of staves off old wooden barrels from the same era. We left via the Peltier channel, which was like sailing down a canyon of ice. At the Bismarck Strait we headed north, this was our furthest south: 64°53'S. We had heard reports of thick ice just a few miles further south from the cruise liners. If they couldn't make it, I wasn't going to risk *Fiona's* fragile glass hull. The NE'ly wind died as we headed out and we powered to Deception Island. This is an ancient volcanic crater several miles across. The entrance is through a break in the crater wall, called, dramatically, by the old whalers 'Neptunes Bellows', due to the erratic winds that funnel in and out. Once inside there are the remains of an old whaling station, inundated by a volcanic eruption many years ago. The buildings and machinery are half buried in ash. You can still find coal, old cans and all the junk abandoned by the whalers. There is also a small hangar still containing the wings and fuselage of a plane. At low tide hot streams run into the sea, causing a mist of steam to rise and reeking of sulfur. The bottom of the bay is extremely irregular, with ridges almost up to the surface of the sea, but 20 feet deep a few yards away. The rapidly falling tide caught me unawares, and *Fiona* grounded fast, lying on her bilge as the tide went out. We were in this embarrassing position when a small Russian cruise liner entered he harbor and called on the radio to see if we needed help. I assured them we would refloat on the next high tide so they invited us over for lunch! The ship was a former Russian ice breaker called the *Professor Malcanov*, under charter to an Australian company. While the Australian tourists wandered through the buildings on shore, we changed the zincs on the propeller shaft, which became accessible as *Fiona* settled on her side at low water. Then we went over to the Russian ship. I am afraid we were obviously regarded as part of the local entertainment put on for the tourists' benefit as myself, Mike and Bruce were divided up to sit at different lunch tables and invited to spin our yarns. When we returned, the tide was making up and *Fiona* was soon free. The captain was nice enough to give us 100 liters of diesel fuel. From Deception we sailed along the north side of the South Shetland group, past the last one, Elephant Island, and into the Scotia Sea, heading for South Georgia. In 1916 Ernest Shackleton and five companions made the same passage in a 22 ft ship's whale boat and entered into Antarctic folklore. Their ship, *Endurance*, had been crushed in the ice further south months earlier. They floated north living on ice floes and finally sailed to Elephant Island in three small boats. Thy had no radio, their only hope of a rescue was to make it to the whaling station on South Georgia, about 700 nautical miles away. Shackleton left most of his men on Elephant Island, made the trip in one of the boats. Conditions were horrible for them, as we sailed the same route I could only wonder at their stamina. We had a comfortable, heated, boat almost twice as long as theirs but it was not a joy-ride. The water temperature was a freezing 32°F. We had heavy swells that broke the shaft of the servo blade on the self steerer. The winds reached gale force a couple of times. Ultimately Shackleton made it, organized a rescue expedition for the men left behind and got them all home without loss of life. We sailed along the north coast of South Georgia with a strong wind behind us. On our right the rugged outline of the high mountains was sharply etched in black and white against a deep blue sky. It looked like a painted backdrop. South Georgia is about the same size as Long Island, N.Y., but instead of millions of people there are millions of penguins. We headed for Grytviken, the site of the largest whaling station, founded by Norwegians in 1906 and operated for nearly sixty years. As we sailed into Cumberland Bay the scenery was magnificent. Several glaciers emptied into the bay - ahead was the 9000+ ft white edifice of

Mount Sugartop slashed with jet black. When we approached the settlement, scores of birds wheeled overhead with shrill cries. Fur seals gamboled in the water and on shore crowds of King penguins looked at us nervously. The buildings at Grytviken are extensive, nearly a thousand people worked there at its peak, but most are now in ruins. Half-sunken whale catchers lie at crumbling jetties. At King Edward Point, about half a mile to seaward, are some well-maintained buildings first built to house scientists but now occupied by a score of British soldiers and the harbor master. South Georgia was briefly occupied by Argentina in 1982 and the troops are there to prevent a repeat. We dropped anchor near the shore. Ahead of us was a sailboat famous to a generation that learned to sail in the 1950's and 60's. It was Eric Hiscock's *Wanderer III*, now belonging to a young Danish couple. Tied up to one of the derelict whale catchers was *Curlew*, an engineless 28 ft. boat over a hundred years old, she was sailed to South Georgia eight years ago by Tim and Pauline Carr. The Carrs run a great museum in a renovated building. There are sections on the natural history of the island, the Shackleton expedition, whales and the operation and life at Grytviken in its heyday. Apart from the early years the factory was designed to use every part of the whale, including the bones. Wandering through the buildings I was extraordinarily impressed by the difficulty they must have experienced in erecting and operating the complex boilers, generators, cutters, centrifuges, etc., in such a harsh climate. All this effort and it resulted in the virtual extermination of the whale species. About 175,000 whales were killed at Grytviken during its working life; 500,000 in the Antarctic as a whole; a holocaust indeed. Quite early on, scientists warned of this likely outcome and government regulations were put into effect to limit the yearly catch. They were circumvented by the whalers who built factory ships that operated on the high seas; out of reach of the regulators. In the end Grytviken closed simply because it became uneconomic to pursue the few remaining whales. Some types, the Blue whale for example, may be so few in number that they will die out. An optimistic note, however, is that fur seals, also hunted to the brink of extinction, are now making a spectacular comeback. These seals are quite aggressive on land and I was chased by two of them along the beach while they made blood-curdling barks.

"One night Pauline and Tim gave a little party at the museum and showed over a hundred slides of expeditions they had made on skis to the interior. We also got invited to the mess at the army base and the harbor master let us use the shower in his cosy living quarters. As you can tell, everyone was very hospitable. Under sail on the evening of the day we left Grytviken a huge iceberg materialized out of the gloom - on the radar it was a mile across, with an absolutely flat top and vertical sides, it had obviously calved on the ice shelves in the Weddell Sea, to our south. It was our last glimpse of Antarctica. On the way to Tristan da Cunha the nights got longer, the sea water got warmer and the wind howled, at least for the first part. The usual gear failures followed but we kept the boat sailing and we arrived off this lonely island early in the morning of the tenth day out. The settlement of about 300 people is nestled on a small plateau under a brooding volcano. In 1961 it erupted and all the islanders were evacuated to England for a couple of years. The community was founded in the early 1800's by a soldier who stayed behind when the military garrison, posted there to guard the southern approach to St. Helena, Napoleon's place of exile, was disbanded. They are largely self-sufficient, growing vegetables and fishing. We only managed to stay a few hours as the anchorage is an open roadstead and *Fiona* rolled violently in the ocean swell. But we did manage to launch the inflatable and get ashore. We bought a few supplies at the small supermarket, visited the museum and post office and sent e-mail messages from the administrator's office. About a dozen graceful sailboats were parked on the shore; they sail them to two nearby islands for guano which is used as fertilizer. Like Pitcairn Island, which I visited a few years ago, I got the feeling on Tristan that the people live an intense, closed life which outsiders simply cannot penetrate, especially in a few hours.

"We had mostly light winds and calms on the way to Cape Town - typical of the high pressure cells that move across the South Atlantic in these latitudes. We made contact with an amateur radio net in South Africa run by a friend of Mike's father. As a consequence Mike's parents drove down to meet us in Cape Town. The 1,500 nautical mile leg took us eleven and a half days. As dawn broke, Table Mountain was silhouetted against the pink sky. Welcome to Africa. Total mileage for cruise so far is 15,129 n.m.

—Until the next time, all the best, Eric



A Field Assessment of Stark's Tables for Clearing the Lunar Distance and Finding GMT by Sextant Observation

By Robert Eno, Eqaluit, NT

Background

Several months ago, the writer acquired a copy of Bruce Stark's *Tables for Clearing the Lunar Distance and Finding GMT by Sextant Observation*. It forced him, once and for all, to make an effort to learn about this venerable old method of determining the correct time by taking advantage of the moon's unique rate of passage across the heavens.

The writer had always intended to master "lunars" - as they are more commonly referred to in navigator's circles - but was deterred by what appeared to be a tedious, cumbersome and intimidating process. Furthermore, the popular consensus among most navigators was, and still is, that lunars are a needless anachronism that have long since outlived their usefulness.

Even as far back as the turn of the century, Squire Lecky conveyed the same sentiments in his classic navigation tome, *Wrinkles in Practical Navigation*:[1]

> "Whether lunars are worth cultivating is not deserving of consideration. They are, in fact, as dead as Julius Caesar; and without in the least being endowed with the mantle of prophecy, it is correct to say that they will never be resurrectionised, for the best of all reasons - they are no longer required . . . *Requiescant in pace*. They have had their day (the reader will please excuse the Latin. Being a dead language, it is peculiarly suitable for funeral orations)"[1]

Lecky, being the practical fellow that he was, dismissed lunars as a pointless endeavor, due to the reliability and simplicity afforded by marine chronometers, which even in his day, seemed to be widely available ("in fact they have become a drug in the market"[2]. If Lecky were alive today, would he have the same thing to say about celestial navigation in this era of satellite global positioning systems? One can only speculate.

Graphic Lunar Distance Solutions

Taking heart from Lecky's words, and given the widespread availability of cheap, and highly- accurate quartz timepieces, the writer was thus able to justify, in his own mind, an avoidance of lunars, which, in reality, was probably masking a lazy streak in his character. Nevertheless, plagued by the feeling that one cannot really profess to be a celestial navigator without attaining at least a rudimentary grasp of lunars, the writer has, over the years, dabbled with a couple of simple graphic methods that have been devised for determining time by lunar distances. One such ingenious method was proposed by Bruno Ortlepp in a paper entitled: "Longitude Without Time."[3]

The technique described by Mr. Ortlepp requires the navigator to take observations of at least two stars and one observation of the moon when it is on, or near, the prime vertical. Ortlepp's procedure is based on the premise that:

1) A star fix will yield the correct latitude, regardless of chronometer error and

2) If one's chronometer is accurate and one's observations are error-free, then the LOPs from a combination of star and moon observations will intersect at the same point. If, however, the chronometer is in error, then the moon LOP will not intersect at the same point as the star LOPs but will lie somewhere to the east or west of that point.

Without getting into the details of the exact mechanism behind the method, determining the chronometer error is accomplished by reckoning the longitudinal distance that the moon LOP lies to the east or west of the star fix and then converting this into time.

The theory behind this and other similar graphic techniques is sound; in practice, however, the techniques can be shaky and often produce unsatisfactory results, mostly due to the potential for coarse errors which are an inevitable consequence of applying a graphic solution to complex calculations. Furthermore, the graphic techniques such as the one described by Ortlepp, assume that a navigator's observations are free of errors, which is not a realistic expectation even under ideal conditions. The fact that a moon LOP does not intersect at the same point as a star fix is not necessarily attributable to chronometer error; more often than not, it is due to observational errors or unpredictable errors in refraction. Obtaining a perfect pinwheel fix, especially when moon observations are concerned, is more a matter of chance than of skill.

Stark's Tables: Lunars Without Pain

Most worthwhile things in life are not easy to come by. Mr. Stark's tables, which are the result of 20 years of research and painstaking development, are no exception to this rule. This becomes apparent as one reads and works through the tables.

Stark has taken all of the tedious and complex calculations formerly required for lunars and reduced the whole process to a simple exercise of addition and subtraction. Furthermore, based on the writer's observations and experimentation over the past several months, a skilled navigator can determine GMT with a remarkable degree of accuracy when using these tables.

The tables are laid out in a logical and easy to follow manner. Stark's instructions are, for the most part, understandable, however, they would be significantly improved with the addition of a cookbook, step-by-step example of a cleared lunar distance, complete with entry arguments from the navigator's field notebook.

In the introduction to the tables, Mr. Stark presents a brief history of lunars as well as his own compelling reasons for the resurrection of this all-but-forgotten art:

"Now GPS is about to do for the rest of

celestial navigation what chronometers and radio time signals did for the lunar. This might seem an awkward time for it, but if you enjoy using a sextant, you will welcome the resurrection of the lunar distance . . . The present justification for celestial is that it provides a backup when electronics fail . . . the electromagnetic shock wave from a nearby lightning strike can derange the timekeepers . . . in the same instant that it takes out the electronics . . . Nothing else comes close to the lunar for developing skill with a sextant - and the observation is demanding enough to hold one's interest for a lifetime . . ."

The tables are divided into twelve sections, the functions of which are explained in the introduction. Stark has also provided work forms for use with the tables; a very important consideration. It is often said that a skilled navigator should be able to reduce a sight on the back of an envelope - a sentiment which the writer tends to agree with. The same, however, cannot be said for these tables. Stark's process involves many steps which entail frequent adding, subtracting and transposition of numbers; a work form is the only reasonable means by which one can keep track of what is going on, thus avoiding stupid mistakes. There is no shame, therefore, in clinging to the work form as one would to a life preserver.

Of notable interest, are the optional "Wrong Way Tables" (WW), which when used, preclude the necessity of taking altitude observations. Their purpose is to provide the neophyte lunarian with an opportunity to concentrate on practicing and perfecting his sextant technique for taking the actual lunar distance observation, which, given some of the unnatural bodily contortions that a navigator must assume for the event, is the most difficult part of the process. Once he has mastered his sextant technique, he can then start to practice lunars in their entirety. The entry arguments for the WW tables are the latitude, longitude and the correct time; from these, the Hc of the moon and the celestial body are calculated. Corrections from the WW tables are then applied to Hc to arrive at the apparent altitude of the centre (Ha) of the celestial body which is a required entry argument for clearing the lunar distance. By employing the WW tables, the navigator simulates sextant altitude observations by putting parallax and refraction errors back into Hc.

Textbook lunars are supposed to be performed by at least three observers; one to observe the lunar distance, while the other two cover off the altitudes. In a perfect world, all three will take their respective observations simultaneously. In practice, this is next to impossible; therefore the observer/s must take altitude observations before and after the lunar distance observations in order to determine the rate of change in the altitude for both the moon and the celestial body. This rate is then applied to the first two altitude observations (the moon and the celestial body) to adjust them to a common time: the time of the lunar distance observation.

Stark has devised a simple technique for employing tables 7 & 8 to adjust the altitudes to a common time. A work form is not provided for this calculation, which is simple enough that it *can* be scribbled out on the back of the proverbial envelope. Nevertheless, being a strong advocate of forms, the writer has made one up and reproduced it here for the benefit of the reader.

Stark suggests that the lone observer should try to take all observations within 10 minutes as the altitudes of celestial bodies do not change at a steady rate over long periods of time. This is a valid concern; however, the writer has had to take as long as 35 minutes - mostly due to weather and equipment - to complete the whole operation which did not appear to compromise the results. Nevertheless, it is still a good idea to complete the observations as expeditiously, but carefully nonetheless, as possible.

Once the observed lunar distance "Ds" is cleared (that is, corrected for index and instrument error, phase, refraction, parallax, and semi-diameter) to arrive at the true lunar distance "D", the next step is to compare it with the calculated or "comparing" lunar distances for the nearest hour before ("D1") and after ("D2") the estimated time of the lunar distance observation. The word "estimated" is used because the navigator is, after all, operating under the premise that his chronometer is in error. A Nautical Almanac is required in order to determine D1 and D2 as the entry arguments for the calculations are the GHA and declination for both the moon and the celestial body.

These comparing lunar distances (D1 and D2) are calculated by solving a spherical triangle; the sides of which are formed by the co-altitude of the moon and of the celestial body, as well as the angular distance between them; while the vertices are formed by the observer's zenith, the moon and the celestial body. As with the process for clearing the lunar distance, Stark has reduced this calculation to simple matter of addition and subtraction.[4]

Once D1 and D2 have been calculated, they are proportionately compared with the cleared distance (D) and from this, the GMT can be determined. A work form, which the writer found to be easier to follow than the one supplied for clearing the lunar distance, is provided for computing the comparing lunar distances and determining GMT.

This then, is the essence of Bruce Stark's tables. Since acquiring them in November 1998, the writer has been outside, as often as possible and as conditions warranted, taking observations and reducing them late into the evenings.

Eight selected observations as well as the results obtained, are presented in the accompanying table. All observations were taken on land, with a C. Plath sextant using a bubble attachment for the altitude observations and a 6X telescope (recommended) for the lunar distance observations. This presented some minor difficulties in that the bubble attachment and telescope had to be switched between altitude and lunar distance observations. Furthermore, bubble horizons are generally only accurate to within a range of 3 to 5 minutes of arc, although a skilled navigator can, with practice, realize a degree of accuracy to within 1 minute of arc. At first, the writer was concerned that employing a bubble horizon would negatively affect the overall results, but according to Stark:

> "... altitudes are not critical. They are only wanted for their refraction and parallax corrections and to determine the shape of the triangle formed by the two bodies and the observer's zenith. Still, try to get the altitudes within 1' or 2' of the truth - especially if the distance is short."

The writer's experiences bear this out: in example #3 from the table, one of the moon altitude observations was in error by a full 6 minutes of arc. Nevertheless, this set of observations yielded a remarkably accurate result: the lunar distance time was determined to be slow on GMT by a mere 11 seconds.

As can be seen from the table, the results of the observations vary but the mode is in the range of just over 1 minute short of actual GMT. When the results are averaged, the error amounts to 1^m02^s slow on GMT. Note the arc error vs. the error in time, for each: this is a clear illustration of the need to be as precise as possible when observing lunar distances, for as Stark indicates, an arc error or just 0.1' results in an error of about 12 seconds of time.

At sea, when taking altitude observations, a navigator is pleased with himself if his observations are accurate to within one minute of arc, however, when observing lunar distances, an error of one minute of arc amounts to about 2 minutes of time, which at 45°N, results in an east-west error of approximately 21 nautical miles.

Wrinkles

Observations

Lecky wrote: "Cheap sextants (are) of no use for lunars . . . the divisions of the arc are unreliable . . . the cutting of the arc at any given angle will often not coincide exactly and judgment may assign the wrong reading."[5] Lecky's words still ring true, even 100 years after they were written. This is not to imply that if one does not own an expensive Plath sextant, that one should be deterred from attempting lunars. Nevertheless, it should be recognized that because lunars require very precise measurements, cheaper sextants, such as plastic models, will not produce accurate results.

When choosing the other celestial body, it is recommended that it be located along the moon's orbit or as close to it as possible. Any celestial body located along the ecliptic, or close to the ecliptic, such as, but not restricted to, the navigational planets, Pollux, Spica, Aldebaran, Regulus and Antares, will fulfill this requirement.

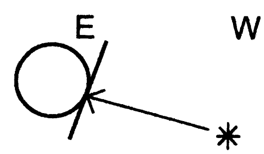
It is standard practice, when taking altitude observations at sea, to bring the celestial body close to, but not touching, the horizon and then, while gently rocking the sextant, allow the body to rise or fall on its own until it "kisses" the horizon. It is suggested that the lunarian adopt a similar technique for lunar distance observations: bring the celestial body close to, but not touching, the lunar limb and while gently rocking the sextant, wait for the moon to make contact with the celestial body.

When taking sun/moon lunar distance observations, one should bring the sun to the moon, rather than vice-versa. This is because the horizon shades, even when they are all in place, do not sufficiently dim down the sun's glare, making it difficult, if not impossible, to observe the lunar distance. It is better to set the appropriate index shades in place and then bring the brighter object, the sun, across to the dimmer object, the moon.

Very bright objects (other than the sun) such as Venus, will present a glared or "fuzzy" image, which makes it difficult to determine the exact time that it makes contact with the lunar limb. Flipping the dimmest index shade into the line of sight remedies this by sharpening up the celestial body's image and cutting down its glare.

Diagrams

It is a good idea to sketch a diagram of the configuration of the moon and the celestial body, in one's observation book. Label each body east or west and clearly indicate which limb of the moon - near or far - was used for the lunar distance observation. One suggested method is to construct a diagram that consists of an asterisk to represent the celestial body and a circle (shaded in according to the phase) for the moon, with an arrow running from the celestial body to whichever limb of the moon that was used for the lunar distance observation. At the same time, one should make note of whether the lunar distance is increasing or decreasing.



In this way, when the observer returns indoors to reduce the sights, there will be no ambiguity as to which limb was used in the observation and in what direction, in relation to the celestial body (towards or away from), the moon was moving.

Arithmetic and Transposition Errors

It is advisable to check and double check arithmetic and entry arguments as one is working through the problem. Even a single arithmetic error or a mis-written number will have a domino effect on the whole calculation, for both clearing the lunar distance and for determining GMT. Verification and careful attention to detail might require an additional five to ten minutes of time, but it is well worth the extra effort.

Non-Standard Conditions

Both the Nautical Almanac and Bowditch provide additional correction tables for non-standard conditions of temperature and pressure. Navigators seldom have to pay attention to these unless they are operating under extreme conditions, such as those which are found in the polar regions.

At the writer's request, Stark developed a set of correction tables - The Cold Weather Increments Table - for lunar distance observations taken under polar conditions. This correction is applied to the calculations for clearing the lunar distance and will have a noticeable effect on the outcome of the cleared lunar distance and consequently, GMT. To illustrate this point, the reader is referred to example #1 listed in the table. Conditions during the observations were as follows: temperature -25C, barometric pressure 1008 millibars, winds NE 3 kts. The resultant time by lunar distance, when corrected for temperature and pressure, was 1^m11^s slow on GMT. In the absence of a temperature/pressure correction, the resultant time by lunar distance was 1^m31^s slow on GMT; a difference of 20 seconds between the corrected and uncorrected versions. In practical terms, this extra 20 seconds amounts to - on top of the 12.5 nautical mile east/west error for a 1^m11^s error in time (at Lat 45°) - an additional 3.5 nautical miles.

Cold weather corrections can be disregarded for temperatures of 0°C and above. The corrections for non-standard conditions - as presented in Bowditch and the Nautical Almanac - *should not be applied* to the calculations for clearing a lunar distance observation; Stark's cold weather increments table takes care of this.

Gross Errors

The cleared lunar distance (D) must always fall between the comparing lunar distances for the hour immediately before (D1) and after (D2) the estimated time of the lunar distance observation. If it does not, then there is something wrong: either the observer has made a blunder - observational, an incorrect entry or arithmetic error - or the chronometer error is on wrong side of the comparing distances; in other words, the lunar distance observation occurred before or after the times used to determine D1 and D2.

Chronometer error will generally be in the range of minutes, however, in extreme cases, the error could be in the order of several hours or - if the navigator has entered the wrong date - days. Such errors will be readily apparent because the cleared lunar distance will differ from D1 -D2 by up to tens of degrees. In such cases, the navigator will have to make a rough estimate of nearest correct hour and then re-calculate D1 and D2 around that estimated hour.

A suggested means to accomplish this is as follows:

1) Determine the hourly rate of change of the lunar distance by noting the difference between D1 and D2, which will be in the range of 24 - 36 minutes of arc per hour.
2) Calculate the difference, in degrees and minutes, between D1 or D2 and the cleared lunar distance (D); convert this into minutes of arc, and divide it by the hourly rate of change between D1 and D2. The result will yield the approximate chronometer error in hours/decimals of hours.
3) Advance or retard the time of D1 or D2 - depending upon whether the lunar distance was increasing or decreasing at the time of the observation - by the chronometer error as derived from steps 1 and 2, to determine the date and estimated whole hour of the lunar distance observation.
4) It might be necessary to re-calculate the cleared lunar distance ("D") for the estimated whole hour if horizontal parallax - the only time-sensitive entry argument required for clearing the distance - differs by 1.0' or more, from the original estimated whole hour for D; otherwise D can be left as is.[6]
5) Re-calculate D1 and D2 for the estimated whole hour. This step might have to be repeated for different whole hours until the cleared distance falls between the two.

It should be noted that this method of roughing out the chronometer error is not reliable when the lunar distance is short and when the celestial body is offset from the moon's orbit by several degrees. This is because the hourly rate of change in the lunar distance decreases appreciably as the moon approaches a celestial body that is offset from the lunar orbit (as it nearly always is), until it reaches zero, when the moon and the body are abreast of each other. The hourly rate of change in the lunar distance then reverses sign and slowly increases again as the moon moves away from the celestial body.

In circumstances where the cleared (observed) lunar distance (D) is short and the difference between it and the comparing lunar distances (D1-D2) is in the order of several degrees, skip steps 1 and 2 and use the rough rule of thumb that the moon moves eastward at approximately 12 degrees per day or 0.50 degrees per hour. This is of particular significance when the moon is closely approaching or departing the celestial body, because, in addition to a change in the hourly rate of the lunar distance, the *sign* of the change will have reversed over a period of hours.

Lunars Resurrected?

It is rather remarkable that in this day and age, when the very survival of celestial navigation seems to be in question, that an individual should suddenly appear on the scene and present to the world, such a brilliant piece of work.

Stark has rendered a great service to the celestial navigation community by simplifying lunars - without compromising on the accuracy of the outcome - to a point where the average navigator will be more agreeable to try them. Had he been born 200 years ago, he might have been remembered with the same veneration as Raper and Chauvenet whose names are now synonymous with lunars. There is no question that practicing lunars really does improve one's skill with the sextant and just as one can derive a tremendous sense of satisfaction by knowing that he can determine his exact position on the face of the earth with a sextant, tables and a chronometer; the same holds true for being able to determine GMT by sextant observations of the moon; perhaps even more so. The writer commends Stark for developing these tables and has no hesitation in recommending them to anyone who is interested in improving their sextant observation skills, while at the same time, broadening their knowledge of the venerable art and science of celestial navigation. Celestial navigators pride themselves on their independence and self-sufficiency of having the ability to navigate anywhere in the world without the aid of electronic devices. Learning how to determine the correct time by lunar distance observations further enhances the navigator's confidence in his own abilities. Now that Stark has made the process so simple, there is no excuse for the serious navigator not to try his hand at lunars.

Notes:

1 Lecky, Squire T. 1917. *Wrinkles in Practical Navigation*. George Philip & Son Ltd. London, England. 19th edition pp. 462-463.

2 Ibid. p. 456

3 Ortlepp, B. 1969. "Longitude Without Time'. *Navigation*: Journal of the Institute of Navigation Vol 16, No. 1 Spring 1969. Washington, D.C. pp 29-31.

4 For those readers with a mathematical bent, Stark has provided a full explanation of the derivation of his tables in issue sixty of *The Navigator's Newsletter, Summer 1998.*

5 Lecky, Squire T. 1917. *Wrinkles in Practical Navigation*. George Philip & Son Ltd. London, England. 19th edition p. 462.

6 In order to determine the degree to which a gross GMT error imparts changes to the cleared lunar distance, the writer re-calculated a lunar distance problem using a time that was in error by 44 hours. The resultant cleared lunar distance changed by 0.1' of arc for a 1.5' change in HP.

Lunar Distance Observations
February 02 - April 22 1999
Latitude 62°27.0'N Longitude 114°21.2'W

Note: All altitudes were corrected for index error and then adjusted to a common time: the time of the lunar distance observation. The latter, as listed in the table, has not been corrected for index error; this takes place during the calculation for clearing the lunar distance. Temperature and pressure corrections were applied when deemed significant; observations were taken at temperatures ranging from -28° C - +3°C.

Time / Date	Observed Altitude Celestial Body (Adjusted)		Observed Altitude Moon (Adjusted)	Observed Lunar Distance	Cleared Lunar Distance	Time By Lunar Distance	Error	
							Time	Arc
05h01m45s 02/02/1999	Pollux	52°19.2'	21°32.6'	39°25.7' Near Limb	38°58.6'	05h00m34s	01m11s slow	0.7' gap
06h27m26s 03/02/1999	Pollux	55°32.0'	22°40.6"	53°17.5' Far Limb	52°22.8'	06h26m22s	01m04s slow	0.5' overlap
05h18m54s 03/03/1999	Pollux	54°57.4'	21°42.7	60°08.3' Near Limb	59°45.8'	05h18m43s	00m 11s slow	>0.1' gap
03h24m25s 23/03/1999	Venus	15°08.9'	35°49.7'	39°09.2' Near Limb	39°45.4'	03h22m00s	02m19s slow	1.3' gap
05h55m41s 25/03/1999	Pollux	46°36.4'	33°50.4'	14°03.0' Near Limb	13°01.8'	05h55m20s	00m21s slow	0.15' gap
06h42m12s 27/03/1999	Pollux	40°59.0'	36°36.9	19°57.4' Near Limb	19°58.3	06h41m02s	01m10s slow	0.55' gap
04h26m49s 20/04/1999	Venus	19°19.6'	23°12.3'	17°23.5' Near Limb	17°50.5	04h25m35s	1m14s slow	0.65' gap
00h19m47s 22/04/1999	Sun	19°23.3'	45°19.9	79°48.9' Near Limb	80°10.6'	00h19m15s	00m32s slow	0.25' gap

Form For Adjusting Observed Altitudes to a Common Time

For Use With Bruce Stark's

Tables For Clearing the Lunar Distance and Finding GMT By Sextant Observation

Date	

Body	

Elapsed Time between 1st Altitude and Time of Lunar Distance Observation

Time of 1st Altitude			
Time of Lunar Distance Obs.			
Difference		Table 8	1

Elapsed time Between 1st Altitude and Last Altitude

Time of 1st Altitude			
Time of Last Altitude.			
Difference		Table 8	2

Subtract 2 from 1	3

Change in Altitude Between 1st and Last Observation

1st Observed Altitude			
Last Observed Altitude.			
Difference		Table 7	4

Add 3 and 4,	5

Enter argument 5 into **Table 7**, extract value, then add or subtract to **1st** observed altitude	

1st Observed Altitude	
Increment to be Added to or Subtracted from, 1st Altitude Observation	
Observed Altitude adjusted to common time	

Robert Eno - Iqaluit, NT

Millennium Madness: 2000 or Bust!

By Peter Ifland

Here's my contribution to the confusion and complexities around when and where to celebrate the arrival of the new millennium.

By definition, a millennium is composed of one thousand years. How long is a year? Early calendars were based on the cycle of the moon. But twelve lunar months of 29.5 days each soon gets out of sync with the seasons. Nowadays, a year is commonly defined as the time it take the earth to make one complete revolution in its orbit around the sun - 365.242199 days, approximately, on average. To accommodate the fractional days, the Gregorian calendar (Pope Gregory XIII, February 24, 1582) turned to leap years - February has 29 days every fourth year. But this rule needs adjustment - The Leap Century rule - there are no leap years in the first year of the three centuries preceding each millennium (the years 1700, 1800 and 1900, in the case of the 2000 millennium.) But even this calendar is running slow by about 11 seconds per year and there will have to be an extra leap year to remove one whole day in the year 4909.

When does the new millennium start? It depends on whose calendar you choose to accept. By the calendar based on the year Rome was established, we are in the year 2753 and the next millennium, the fourth, won't start for another 247 years. A more modern calendar, based on the start of the reign of the Roman Emperor Diocletian, puts us in year 1716 with the third millennium yet to come in 284 years.

There's more! In the year 1285, by the calendar based on the date of the founding of Rome, or 248, based on the start of the reign of the Emperor Diocletian, (take your choice), Pope John I asked an abbot and mathematician named Dionysius Exiguus, Dennis the Little, to calculate the dates for future Easters. Dennis decided that it was inappropriate to base a Christian calendar on pagan events and that he would start counting from the birth of Christ. Dennis' calendar, fine-tuned by Pope Gregory and further polished by Aloysius Lilius, who developed the leap-century rule, finally became the world's calendar when the Chinese adopted it in 1949.

Thus, the count of years, centuries and millennia in the modern Christian era started with the moment of Jesus' birth, at 0000 hours in the morning (assuming that he was born at midnight) on January 1 of year 0000. By this logic, the end of his first year of life was 2400 hours, December 31, 0000 and the second year of his life started 0000 hours, January 1, 0001. Thus, the end of the first century was 2400 hours, December 31, of the year 0099 and the start of the next century, the second century, was 0000 hours, January 1, 0100. Pursuing this logic further, the first thousand years ended 2400 hours, December 31, 0999 and the second millennium started 0000 hours, January 1, 1000; the second millennium ends 2400 hours December 31, 1999 and the third millennium starts 0000 hours January 1, 2000.

Not quite! Dennis the Little started his calendar with the year of Christ's birth as A.D. 1. Thus, two thousand years after Christ's birth by our Gregorian calendar get us to 2400 hours, December 31, 2000 and the start of the third millennium at 0000 hours January 1, 2001. But wait a minute! Modern biblical scholars place Christ's birth several years earlier, in 5 or 6 BC by Pope Gregory's calendar. This would say that the third millennium following Christ's birth started in 1995 or 1996. Furthermore, the belief is that Christ was born on Christmas day, six days before New Years day. Still more, he was born in Bethlehem, longitude 35 degrees, 23 minutes East or two hours twenty-one minutes earlier than Greenwich. This gets us to 2139 hours on December 25, 1999 as the time to celebrate.

If you accept this interpretation, then what is the precise instant during December 31, 1999 to January 1, 2000 to celebrate? It makes a difference! (1) When it is midnight Universal Time at the International Date Line, from which all dates are now measured; (2) when it is precisely twelve hours after Local Solar Noon on December 31, 1999, i.e. Solar Midnight at the International Date Line; (3) when it is 0000 hours, January 1, Universal Time at the prime meridian at Greenwich Observatory, the point from which time is measured; (4) when it is 0000 hours January 1, Local Time in the time zone where one happens to be; (5) when the sun is precisely 180° opposite the meridian where one happens to be, i.e., when it is Local Solar Midnight, 2400 December 31. Taking these possibilities one at a time.

1. When it is 0000 Universal Time, January 1, 2000 at the International Date Line. What time shall we celebrate by Local Time in the local time zone? Easy!

Paris	London	Washington DC
1300 Dec 31	1200 Dec 31	0700 Dec 31
San Francisco	Honolulu	Tokyo
0400 Dec 31	0200 Dec 31	2100 Dec 31

2. When it is precisely twelve hours after solar noon on December 31, 1999 at the International Date Line. More difficult! At 1200 on December 31, 1999, the sun is 23°06.5 south of the celestial equator. In this vicinity, the International Date Line deviates 5° to the east to avoid dividing the Samoan Island into two time zones. Thus, during the winter when the sun is this far south of the equator, the sun passes over the International Date Line 5° or 1/3 of an hour i.e., 20 minutes earlier than at other seasons. Now:

Paris	London	Washington DC
1240 Dec 31	1140 Dec 31	0640 Dec 31
San Francisco	Honolulu	Tokyo
0340 Dec 31	0140 Dec 31	2040 Dec 31

3. When it is midnight at the prime meridian at Greenwich Observatory from which point time is mea-

sured. Simply add or subtract the number of the Local Time Zone from 2400 hours.

Paris	London	Washington DC
0100 Jan 1	0000 Jan 1	1900 Dec 31
San Francisco	Honolulu	Tokyo
1600 Dec 31	1400 Dec 31	0900 Jan 1

4. When it is midnight by the clock at the time zone where we happen to be. This is the no-brainer that the masses will follow.

Paris	London	Washington DC
0000 Jan 31	0000 Jan 1	0000 Jan 1
San Francisco	Honolulu	Tokyo
0000 Jan 1	0000 Jan 1	0000 Jan 1

5. At local clock time precisely twelve hours after the sun has passed through the meridian where we happen to be, i.e. when it is local solar midnight on December 31. To determine this, you have to have the longitude of the locality.

Paris	London	Washington DC
2°20'E	0°05'	77°02'W
0053 Jan 1	0003 Jan 1	0011 Jan 1
San Francisco	Honolulu	Tokyo
122°25'W	157°52'W	139°45'E
0013 Jan 1	0035 Jan 1	2345 Dec 31

If you are unusually fond of twentieth century and the third millennium and hate to see it go, the place to be is at the south Pole. There you can stand just to the east of the 180th meridian at midnight, local time in the twelfth time zone and savor the last moment of this millennium. Or, if you feel really adventuresome, stand astride the international date line with one foot in each millennium. Another approach is to go to the eastern edge of the twelfth time zone at 172°30' West on the night of December 31 and wait on the eastern side of this line for the stroke of midnight.

The conclusion from all this is, just start the celebration early and let it run as long as it will.

The Development of Sight Reduction Tables for Air Navigation

By Ernest Brown

(Continued from Issue Sixty-four, summer 1999, in which issue the second part of the article is in the DO YOU KNOW . . .? section.

The late D. H. Sadler, a former director of Her Majesty's Nautical Almanac Office, Royal Greenwich Observatory, published a review of the preliminary edition (1947) of H.O. Pub. No. 249, then titled *Star Tables for Air Navigation*. The following three paragraphs are from this review (Volume 1, No. 1, January 1948 of the *Journal of the Institute of Navigation)* and are used here with the permission of the Royal Institute of Navigation, London ©1948:

"THE PUBLICATION of these tables represents a major event in astronomical navigation, and accordingly they will be reviewed and assessed in some detail.

"The reviewer cannot claim to know the full early history of these tables or even of the method of tabulation used. According to the Preface, 'These tables were conceived and designed by Commander C. H. Hutchings, U.S. Navy . . .'; it is not clear, however, whether this refers to Hutchings' original suggestion of tables in this form* which the reviewer was privileged to see at the time in 1942) or whether he did more detailed work on them subsequently. Many detailed improvements have certainly been introduced, most in accord with the reviewer's criticism of the original proposals. It seems inconceivable that no star tables using sidereal time as argument, and with the stars arranged in order of azimuth, should have been published prior to the last war, but no such tables are known. The idea of using sidereal time (or LHA Aries) as the main argument for the stars was, of course, considered in 1937 when the *Astronomical Navigation Tables* were designed; but it was only considered in relation to the tabulation for a single star and, in such case, the disadvantage of twice the amount of tabulation outweighs the other advantages. Oddly enough, the arrangement of several stars on the same page, in order of azimuth, was used in the Japanese Celestial Air Navigation Tables, volume three of which was published in August 1940; but here the argument used is local hour angle and there would seem to be little, if any, advantage to be gained by the arrangement.

"All other tables using this arrangement seem to be subsequent to 1942. First there is Hoehne's *Practical Celestial Air Navigation Tables* of which only a limited number of copies of Vol. II, published in 1943, were issued under a 'Restricted' classification before being withdrawn. Secondly, there is the *Experimental Astronomical Navigation Tables* issued in 1943 'For Official Use Only' as an eight-page leaflet for experimental work; in these tables a still further artifice is used to replace the sidereal time scale by a mean time scale. Finally, there is the German *Höhentafeln*, of which a volume for latitude N. 50°-56° was published in 1944 and which is essentially the same in principle as the tables now under review; it is possible that tables for other latitudes and epochs were published earlier. In this list mention must also be made of the statement in Blackburn's *Basic Air Navigation* (New York, 1944) on p. 234: 'Use of Navigation Tables—Blackburn's . . . A page taken from one of the more recent navigation tables is reproduced in Fig. 271. . . .The names of the principal navigational stars are printed in alphabetical order across the top of the sheet. The calculated altitude and azimuth for each star is given opposite the *t* value shown in the left-hand column.' No such tables have been issued and the statement must be regarded as over-optimistic anticipation."

*Since writing the above I am informed that Hutchings published his suggestions in the *Proceedings of the U.S.*

Naval Institute, Vol. 68, pp. 1279-84, September 1942, and comments by Ageton, Weems and Aquino appeared in subsequent numbers of the same publication.

The following is an excerpt from page 542 of the 1958 edition of H.O.Pub.No 9, *American Practical Navigator* (Bowditch) edited by the late Alton B. Moody, a past president (1958-59) of the Institute of Navigation (U.S.):

> "**H.O.Pub.No.249**, *Sight Reduction Tables for Air Navigation*, in three volumes, are published by the U.S. Navy Hydrographic Office. A preliminary edition of volume I for selected stars was published in 1947 under the title *Star Tables for Air Navigation*, using the general plan conceived by Commander C. H. Hutchings, USN, in 1942. The altitudes of this edition were adjusted for refraction at a height of 10,000 feet. This volume met with immediate success. By the time the 'first' edition was printed in 1951, for epoch 1955.0, more than 20,000 copies of the preliminary edition had been distributed. The 1951 edition dropped the refraction adjustment feature from the altitudes, and had an improved selection of stars. It was followed in 1952 with two volumes for declination entry at 1° intervals from 0° to 29°. In 1952 and 1953 a British edition was published with identical tables (A. P. 3270) but altered explanation. The tables have been accepted as standard by the air forces of Great Britain, Canada, and the United States. They are in limited use by mariners."

The following is an excerpt from page 541 of the same printing:

> "**Hoehne**. In October 1941 George G. Hoehne, an American, proposed a set of tables similar to the star section of H.O.Pub.No.218, except that a value approximating LHA♈ would replace meridian angle of the star as an entering argument, and a maximum of ten stars would be given in parallel columns for each whole degree of entering value. The value used for entering the tables would be determined by adjusting LHA♈ by an amount tabulated for each year for each star used. This would prevent the tables from becoming inaccurate because of precession of the equinoxes (Art. 1419). Refraction at altitude 5,000 feet would be included as in H.O.Pub.No.218. One volume of these tables (volume II, lat. 20°N to 39°N) was published in 1943."

Alton B. Moody clearly confused Hoehne's October 11, 1941 proposal with what was to become *Practical Celestial Air Navigation Tables* (*PCANT*). A possible reason for this is Hoehne's 1941 proposal could have been in the National Archives (not Federal Records Center as would be the case today) during the time Moody was working on the 1958 edition of Bowditch and during such time that Moody had access to much information pertaining to Hoehne and the *PCANT*. Moody could have assumed that the tables actually published by Hoehne were the same as the 1941 proposal. Whatever the reason, Moody clearly confused *PCANT* with the October proposal as will now be demonstrated.

First. In his 1941 proposal Hoehne used *integral* values of LHA♈. There was no value approximating LHA♈.

Second. In his 1941 proposal Hoehne had not yet developed a tabular correction method for precession in right ascension. His compilations were current and satisfied the air navigation accuracy requirements of the immediate future. Moody addressed an adjustment due to precession of the equinoxes. (Even if he had referred to *PCANT*, not the 1941 proposal, he erred with respect to the application of the correction. With *PCANT* the correction was applied to the GHA♈ (not LHA♈ as stated by Moody). An assumed longitude would be taken to obtain an integral value of T (approximate LHA♈) for entering the main body of the table.

Third. Approximate LHA♈ comes from the clever method Hoehne used to construct *PCANT* from H.O.218. Sometimes Hoehne used approximate LHA♈ for the integral value because the integral value is usually different from the arc measure of the actual LST (local sidereal time) or LST at a given moment.

Conclusion. Moody confused *PCANT* with Hoehne's October 11, 1941 proposal.

(To be continued)

CORRECTION

A Simplification of the Method of Lunars

By Michael S. Preston

On page 7 of Issue Sixty-four (Summer 1999), in the right-hand column, and lines 7 and 9 from the top, the quantities in parentheses should read 15° and 45°, respectively.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

The first time ball was dropped in Portsmouth, England, in 1829.

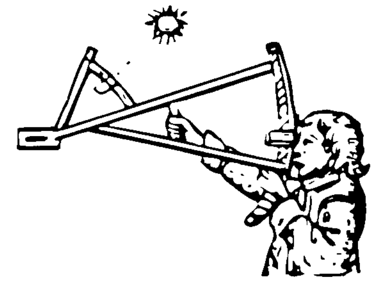
The time ball is a visual time signal in the form of a ball. Before the widespread use of radio time signals, time balls were dropped, usually at local noon, from conspicuously-located masts in various ports. The accuracy of the signal was usually controlled by a telegraphic time signal from an observatory.

Beginning in 1845 a ball was dropped every day at noon at the U.S. Naval Observatory, then at 23rd and E Streets, N.W., so that time would be known every day to the inhabitants of Washington, D.C. The New York City time ball drop was inaugurated in 1877 using a telegraph signal from the U.S. Naval Observatory delayed 12 minutes to allow for the time difference between New York and Washington, D.C. in those pre-time-zone days.

In 1885, the daily time ball drop was relocated to the State, War and Navy Building (now the Old Executive Office Building) next to the White House. The practice ended in 1936.

A golden time ball will be dropped to mark the precise instant the year 2000 arrives in Washington, D.C. This ball will be dropped again a year later to mark the precise instant the 21st century arrives in Washington, D.C.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-SIX, WINTER 1999-2000

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

The New Year is here and we are still serving our many loyal members. When Admiral Davies and I started The Foundation, he thought if anyone was interested at all The Foundation would not last beyond a couple of years. We are happy to say that since getting our tax exempt status we have been serving our members for 18 years.

From time to time we receive a bank draft with no identification other than the name of the bank. If you use a bank to send in your membership contributions, please put in a note identifying the member. We want to keep all of our members lists up to date and correct.

Director Luykx informs me he has a complete set of Nautical Almanacs from 1970 to 1999. The only exception to all U.S. Gov't. issues is the 1974 that, I believe, is the British Edition. If any member is interested in purchasing the entire set call John at 301-420-2468 or e-mail him at navluykx@netscape.net. He is not interested in selling individual copies.

CelestAir has published a new catalog and along with it has produced a companion to it. It is called "Celestial Positioning". A Teacher's Guide to an Earth Science Project. It has History, Mathematics and astronomy integration. Contact CelestAir at info@celestair.com, call them toll free at 1-800-727-9785 or 1-316-686-9785, or check their web page at http://celestair.com.

A few reminders: your contribution is tax deductible on your Federal Income Tax Form; we are a book dealer for McGraw-Hill and can provide books on any subject, from them. Discounts on some publications may vary but I believe we can still provide the 20% on all books ordered from them.

I am sad to report that long time member Captain Robert T. Campbell of Boothbay Harbor, Maine has passed away. We received many notes of appreciation from him on the contents of The Navigator's Newsletter.

If a member does not receive a copy of the Newsletter, a replacement copy will be sent at no charge. If a member wishes to order back issues or has lost an issue or issues that they want replaced, the prices are as follows, postage paid: 1 to 3 copies of back issues $5.00 each; 4 to 10 issues $4.00 each copy; 10+ copies $3.00 each. We apologize for the increase for back issues but we now have to photocopy many of the back issues and the increased cost has dictated that we charge more.

DO YOU KNOW . . .?
By Ernest Brown
When the H.O. 249 method was first used in air navigation?
(See final page of this issue.)

READERS FORUM

Edited by Ernest Brown

Member Richard Preston wrote from DeKalb, Illinois on November 25, 1999:

"Enclosed is a note in answer to the question from Richard Stachurski as to how far away the horizon or other object must be when checking index error. He also asked for help in understanding the geometry of the index error. I hope this note provides satisfactory answers."

—— *Sincerely, Richard Preston*

Director Allan E. Bayless wrote from Pompano Beach, Florida on December 10, 1999:

"You are quite right. The 1938 Admiralty Manual shows the same divided triangle for the Aquino method as the Ageton method, i.e., the perpendicular is dropped from the body to the meridian. A duplicate of this diagram also appears in Aquino's *Universal Sea and Air Navigation Tables*, 1938, on page xxviii. Further, the same diagram appears in Aquino's *Modern Methods in Sea and Air Navigation* in the *U.S. Naval Institute Proceedings* for January 1927, pp. 17-34 on page 27.

"However, in the 1943 edition of Aquino's *Universal Nautical and Aeronautical Tables*, on page 7, he shows the perpendicular dropped from the zenith to the hour angle of the body. It was on the basis of this figure I compared Aquino with Davies' *Concise Tables* of 1984 (Janiczek sent me the info on Davies' method in 1983). I guess it was from this comparison I remembered *only* the division of the azimuth angle. The earlier figure (perpendicular from body to meridian) appears on page 16.

"The numerical tabulations appear the same in the two editions, but the entering arguments differ and are multiple. Although he doesn't say so, I suspect the tables of 1943, seemingly unchanged from 1927 except for the multiplicity of entering arguments, apply to *either* diagram as Aquino was always zealous in adapting his tables to *everyone's* method. After all, any method using the divided triangle can be thought of as a division of the general right spherical triangle with differing notation depending on which vertex is divided. At least, that's what occurs to me at the moment. If you think it's worth pursuing, I'll look into the matter further. (I recall D.H. Sadler devised a 'short method' with division of the polar vertex, for example.)

"The 1943 edition lists all the prior Aquino editions:

First Brazilian edition	1903
First English edition	1910
Second English edition	1912, 1917, 1918 (H.O. 200)
Third English edition	1924
First North-American edition	1927
'Universal' North-American edition	1938
Second Brasilian edition	1943

"The 1943 edition was printed in Brazil, but is written in English. The original was apparently a presentation copy. I don't remember the source.

"An interesting quotation from Aquino's 1938 edition, Chapter II, The Aquino Methods of Solution, p. x:

> 'The principle upon which these tables are based is as old as Spherical Astronomy itself, and naturally it was the only way of solving spherical triangles until, as DOTT. PESCI informed us, ALBATANI (880-928 A.D.) discovered the well-known relation (erroneously attributed to Euler) between the three sides and an angle of a spherical triangle
>
> $$\cos a = \cos b \cos c + \sin b \sin c \cos A$$'"

—— *Cordially, Allan*

Member Frederic C. Kapp wrote from St. Simons Island, GA:

"In this day of electronic ditsies, the use of celestial navigation is on the decline. This is too bad, because navigating by celestial is rewarding and most important, serves as a backup should the black box fail.

"In June, I had the pleasure of occupying the navigators berth aboard Ron Chevrier's lovely sloop *Seaflower* in the Marion/Bermuda Race. We were in the celestial division. Some twenty hours into the race, the log went south and did not return for the rest of the voyage. Although this failure did not cause undo consternation to Ron and myself, it did point up the fact that electronics, in a salt water environment, on small vessels, are at risk.

"I used a celestial calculator (Celesticomp V) and it is dandy, but it is allergic to salt water and there is always the possibility of a break down. I also carried as a backup a scientific calculator which can reduce a sight with no tables at all. Once again, this is a gadget and could fail. Ron had on board Vol III, HO 229 as a tabular backup for the calculators. The discussion here, however, is what reduction method should the small boat navigator carry on board as a celestial navigation backup?

"Many years ago I taught myself celestial navigation. The first reduction method I used was HO 211 and I still use it today. This wonderful little set of tables was developed by Lt. Arthur A. Ageton in 1939. My copy was published in 1943. All LOPs are plotted from the DR position and Hc and the True Az of the sun can be had without interpolation. The book itself is small (6"x9

CORRECTION

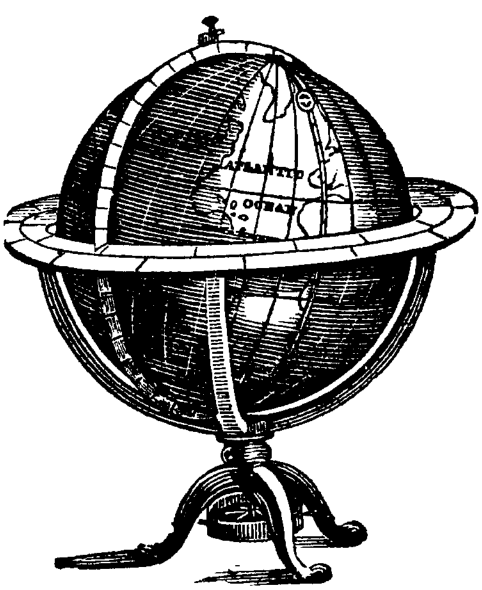
In Issue Sixty-five, right-hand column of page 2 and in second whole paragraph from bottom of page, delete last sentence which reads: "I'm inclined to suspect that if any two altitudes of the sun will give a good latitude and/or local hour angle using lines of position, they'll give a good latitude and/or local hour angle using Douwes' method."

In his e-mail of 6 December 1999, reporting the incorrect statement above, Bruce Stark added: "The fact is, with a line position fix you use the correct declination for each altitude. With Douwes you have to choose one declination and stick with it – that of the greater altitude if you're most interested in latitude, that of the lesser altitude if you're most interested in local time. Or you can use a declination somewhere in between. Any way you work it, the change of declination hurts accuracy."

1/4") and about 1/4" thick. It is very light and easy to stow. A sailor can navigate anywhere using any body. One could use The Concise tables in The Nautical Almanac, but I find them to be difficult to use and they require two separate entries. HO 229 consists of six volumes and HO 249 consists of three volumes. All of these books are large and on a small vessel can be unwieldy and all require interpolation. Weight and stowage space are a major factor. Also, Vol II and III of HO 249 are limited to bodies with a Declination of 29 degrees or less. Vol 1 is for only seven selected stars, and all of the above mentioned reduction methods require the plotting of assumed positions (i.e. four stars, four APs) to be plotted from which the azimuth and intercept are plotted. Advancing or retiring four APs can be tedious.

"One disadvantage of HO 211 is that the tables do not lend themselves to the use of a multiple sight form. However, we are talking about a celestial backup, and working with the sun four or five times during the day is not an onerous task. Stars have to be done on a separate form for each sight.

"One other difference between HO 211 and the more modern tabular methods is that it requires the finding of meridian angle (t) as an entering argument. HO 249 and HO 229 use Local Hour Angle as an entering argument. LHA is the angle at the elevated pole between the meridian of the observer and the meridian of the body, measured westward through 360 degrees, while meridian angle is the angle at this pole between the meridian of the observer and the meridian of the body measured ***Westward to 180 degrees or eastward to 180 degrees.*** Thence (t) is labeled East or West. When taking out the azimuth Z, the azimuth is labeled by the prefix of the latitude and the suffix of East or West the same as (t). The Zn is thus determined. Therefore, the use of a time diagram is essential. The book has several example problems in the front, but it refers to LHA which is really meridian angle (t). There are a few simple rules to follow, and these are detailed on every page. With a proper form, HO 211 is an ideal method, it is inexpensive, takes up very little room, and it is fun to use.



"I quote from the introduction:

"The distinctive features of this method of navigation are

1. The D.R. position of the ship is used for working sights and plotting lines of position.
2. There is no *interpolation* for practical navigation.
3. The azimuth is most positively determinate.
4. The solution is short, simple, and *uniform* under all conditions.

"The method of solving navigational problems here given is applicable to all problems regardless of the position of the heavenly body, be it sun, moon, star, or planet.

"It requires few figures and gives quick solution for determining (a) line of position, (b) compass error, (c) Great Circle source and distance, (d) time of body on the prime vertical, (e) reduction to the meridian.

"I enclose a blank form which I have constructed and two worked out sights. The sun sight gives an example of converting LHA to meridian angle (t) and gives an example of Z=N 106 52 E to give Zn 106.9.

"The Antares sight gives an example of naming of Zn = 360-Z.. (N 160 04 W) to give Zn 199.9. In South latitudes, Z would be prefixed S and suffixed E or W according to the label of t. For example S 55 – 25'W would be 180 + Z to give Zn 235-25'; S 55 - 25E would be 180 -Z to give Zn 124 -35.

"Both examples show the use of a time diagram to determine t from GHA and the observers meridian.

"A few hours working problems should make the user proficient. Using the form makes the entering of numbers easy, and the sequence follows logically to its conclusion. The user will quickly learn tricks to speed the process.

"I love these tables and I hope the reader, after time, will love them too.

"For a small expenditure, the navigator can go anywhere with confidence. All he needs is an inexpensive digital watch set to GMT, HO 211, a current Nautical Almanac, a sextant, and I would also suggest another favorite of mine, HO 2102D Rude Star Finder. It is assumed that the navigator has a reliable source for time signals, and/or that he has rated his watch.

"Besides being an intellectually stimulating exercise, no machine can supply the reward and satisfaction that is achieved by the ability to locate yourself by celestial means."

Editor's note — See page 4 and 5 for the two sight reductions.

TIME	SIGHT DATA	ALTITUDE
	Sight No. 1	

Date 30 AUG 1999 Body ☉

GMT 13 00 00 DRL 38 30.0' N

G Day/Mo 30 AUG DRLo 68 30.0' W

He 8.0 ft

Hs 33 29.2'

IC ( ) 0.0'

SHA * ___ ___ . ___'

Dip (−) 2.7'

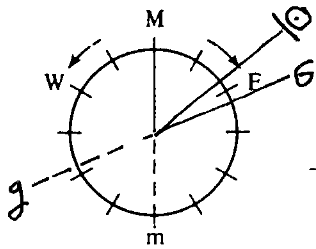
Ghr 14 49.1'

hsc (−) 2.7'

Gms 0 00.0'

ha 33 26.5'

v ( ) __ . __'



[HP Moon ____ . __']

v corr ( ) ___ . __'

Declination

Main (+) 14.5'

Total GHA 14 49.1'

Dec 13 hr

[Ad PL ( ) ____ . __']

+ 360

GHA 374 49.1' 9.02.7 (N)/S [UL Moon (-) 30.0']

DRLo 68 30.0'W d (−) 0.9' [Addl Ref ____ . __']

LHA 306 19.1' Dcor 0.0

hac (+) 14.5'

Dec 9.02.7 (N)/S Ho 33 41.0'

t 53 40.9'E A 9380

Dec 9 02.7'N B+ 543 A 80368

A 9923 B- 21778 B 21778 A 9923

K 15 02.5N <---------------- A 58590

DRL 38 30.0N

K~L 23 27.5 -------------------------------------> B+ 3747

Hc 33 45.0 <------------------------------------- A 25525 B- 8015

Ho 33 41.0

a = 4.0 Awy Zn = 106.9 Z = N 106 52.E <--------- A 1908

* K name same as Dec ** L same as K subtract L diff than K add

(See Frederic C. Kapp in READERS FORUM)

TIME | SIGHT DATA Sight No. 1 | ALTITUDE

Date 30 AUG 1999 | Body ANTARES | He 8.0 ft

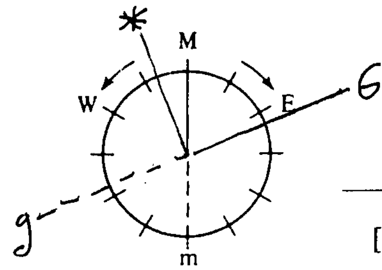
GMT 23 51 00 | DRL 38 30.0' N | Hs 22 22.1'

G Day/Mo 30 AUG | DRLo 68 30.0' W | IC ( ) 0.0'

SHA * 112 39.4' | Dip (–) 2.7'

Ghr 323 41.3' | hsc (–) 2.7'

Gms 12 47.1' | ha 22 20.0'



v ( ) __ . __'

v corr ( ) __ . __' | [HP Moon __ . __']

Declination | Main (-) 2.3'

Total GHA 449 07.8' | Dec 23 hr | [Ad PL ( ) __ . __']

– 360

GHA 89 07.8' | 26 . 25 . 8 N(S) | [UL Moon (-) 30.0']

DRLo 68 30.0' W | d ( ) ___' | [Addl Ref __ . __']

LHA 20 37.8' | Dcor __ . __ | hac (–) 2.3'

Dec 26 . 25 . 8 N(S) | Ho 22 17.7'

t 20 37.8' W A 45298

Dec 26 25.8' S B+ 4796 A 35149

A 50094 B- 2277 B 2277 A 50094

K 27 58.5 S <---------------- A 32872

DRL 38 30.0 N

K~L 66 28.5 ------------------------------------> B+ 39886

Hc 22 15.5 <------------------------------------ A 42163 B- 3363

Ho 22 17.7

a = 2.2 TWD Zn = 199.9 Z = N 160 04 W <--------- A 46731

* K name same as Dec ** L same as K subtract L diff than K add

(See Frederic C. Kapp in READERS FORUM)

Member Lanny Petitjean sent by e-mail on 29 November 1999:

"I was wondering if it is possible to obtain back issues of the Navigator's Newsletter. If it is, I would like to obtain issue sixty of The Navigator's Newsletter, Summer 1998. I am very interested in reading Bruce Stark's article. I will be happy to send a check for whatever the costs are. Please let me know when you get a chance. My e-mail address is LannyNoel@aol.com.

"I recently became a member of The Foundation and have really enjoyed reading issues 64 and 65, especially the articles on lunars. As a backyard navigator, I have taken a number of lunar distance observations in the last year using Bruce Stark's book and have come up with results similar to those shown by Robert Eno in his article. I wholeheartedly agree with Robert Eno's conclusion that Stark has made the process simple enough for the average navigator to try his hand at lunars.

"In addition to using Bruce Stark's book to clear the lunar distances, I have also used a pocket calculator and the formulae developed by John Letcher, Jr. In his book *Self-Contained Celestial Navigation With H.O. 208* to clear the same observations and found the results to be the same as obtained by Stark's book. It has been interesting to me to learn two methods for clearing the lunar distance."

— *Sincerely, Lanny Petitjean.*

Kieran Kelly wrote from Sydney, Australia on October 14, 1999:

"I recently commanded (and was the navigator for) the North Australian Expedition 1999 – a pack horse trip into the Australian desert commemorating A C Gregory – our Meriwether Lewis. The instruments used were a C Plath sextant and an 1850 Dolland artificial horizon (London). Would you please supply your e-mail address.

"I am particularly interested in celestial navigation and the use of sextants in land based exploration and would be interested in hearing from other members familiar with this type of navigation, especially those with experience in the field."

— *Regards, K. Kelly*

Member Leslie J. Finch forwarded on 4 December 1999 the following account of his last Army National Guard deployment outside the United States:

A SATISFYING SIGHT

By Leslie J. Finch, Staff Sgt., NYANG, Ret.

Errol Flynn started it all. I was ten years old and "'Double Features" cost a whole quarter – but Flynn never failed to surprise the Spanish captain's ship. Thousands of miles through raging seas, (no reefs in his sails!), and suddenly there he was right on station – "Wham" – the raging battle, the leaping, ringing swordplay and VICTORY! Heady stuff but how did he find his way there? He couldn't just ask directions. Could he simply follow a compass heading for weeks at a time and make a calculated landfall? Exactly? There was a mystery here, and a simple acceptance, without understanding, among adults that you "navigated" to your destination. O.K., but "how"? Things unraveled pretty quickly at that question. Thanks to my Dad, who took my questions seriously and gave me serious answers, I built a crude sextant and began to understand just how incredibly difficult it is to tell exactly where you are on this wobbling globe of ours. Thus began a lifelong fascination with determining for myself where I, or, where I wanted to be was – and how to get there. I'm a self-taught amateur who still feels the thrill of discovery when my sights match the published position indicated.

Granted, one can purchase handheld GPS equipment today for the price of a good lunch, but what happens when the battery gives up or the satellites go down?

My last year in The Guard before retiring was also the first year our Engineering Company Detachment would deploy outside the United States for "Summer Camp". (Our yearly two weeks of training.) In this case, "Summer" was defined as the last week in January 1997 and the first week of February 1998. Detachments generally tend to be orphans and pretty much out of the loop. Due to a technically competent CO who totally lacked people skills, us "orphans" were really in the dark. Basic wheedling, deviously and repetitively applied, disclosed we would be going somewhere in Honduras near a town possibly named "San Pueblo". Our mission was "Hearts and Minds Through Better Engineering" – we were actually going to build something for them and not tear it down when we left. It was made crystal clear that stripes would be lost if we "bothered" them further.

"Shut-up and follow orders!" left something to be desired, so I set about finding out all I could about Honduras and Guard policy from public sources. (Library, Congress, Internet, etc.). It seems the USA was less than loved by the public in this crushingly poor and still backward nation and our military held in even lower regard. Having locals decide what construction would best serve their needs became policy to, hopefully, ameliorate this situation. While I learned a great deal about their history, economy, exchange rate, tourism, corruption, violent crime, etc., I could find nothing helpful to someone who intended to do construction work. Terrain, rainfall, ground cover, local agriculture, typical weather pattern for the time of year, and climatic expectations – Nada. Neither could I find "San Pueblo" on any map – I did find an airfield, Coronel Enrique Soto Caro, in South Central Honduras, and guessed that would be our entry point.

I looked at this as an explorer might, and worked up my land navigation kit. I purchased Tactical Air Charts and talked to an Air Guard pilot friend who had experience in these kinds of deployments. He suggested the probable aircraft type and the refueling site. We would start from Stewart AFB in Newburg, NY, probably refuel at Montgomery, Alabama, and then go non-stop to Honduras. I calculated a point to point course, distance, and time of flight. I had read about early explorers determining altitude using the boiling point of water. No one I contacted had a reference, but by dumb luck, I stumbled across "Babinet's Formula for Determining Elevation by the Difference in Barometric Pressure" in the 1943 edition of The American Practical Navigator. One needed the Vapor Pressure tables in The Hand Book of Chemistry and Physics, which I photocopied, a calculator, and a thermometer. (Given the realities of Army deployment mercury/glass was out – I took a metal Taylor's digital cooking thermometer.) Also into my Alice, Large, rucksack went my Davis Mk 15 sextant with my homemade artificial horizon. (From Peary's design for his 1908 North Pole expedition), Almanac reduction form, and scrounged maps. I had my point to point and my equipment – I was ready to go.

We lifted from Stewart in a chartered L1011 on a nasty, freezing cold, rainy day. In any case, we did land at Montgomery, Alabama and I chatted with the pilot, explaining my interest in navigation and the point to point I had hand calculated. My guess that Coronel Enrique Soto Caro airfield was our destination proved correct. He very kindly punched my plan into the aircraft's flight computer and it matched his. "I could fly by that, Sarg," he said. (Eat your heart out, Flynn!)

We debarked the plane into another world, one with a sun blazing from a brilliant blue sky. Hot, and very dry, as if a huge furnace was breathing in your face. There were exuberantly flowering shrubs, banana and breadfruit trees, and pastel colored cottages with red-tiled roofs. Winslow Homer would have loved it, but kicking at the hard as rock clay laden soil gave this engineering grunt a bad feeling.

We boarded chartered local buses to convoy us to our base out in the boondocks. This ranked as one of the most unforgettable rides of my life – right up there with my first roller-coaster ride. Our Honduran driver informed us in no uncertain terms that his handle was "Spider Man" and we would learn that he had earned it. Now, to plodding Army types such as myself, the term "Convoy" contains not a whit of inter-mural competition – simple nose to tail all the way home. To Spider Man, and apparently every other Honduran bus driver, "Convoy" translates as "Race to the Death." True to his word, he clung to road edges, leapt ditches in a single bound, just touched buildings, trucks, other buses, pedestrians and livestock without causing major damage, made some incredible saves when it was clear we would roll over, and delivered us intact, if car-sick, to base. I saluted him as he pulled away – he had real talent.

As soon as I heaved my gear on my cot, I dug out a thermometer, a trioxane fuel bar, and boiled up the water I had carried all the way from New York in my canteen cup. I had intended to do a boiling point reading every day to average out barometric pressure changes, but remember that solid as rock "dirt" I had tried to kick up? Right – we had a terrible time and worked until we literally dropped in order to get our building tasks completed. We did the job, leaving the local people two good sized, really well constructed concrete block, steel reinforced, buildings destined to become a school and an infirmary, but it left me practically no free time from my supervisory duties to pursue my passion. That one reading after calculation and plugged into Babinet's Formula indicated an altitude of 4,500 feet. My Air Charts and a buddy's altimeter watch said 2,500 feet – ah well, one of life's little disappointments, but getting those buildings up right came first. I was really dragging. (Our other sergeant became ill and I was "up" all the time.)

I did get in two morning sun sights one day, and two days later three afternoon sights. I worked out lines of positions sitting on my cot whenever odd moments of free time presented themselves. The fix was close to the A. P. I had picked, but my exhaustion stole the thrill I had expected to feel. However, it seemed possible, given our location, that the Southern Cross might be visible low on the horizon very early in the morning. I managed to get up at 0230 hours and sure enough, there it was — low on the southern horizon. The "Victory at Sea" theme, "Under the Southern Cross", came to mind, and the hair stood up on my arms. Naval battles that changed the tides of war; History made by those who had gone South – sailors, explorers, whalers, and Australians. Brave men all. At the same time, the Dipper and Polaris lay low on the northern horizon. Strange and wonderful to this Yankee who had never in his lifetime expected to see such a sight.

Note: If there is any interest, I would be glad to provide details concerning Babinet's Formula and on constructing an artificial horizon.

Editor's note: The following in an excerpt from that part of the 1943 edition of Bowditch referred to by Member Finch:

Determination of heights by barometer –

The barometer may be used to determine the difference in heights between any two stations by means of the difference in atmospheric pressure between them. An approximate rule is to allow 0.0011 inch for each difference in level of 1 foot, or, more roughly, 0.01 inch for every 9 feet.

A very exact method is afforded by Babinet's formula. If B_o and B represent the barometric pressure (corrected for all sources of instrumental error) at the lower and at the upper stations respectively, and t_o and t the corresponding temperatures of the air, and C a computed value; then,

$$\text{Diff. in height} = C \times \frac{B_o - B}{B_o + B}$$

If the temperatures be taken by a Fahrenheit thermometer,

$$C(\text{in feet}) = 52{,}494\left(1+\frac{t_0+t-64}{900}\right);$$

If a centigrade thermometer is used,

$$C(\text{in meters}) = 16{,}000\left(1+\frac{2(t_0+t)}{1000}\right)$$

Member E. B. Forsyth wrote this Newsletter #3 from Long Island, New York in May, 1999:

"Dear Friends, This last newsletter of the trip covers our mad dash up the Atlantic from Cape Town to Long Island and the brief stops we made on the way. I wanted to be home in time for the annual Vintage Bentley rally held in late May. We made the roughly 6000 mile journey from South Africa to Bermuda in eight weeks, including stopovers. The South Atlantic gave us fair but mild winds up to the doldrums. We never reefed the main during the two-month cruise. A couple of hundred miles south of Barbados the trade Winds became light and erratic and we powered more than I liked until we got to Bermuda. We spent eight days there, during which my daughter Brenda joined us. When she left, we had a stormy passage to Newport, Rhode Island.

"When we pulled into Cape Town, Mike's parents, Jean and Roy Demont, were waiting at the Royal Cape Yacht club to greet us. Thanks to the ham radio net we had joined on the way from Tristan da Cunha they knew exactly when we would arrive. They gave us a quick tour of the Cape of Good Hope region south of Cape Town and the new waterfront development in the city itself, then Mike left with them to spend nearly two weeks at the farm. The remaining crew member, Bruce, looked up some of his old pals from the time he was a student and after a couple of days became so nostalgic for his homeland in Zimbabwe he decided to stay and so once again I was looking for crew. Fortunately, finding replacement proved easy. Bill Steenberg had just spent a year working as a volunteer on a housing project in Zimbabwe and decided it would be neat to sail home to the U.S. We linked up at the yacht club and he signed on. There was a fair amount of maintenance needed to repair the ravages of Our Antarctic cruise. Each day Bill and I worked on those in the mornings and behaved like typical tourists in the afternoon. A complication was the heavy wind at the yacht club dock, it howled every day. When a large oil drilling platform that was undergoing repairs broke loose at a dock about a mile away the local paper reported the wind at 65 kts, the highest we experienced during the voyage. The wind rapidly shredded flags, burgees and halyards, anything that was free to flap. To make matters worse the covers blew off some railway cars upwind and distributed the contents, copper ore, over all the boats at the club. The oil rig sank several small ships as it ricocheted down Cape Town harbor. Cape Town far exceeded my expectations, it is a clean, modern city with pleasant streets, parks and museums. I never felt threatened and met nothing but courtesy from the locals of all colors. A bonus, thanks to the ludicrously under-valued rand, are the low prices to anyone with dollars. For example, Bill and I ate out on the last night in Cape Town at a nice restaurant for a total bill of $8, including beer. Bill had rented a car during his stay for $17 a day, which we used to restock the galley in several heavily loaded trips from the local supermarket. When Mike returned we left for St. Helena.

"Jamestown, the capital of St. Helena, lies on the west coast in a steep valley. Apart from this rather dramatic setting it reminded me of a small English village of the 1950s. There is no airfield and contact with the outside world is maintained by infrequent ships. This has led to a leisurely pace of life and feeling of timelessness. The shops have heavy wooden counters that smell of furniture polish. When I bought some onions, they were weighed on a scale with iron weights in one pan. There is a sunken steamer in the harbor (it caught fire and sank in 1911) which provides great snorkeling. We rented a car and toured the sights, of which the most famous is Longwood, Napoleon's place of exile after he was defeated at Waterloo in 1815. It is quite a modest house for a man who was once an emperor. He lived there with a few aides and servants until he died in 1821. During the tour we saw huge fields of flax left to grow wild. Apparently some years ago the British Post Office decided to switch from string to elastic bands and that killed the market for St. Helena flax. We ate out each night in a beautiful open air restaurant surrounded by tropical shrubs and flowers.

"When we left we had the south equatorial current under us which added about 20 miles a day to our progress. The days and evenings were warm, at night the stars shone with great brilliance, each morning we had a crop of flying fish to consign to the deep. Dolphins cavorted alongside and sometimes birds would alight on the whisker pole or radar post and hitch a ride. Mike and Bill honed their skill at celestial navigation, the sun sights got pretty good, within a few miles, but their one star sight that gave a credible fix was twenty miles off - good job the GPS receiver was working. The 1,900 mile leg to Fernando de Noronha took two weeks. Fernando is a small island about 150 miles off the northeast coast of Brazil. It has lush vegetation and startling, steep, pinnacles of volcanic origin. There is a runway, built by the allies in WWII, and a small tourist economy based on modest hotels and restaurants. The locals all drive dune buggy versions of the VW beetle, which is still produced in Brazil. We took a tour in one and discovered most of the roads are awful, just dirt tracks with lots of muddy puddles. Still, Fernando made a very pleasant interlude, especially the change from boat cooking. Unfortunately there was a dark side to the island's past. When Brazil was a Portuguese colony, Fernando was a prison. The ruins of the grim fort we explored witnessed a couple of centuries of cruelty to the unfortunate inmates.

"Almost as soon as we left Fernando de Noronha we ran into the doldrums, a region several hundred miles wide of calms, fickle winds and intense squalls. We slowly worked our way through and once we were far enough north we picked up the northeast trade winds. Now we started to move, past Sao Luis of so many memories from the 1995-97 cruise, past the Amazon delta - the sea was muddy even a hundred miles to seaward - and past the coast of French Guiana. Here we enjoyed a spectacular sight, just after sunset a large rocket, launched by the European Space Agency, blasted into the sky on our bow. When it was overhead, it separated with a huge smoke ring and the booster fell into the sea on our starboard, trailing sparks. When we crossed the equator, Bill was inducted as a son of Neptune, which we sealed with a toast of Umzumbe Dew, a potent liqueur made from sugar cane which Mike brought back from Natal. By coincidence, we held the ceremony on the *Blue Moon* in March. A few nights later we had a brilliant stellar display after moonset - the Pole Star and the Big Dipper on the starboard, Orion overhead and the Southern Cross on the port quarter. A few hundred miles from Barbados we experienced a light counter current instead of the steady push we had before from the equatorial current. This, combined with a drop in the Trades, slowed us down but we made it to Barbados in two weeks from Fernando de Noronha. My main reason for choosing Barbados as our Caribbean landfall was to find the grave of my great-grandmother Susannah who was buried there is 1882. She was the wife of the Regimental Sergeant Major of a British regiment stationed in Barbados, the main British military base in the Caribbean by then. She died in childbirth and I found the grave of Susannah and her baby in the neatly kept military cemetery. After that we went on a tour of the island in a taxi driven by one Dwight. We wound up at the Mount Gay Rum Distillery. Dwight said it was his birthday, what with the sample rum and the toasts to Dwight's birthday we all got pretty merry. We planned to sail to a beach for the afternoon and considering Dwight's condition, we thought he would be safer off the road so we invited him along. Unfortunately poor Dwight got as sick as a dog in the brief two-mile sail from our anchorage to the beach. When we were leaving Barbados I went to the customs officer for outward clearance. As he was completing the forms, the official asked where we had come from. I mentioned Cape Town, but said before that we had been in Tristan da Cunha, South Georgia and Antarctica. He didn't know where they were but there was a large world map on the wall of the office, so, ever helpful, I sprang up to point out these places. Unfortunately the map's border came a little south of Cape Horn, so I pointed vaguely below the edge of the map and said, "Down there!" He was profoundly impressed - his jaw almost literally fell and he repeated, "You sailed off the edge of the map!" I felt like the ancient mariner who feared they would sail off the edge of the world. Our next stop was St. Martin, partly to restock our vital Mount Gay rum supply and also to see our old friends Kay and Victoria Pope. After a day we sailed for Bermuda. The highlight was a flying visit to the boat by my daughter Brenda, fortunately the weather cooperated as we cruised the beautiful western shore. As soon as Brenda left, we sailed for Newport RI despite gloomy weather predictions. They were right, we had northeasterly winds the whole way, usually 20 to 30 kts which certainly kicked up a rumpus in the vicinity of the Gulf Stream. Although it was a wet sail, we set a record for *Fiona*: 3 3/4 days from the Mills buoy off St. George to Brenton Reef buoy off Newport. In contrast to the first part of the cruise, we had two reefs in the main nearly all the way. After clearing customs Mike and Bill toured historic Newport and I attended a meeting of the Cruising Club of America which, coincidentally, was held in Newport at the same time. We spent a night at Wickford visiting old friends from the Bentley Driver's Club and then sailed home in thick, thick fog via Block Island. We sailed up the Patchogue River at high tide on the evening of 9th May (a day later than the cruise timetable) and tied up at F.M.Weeks Yachtyard. We had logged 21,785 nm since leaving last July. Until my next cruise, best wishes."

— *Eric*

NAVIGATION NOTES

Lewis & Clark's Equal Altitudes

By Bruce Stark

As with their other astronomical observations, Lewis and Clark's "equal altitudes" make more sense if you understand how they were observed, worked, and used two centuries ago.

Like a time sight, an equal altitudes observation finds local time. But it is more trouble than a time sight. It ties the navigator up both morning and afternoon, and if he isn't set up and awaiting at the right moment in the afternoon, or if a cloud drifts over, the observation is lost. For the Corps of Discovery, having to lay over a day to complete the observation was no small matter. It meant the loss of a day's travel.

But an equal altitudes observation, taken on shore with a reflecting pool horizon, finds the time more precisely than a time sight. Unknown instrument error cancels out. And with the procedure Lewis follows —observing contact, overlap, and separation both morning and afternoon—personal error tends to cancel out as well. I'll explain this procedure shortly.

The primary use of equal altitudes was in determining a chronometer's rate of gain or loss. The idea was to find how fast or slow it was on one day, and then again some days later. Any difference showed that the chronometer was gaining or losing. Dividing the difference by the number of days gave the chronometer's rate.

Whenever he was in port, a ship's navigator wanted to update the chronometer's rate before putting to sea again. If there was no time ball or observatory to rely on he did the job himself with equal altitudes.

Henry Raper, in his *Practice of Navigation*, (on page 276 in the 10th, 1870 edition) wrote that "As the chronometer rarely goes for any length of time without some irregularity, the rate should be deduced afresh at every opportunity." And "The best observation (out of the observatory) for the purpose, is equal altitudes carried on for several days."

The United States government had provided Lewis and Clark with a chronometer. Any chronometer would be expected to change rate often on an expedition such as they were undertaking. The motions, jolts, and temperature changes would be worse than anything experienced on a ship. That, I believe, is why the captains observed equal altitudes instead of time sights—to keep a running record of the chronometer's rate.

Unfortunately this didn't work as well as it might have. Observations ought to be made at the same location, ideally five days or more apart. But, since their primary goal was to cross the continent, Lewis and Clark had to keep moving. So chronometer error found at one camp generally has to be compared with that found at another camp. For this to work, change of longitude between camps must be allowed for; and change of longitude—as determined by dead reckoning—is seldom accurate.

But to get to the observation itself. Here, I believe, is the way Lewis made it: In the morning when the sun was high enough to be reasonably free of abnormal refraction—but the nearer due east the better—he made himself as comfortable as he could with his sextant and reflecting pool horizon. He pulled the sun's image in the sextant mirror down below the image reflected in the water, leaving a gap between the two images. He clamped the index and waited. A moment later the limbs of the sun's images touched and he called out. Whoever was watching the chronometer recorded what it read at that instant. When the sun's two images exactly overlapped, Lewis called out again—and a third time as the two images separated. Then he read the sextant, so he could set it to the same angle for the afternoon part of the observation.

In the afternoon Lewis had to be in place and ready when the sun came down to that angle. It would be descending as it touched, overlapped, and separated from its reflection in the artificial horizon. Otherwise, this was a repeat of the morning half.

Here is an observation Lewis took on July 17, 1804. You can find it on page 389, volume 2, of Gary E. Moulton's *The Journals of the Lewis & Clark Expedition*, University of Nebraska Press. It's of special interest because results are shown. Lewis apparently worked it in the field, rather than leaving the job for someone else.

	h	m	s		h	m	s
A.M.	7	50	8	P.M.	4	4	38
	"	51	28		"	6	3
	"	52	55		"	7	24

If you have pencil and paper at hand, and trig-log tables (any edition of Bowditch will have them), you can verify the chronometer error Lewis found. Everything else you need is here. But since logarithms will be involved, you may want to look up something on logs and read about "characteristics."

First, find the average of the morning times, and the average of the afternoon times. Increase the afternoon average by twelve hours and subtract the morning average from it. That gives you the **interval.**

According to my figures, the morning average is 7:51:30.3. The afternoon average, plus 12 hours, is 16:06:01.7, and the interval is 8:14:31.4.

Now take half the interval and add it to the morning average to find the **middle time**—11:58:46.0.

If the sun's declination had been the same in the afternoon as it was in the morning, middle time would be what the chronometer read at local apparent noon—the instant the sun crossed the meridian. But the sun's declination is always changing and an allowance has to be made. This is called "the equation of equal altitudes."

The particular way of calculating the equation shown here comes from *Norie's Navigation.* It's an abbreviated method, but requires only a one-page table. I've included a copy of the table as well as a copy of the necessary page from the 1804 *Nautical Almanac.* Enter the table with the nearest value of the **interval** and take out Log. A and Log. B.

You will find from the page copied from the *Almanac* that the sun's declination at Greenwich noon on the previous day (the 16th) was 21°23′33″. Two days later, on the 18th, it was 21°3′11″. The difference, reduced to seconds of arc, is 1222″. Find the logarithm of 1222 in a logs-of-numbers table and put it under both log A and log B. The latitude according to Clark's noon observation with the quadrant, was 40°27′. Put the log tangent of the latitude in the "A" column and the log tangent of the approximate declination, 21°, in the "B" column.

A.	7.8123	B.	7.4874
1222 log	3.0871		3.0871
Latitude: log tan	<u>9.9307</u>	Dec: log tan	<u>9.5842</u>
	0.8301		0.1587

Add each column, drop the unwanted ten's from the characteristics, and find the numbers corresponding to the logs. For the "A" column the number is 6.762. For the "B" column it is 1.441. These are seconds of time.

Since the pole nearest you is the North Pole, and the sun is moving south, the sun's polar distance is increas-

Days of the Week.	Days of the Month.	THE SUN'S Longitude.	Rt. Ascen. *in Time.*	Declin. *North.*	Equation of Time. *Add.*	Diff.
		S. D. M. S.	H. M. S.	D. M. S.	M. S.	S.
Sun.	1	3. 9.20.25	6.40.39,7	23. 8. 9	3.19,8	11,5
M.	2	3.10.17.38	6.44.47,8	23. 3.56	3.31,3	11,3
Tu.	3	3.11.14.50	6.48.55,7	22.59.18	3.42,6	11,0
W.	4	3.12.12. 3	6.53. 3,3	22.54.16	3.53,6	10,7
Th.	5	3.13. 9.17	6.57.10,6	22.48.51	4. 4,3	10,4
F.	6	3.14. 6.31	7. 1.17,5	22.43. 1	4.14,7	10,0
Sa.	7	3.15. 3.45	7. 5.24,1	22.36.48	4.24,7	9,7
Sun.	8	3.16. 0.59	7. 9.30,4	22.30.11	4.34,4	9,2
M.	9	3.16.58.13	7.13.36,3	22.23.12	4.43,6	8,9
Tu.	10	3.17.55.28	7.17.41,7	22.15.48	4.52,5	8,4
W.	11	3.18.52.42	7.21.46,7	22. 8. 2	5. 0,9	8,0
Th.	12	3.19.49.56	7.25.51,2	21.59.53	5. 8,9	7,5
F.	13	3.20.47.11	7.29.55,3	21.51.21	5.16,4	7,0
Sa.	14	3.21.44.25	7.33.58,9	21.42.27	5.23,4	6,4
Sun.	15	3.22.41.40	7.38. 1,9	21.33.11	5.29,8	6,0
M.	16	3.23.38.55	7.42. 4,5	21.23.33	5.35,8	5,5
Tu.	17	3.24.36. 9	7.46. 6,5	21.13.32	5.41,3	4,9
W.	18	3.25.33.24	7.50. 7,9	21. 3.11	5.46,2	4,3
Th.	19	3.26.30.39	7.54. 8,8	20.52.28	5.50,5	3,8
F.	20	3.27.27.55	7.58. 9,2	20.41.24	5.54,3	3,2
Sa.	21	3.28.25.11	8. 2. 9,0	20.29.59	5.57,5	2,6
Sun.	22	3.29.22.27	8. 6. 8,2	20.18.14	6. 0,1	2,1
M.	23	4. 0.19.44	8.10. 6,8	20. 6. 8	6. 2,2	1,6
Tu.	24	4. 1.17. 2	8.14. 4,9	19.53.42	6. 3,8	0,9
W.	25	4. 2.14.20	8.18. 2,5	19.40.56	6. 4,7	0,3
Th.	26	4. 3.11.40	8.21.59,4	19.27.50	6. 5,0	0,1
F.	27	4. 4. 9. 1	8.25.55,8	19.14.25	6. 4,9	0,7
Sa.	28	4. 5. 6.23	8.29.51,5	19. 0.41	6. 4,2	1,4
Sun.	29	4. 6. 3.45	8.33.46,7	18.46.38	6. 2,8	1,9
M.	30	4. 7. 1.10	8.37.41,4	18.32.16	6. 0,9	2,5
Tu.	31	4. 7.58.35	8.41.35,5	18.17.36	5.58,4	

LOGARITHMS for computing the EQUATION of EQUAL ALTITUDES.

Interval.	Log. A.	Log	Interval.	Log. A.	Log. B.	Interval.	Log. A.	Log. B.	Interval.	Log. A.	Log. B.
h. m.			h. m.			h. m.			h. m.		
2 0	7.7297	7.7146	4 0	7.7447	7.6823	6 0	7.7703	7.6198	8 0	7.8072	7.5062
2	7.7298	7.7143	2	7.7451	7.6815	2	7.7708	7.6184	2	7.8079	7.5036
4	7.7300	7.7139	4	7.7454	7.6807	4	7.7713	7.6170	4	7.8086	7.5010
6	7.7302	7.7136	6	7.7458	7.6800	6	7.7719	7.6156	6	7.8094	7.4983
8	7.7304	7.7132	8	7.7461	7.6792	8	7.7724	7.6142	8	7.8101	7.4957
10	7.7305	7.7128	10	7.7464	7.6784	10	7.7729	7.6127	10	7.8108	7.4930
12	7.7307	7.7125	12	7.7468	7.6776	12	7.7736	7.6113	12	7.8116	7.4902
14	7.7309	7.7121	14	7.7472	7.6768	14	7.7740	7.6098	14	7.8123	7.4874
16	7.7311	7.7117	16	7.7475	7.6759	16	7.7745	7.6083	16	7.8130	7.4846
18	7.7313	7.7113	18	7.7479	7.6751	18	7.7751	7.6068	18	7.8138	7.4818
2 20	7.7315	7.7109	4 20	7.7482	7.6743	6 20	7.7756	7.6053	8 20	7.8145	7.4789
22	7.7317	7.7105	22	7.7486	7.6734	22	7.7762	7.6038	22	7.8153	7.4760
24	7.7319	7.7101	24	7.7490	7.6726	24	7.7767	7.6023	24	7.8160	7.4731
26	7.7321	7.7097	26	7.7494	7.6717	26	7.7773	7.6007	26	7.8168	7.4701
28	7.7323	7.7092	28	7.7497	7.6708	28	7.7779	7.5991	28	7.8176	7.4671
30	7.7325	7.7088	30	7.7501	7.6700	30	7.7784	7.5975	30	7.8183	7.4640
32	7.7327	7.7083	32	7.7505	7.6691	32	7.7790	7.5959	32	7.8191	7.4609
34	7.7329	7.7079	34	7.7509	7.6682	34	7.7796	7.5943	34	7.8199	7.4578
36	7.7331	7.7075	36	7.7513	7.6673	36	7.7801	7.5927	36	7.8206	7.4546
38	7.7333	7.7070	38	7.7517	7.6663	38	7.7807	7.5910	38	7.8214	7.4514
2 40	7.7336	7.7065	4 40	7.7521	7.6654	6 40	7.7813	7.5894	8 40	7.8222	7.4482
42	7.7338	7.7061	42	7.7525	7.6645	42	7.7819	7.5877	42	7.8230	7.4449
44	7.7340	7.7056	44	7.7529	7.6635	44	7.7825	7.5860	44	7.8238	7.4415
46	7.7342	7.7051	46	7.7533	7.6626	46	7.7831	7.5843	46	7.8246	7.4381
48	7.7345	7.7046	48	7.7537	7.6616	48	7.7836	7.5825	48	7.8254	7.4347
50	7.7347	7.7041	50	7.7541	7.6606	50	7.7842	7.5808	50	7.8262	7.4312
52	7.7349	7.7036	52	7.7545	7.6597	52	7.7848	7.5790	52	7.8270	7.4277
54	7.7352	7.7031	54	7.7549	7.6587	54	7.7854	7.5772	54	7.8278	7.4241
56	7.7354	7.7026	56	7.7553	7.6577	56	7.7860	7.5754	56	7.8286	7.4205
58	7.7357	7.7021	58	7.7557	7.6567	58	7.7867	7.5736	58	7.8294	7.4168
3 0	7.7359	7.7015	5 0	7.7562	7.6556	7 0	7.7873	7.5717	9 0	7.8302	7.4131
2	7.7362	7.7010	2	7.7566	7.6546	2	7.7879	7.5699	2	7.8311	7.4093
4	7.7364	7.7005	4	7.7570	7.6536	4	7.7885	7.5680	4	7.8319	7.4055
6	7.7367	7.6999	6	7.7575	7.6525	6	7.7891	7.5661	6	7.8328	7.4016
8	7.7369	7.6993	8	7.7579	7.6514	8	7.7898	7.5641	8	7.8336	7.3977
10	7.7372	7.6988	10	7.7583	7.6504	10	7.7904	7.5622	10	7.8344	7.3937
12	7.7374	7.6982	12	7.7588	7.6493	12	7.7910	7.5602	12	7.8353	7.3896
14	7.7377	7.6976	14	7.7592	7.6482	14	7.7916	7.5582	14	7.8361	7.3855
16	7.7380	7.6970	16	7.7597	7.6471	16	7.7923	7.5562	16	7.8370	7.3813
18	7.7383	7.6964	18	7.7601	7.6460	18	7.7929	7.5542	18	7.8378	7.3771
3 20	7.7386	7.6958	5 20	7.7606	7.6448	7 20	7.7936	7.5522	9 20	7.8387	7.3728
22	7.7388	7.6952	22	7.7610	7.6437	22	7.7942	7.5501	22	7.8396	7.3684
24	7.7391	7.6946	24	7.7615	7.6425	24	7.7949	7.5480	24	7.8404	7.3639
26	7.7394	7.6940	26	7.7620	7.6414	26	7.7955	7.5459	26	7.8413	7.3594
28	7.7397	7.6934	28	7.7624	7.6402	28	7.7962	7.5437	28	7.8422	7.3548
30	7.7400	7.6927	30	7.7629	7.6390	30	7.7969	7.5416	30	7.8430	7.3501
32	7.7403	7.6921	32	7.7634	7.6378	32	7.7975	7.5394	32	7.8439	7.3454
34	7.7406	7.6914	34	7.7638	7.6366	34	7.7982	7.5372	34	7.8448	7.3406
36	7.7409	7.6908	36	7.7643	7.6354	36	7.7989	7.5350	36	7.8457	7.3357
38	7.7412	7.6901	38	7.7648	7.6342	38	7.7995	7.5327	38	7.8466	7.3307
3 40	7.7415	7.6894	5 40	7.7653	7.6329	7 40	7.8002	7.5304	9 40	7.8475	7.3256
42	7.7418	7.6888	42	7.7658	7.6317	42	7.8009	7.5281	42	7.8484	7.3205
44	7.7421	7.6881	44	7.7663	7.6304	44	7.8016	7.5258	44	7.8493	7.3152
46	7.7424	7.6874	46	7.7668	7.6291	46	7.8023	7.5234	46	7.8502	7.3099
48	7.7428	7.6867	48	7.7673	7.6278	48	7.8030	7.5211	48	7.8511	7.3045
50	7.7431	7.6859	50	7.7678	7.6265	50	7.8037	7.5186	50	7.8520	7.2989
52	7.7434	7.6852	52	7.7683	7.6252	52	7.8044	7.5162	52	7.8530	7.2933
54	7.7437	7.6845	54	7.7688	7.6239	54	7.8051	7.5137	54	7.8539	7.2876
56	7.7441	7.6838	56	7.7693	7.6225	56	7.8058	7.5112	56	7.8548	7.2817
58	7.7444	7.6830	58	7.7698	7.6212	58	7.8065	7.5087	58	7.8558	7.2758
4 0	7.7447	7.6823	6 0	7.7703	7.6198	8 0	7.8072	7.5062	10 0	7.8567	7.2697

ing. When polar distance is increasing the "A" seconds are additive to the middle time. Otherwise they are subtractive. The "B" seconds depend on the declination. Whether it be north or south, if it's increasing "B" is additive. Here it's decreasing, so the "B" seconds are subtractive. Combine the two and you have the equation of equal altitudes, 5.3 seconds, additive to middle time. Lewis would have used a different method to calculate the equation. He got 0.3 second less—or else just rounded to the nearest second. He added those 5 seconds to the middle time and put down:

	h	m	s
M.T.P.M. Chronometer at	11	58	51

That's what the chronometer was reading at local apparent noon—the instant of the sun's meridian transit. Obviously it is slow on local apparent time by one minute, nine seconds.

Or you could just say it was one minute and nine seconds slow since, in those days, local apparent time WAS the time. There were no time zones, and mean time was an esoteric concept. For the navigator and nearly everyone else, time and the local hour angle of the sum were one and the same. A navigator had no interest in mean time—unless, that is, he had the use of a chronometer.

The earth's daily rotation being what it is, the length of a day—from one meridian transit of the sun to the next—varies slightly with time of year. An hour of apparent time at one season is not exactly the same length as an hour of apparent time at another season. A chronometer can hardly be expected to take this into account, varying its rate with the season. But, with a steady rate, it can keep track of the average (or mean) of solar time.

So, for the convenience of observatories with compensated pendulum clocks regulated to solar time, and those ships with chronometers, the *Nautical Almanac* provided the "equation of time." It is the minutes and seconds that mean time differs from the time kept by the real sun that "appears" to us in the sky.

When you're converting apparent time to mean time you apply the equation according to the "Add" or "Sub." at the top of the column. When you're converting mean time to apparent time you apply the equation the opposite way.

As you can see from the *Almanac* page, the equation of time at Greenwich noon on the 17th was 5 minutes 41.3 seconds, additive. Twenty-four hours later it was 4.9 seconds more.

Lewis and Clark were camped on the Missouri River some 95° west of Greenwich. When it was noon at their camp it was about 6.3 hours past noon at Greenwich. Multiply the 4.9 second change by 6.3 hours, divide by 24 hours and you get 1.3 seconds change. Since the equation is increasing, you add that to the 5 minutes 41.3 seconds. Now you know what the equation of time was at noon at Lewis and Clark's camp on the Missouri. It was 5 minutes 42.6 seconds, additive to apparent time.

So when the sun crossed the meridian that day (12:00:00 local apparent time) the local mean time was 12:05:42.6. That's what the chronometer would have read if it had been keeping perfect mean time for the meridian. What it did read—as you found with the equation of equal altitudes calculation—was 11:58:51.3. As you can see, the chronometer was 6 minutes 51.3 seconds slow on mean time.

But remember: Lewis either got 0.3 second less than we did for the equation of equal altitudes, or else he dropped the fraction at some point. So according to his calculation the chronometer is 6 minutes 51.6 seconds slow on mean time. He wrote:

		m	s
Chronometer too slow M.T.	6	51.6	

Maybe it was the printer who got the numbers out of column.

The reason for going into such detail, and providing a copy of *Norie's* Table, LII, is that I believe equal altitudes are the place to start if you want to make sense of Lewis and Clark's astronomical observations. For one thing, bad numbers are easy to spot. To see what I mean, look on pages 387 and 388 of *The Journals* ... and you will find Clark's copies of the observation just worked. In both of them the time of the morning overlap is clearly wrong. Because of the contact-overlap-separation procedure the differences in times should be fairly even. Generally the difference between the first and second times will nearly match that between the fifth and sixth. The difference between the second and third will nearly match that between the fourth and fifth.

Equal altitudes also give you a preparatory whiff of the old *Nautical Almanac*, and of the peculiar way the navigators of Lewis and Clark's day looked at questions of time and longitude. If there's enough interest to justify it, I'd like to say more on those subjects in a future issue of the *Newsletter.*

From a Set of Tables included with the 1848 edition of Norie's navigator (see page 19). Reproduced by courtesy of Imray Laurie Norie & Wilson Ltd., Publisher, of Nautical Charts and Books, (including *Norie's Nautical Tables)*, Wych House, The Broadway, St. Ives, Huntingdon, Cambridgeshire PE 17 4BT England.

Checking Index Error by Sighting on a Terrestrial Object

By Richard Preston

In issue 64 of *The Navigator's Newsletter* (Summer 1999), Richard J. Stachurski asks, "When checking the index error of a sextant, how far away must the horizon or other object be in order to avoid parallax problems? I would also appreciate some help in understanding the exact geometry of the index error."

My reply to this is that for my own sextant, 6 or 7 statute miles is far enough. My reasoning, including the geometry behind it, follows:

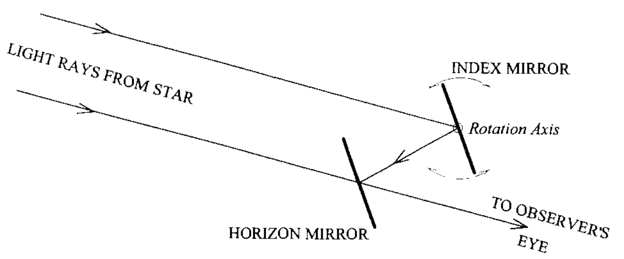


Figure 1. Side view of sextant mirrors. Parallel light rays from a star are being used to measure the index error.

Figure 1 shows representative rays from a star striking the index and horizon mirrors of a conventional sextant. The horizon mirror is attached rigidly to the frame of the sextant, but, by changing the sextant reading, the index mirror can be rotated about an axis which is fixed to the frame and is perpendicular to the plane of the figure. In this figure the index mirror has been rotated relative to the horizon mirror to the point where the two images of the star are superimposed in the observer's eye.

A sextant is used to measure the angle between light rays arriving at the two mirrors. Because all rays from the star are effectively parallel when they reach the sextant, the angle between the upper and lower rays in the figure must be zero. In this case, where the angle is zero and the images are superimposed, we would like the sextant to *read* zero. Typically, a sextant would not read exactly zero at this point, and the actual sextant reading would be what is called the index error. Therefore, any sextant reading of the angle between rays striking the two mirrors must be corrected by an amount equal to this index error.

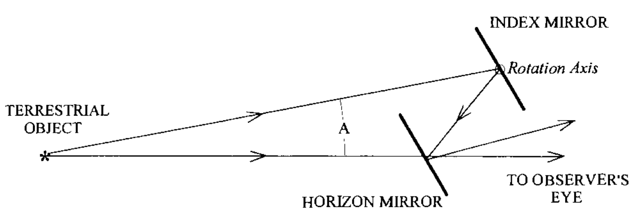


Figure 2. The index mirror is oriented so that the images of a star would be superimposed. To superimpose the images of a terrestrial object, this orientation must be changed.

Suppose that while a sextant is set to superimpose the images of a star, the observer decides to view a terrestrial object though the horizon mirror. Then, as shown in Figure 2, the two representative rays from the terrestrial object make a non-zero angle A with each other and the two images are separate. To measure A, the observer must now change the sextant reading until the two images are superimposed. When this is done, the corrected value of A is given by

A = new sextant reading – index error

from which it follows that

New sextant reading = index error + A

Now consider the case of an observer who has actually *not* been able to determine the true index error, and is content to adopt this new sextant reading as a reasonable approximation to the index error. The equation above shows that this estimate will be wrong by an amount equal to A. Clearly, if circumstances necessitate the use of a terrestrial object to determine an approximate value of the index error, it is important to limit A to an acceptably small value.

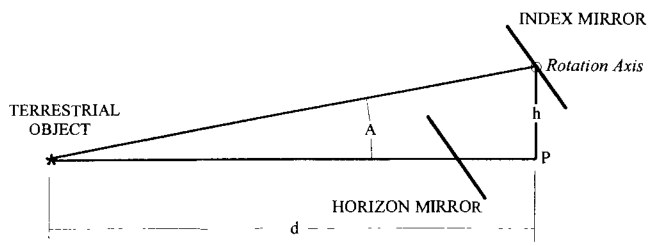


Figure 3. Right triangle formed by the two representative rays from the terrestrial object and a line drawn perpendicular to the lower ray from the center of the index mirror.

Figure 3 shows how to evaluate A. This figure shows a right triangle, two sides of which are formed by the rays from the terrestrial object depicted in Figure 2. The side opposite angle A is a line of length h drawn from the rotation axis of the index mirror perpendicular to the ray through the horizon mirror, which it intersects at point P. The length d of the side adjacent to A is the distance from the terrestrial object to P.

From the definition of the tangent we have

$$\tan A = h/d$$

where h and d must be in the same units. This shows, as expected, that the farther away the object is, the smaller A will be.

Solving for d gives

$$d = h/\tan A$$

from which the minimum value of d can be calculated if h and the maximum allowable value of A are given.

My own sextant has a vernier which reads angles to the nearest .2 minutes of arc. To make measurement with my sextant that will be reliable to within about .2 minutes, the uncertainty in the index error has to be significantly less than .2 minutes. In my opinion, the index error should not be wrong because of parallax by more than a tenth of this amount. That is, I would like angle A to be less than .02 minutes. Also, a visual estimate of h for my sextant is 2.5 inches.*

Using .02 minutes for A and 2.5 inches for h in the second equation, I get d = 429718 inches or 6.8 statute miles as the minimum permissible distance from my sextant to the terrestrial object. (I round off to two significant figures because of the uncertainty in my estimate of 2.5 inches for h and because my limit of .02 minutes for A is arbitrary.)

Readers who select larger or smaller maximum values of angle A, or have sextants with other values of h, can use these values in the same equation to get acceptable values of d for their own instruments.

As a "terrestrial object", the horizon presents a special problem. The distance from the sextant to the horizon is not fixed, but increases with increasing height of the sextant above the water.

Therefore, whether the horizon should be used for measuring the index error depends on how high up the sextant is. For example, a sextant would have to be about 30 feet above the water for the horizon to be 6.7 miles distant.

In principle, if you know the height of your sextant above the water you can

- sight on the horizon to obtain an approximate index error
- calculate the distance to the horizon using the height of the sextant above the water and the radius of the earth (or using the radius of the earth and the tabulated dip angle for that height)
- calculate the angle A using the distance to the horizon, the value of h for your sextant, and tan A = h/d
- correct the approximate index error by the amount A to get the true index error, being careful about the sign of A

I leave this as an exercise for the reader.

*I would not bring a measuring stick anywhere near the optical components of any sextant for fear of scratching their surfaces. Thus, 2.5 inches is only an estimate of h for my sextant.

HISTORY OF NAVIGATION

A Chronology of the Development and Publication of Ephemerides and Almanacs Used for Navigation

By Peter Ifland

The chronology presented here was developed partly in recognition of the 150th anniversary of the establishment on March 3, 1849 of The Nautical Almanac Office then located in Cambridge, Massachusetts and partly to provide a sense of the evolution of the production of this indispensable information for the navigator. This piece is not a history since it does not provide any details about the organizations and the astronomers, mathematicians and navigators that developed the data. Nor does it deal with the history and chronology of the mathematical sight reduction methods and tables that are a requisite for finding a position.

160 BC Hipparchus produced a star catalogue, proposed that time could be used to measure distances east and west and suggested the use of lunar eclipses for determining time.

Mid second century BC - Ptolomy publishes The *Syntaxis* or *General Composition of Astronomy* called *Almagest* in Arabic. The model of the universe placed a stationary earth at the center with the planets, the moon and the sun moving around the earth in circles.

Mid ninth century AD - The Syrian, Al Battani, produced more accurate astronomical tables predicting the movement of the moon and planets.

1080 The *Toledan Tables* of celestial positions was developed by a team of scholars in the Castilian city of Toledo.

1252 The *Alphonsine Tables* were published under the sponsorship of the Castilian King Alphonso X.

1457 George Purbach published the first almanac in Vienna, based on the observations made by Regiomontanus at the observatory at Nuremberg.

1474 Abraham Zacuto published his *Almanac Perpetuum* giving improved accuracy to predictions of the suns declination, critical to navigation south of the equator.

1543 Copernicus published his heliocentric system in which the earth rotates on its axis and in turn, rotates around the sun.

1514 John Werner of Nuremberg suggested that the angular distance between the moon and the fixed stars, lunar distance, could be used to determine time.

1551 *Tabulae Prutenicia*, published by Erasmus Reinhold, giving the navigator the first tables based on Copernican principles.

1572 Tycho Brahe undertakes to correct and update existing star catalogues and refine observations of the movement of the planets.

1609 Johannes Kepler published *Astronomia Nova* expounding the theory of the elliptical orbits of the planets.

1610 Galileo proposes the predicted times of appearance and disappearance of the moons of Jupiter as a means of determining longitude.

1627 Tycho Brahe and Johannes Kepler, at the Uranibvurgum, Denmark, observatory published the *Rudolphine Tables*.

1675 King Charles II established the Greenwich Observatory with the specific mission of working out celestial methods for determining longitude.

1687 Newton published his theories on the laws of motion and universal gravitation that formed the cornerstone of modern astronomical predictions.

1696 - The French National Observatory, Urbain Leverrier, director, published the first official almanac, *Connaissance des Temps*.

1766 Sir Nevil Maskelyne, Astronomer Royal, first published *The Nautical Almanac and Astronomical Ephemeris for the year 1767* under the order of The Commissioners of Longitude, London.

1818-49 E. and G.W. Blunt, New York, privately republished a corrected version of the British Admiralty Nautical Almanac, in biannual editions.

1830 The Depot of Charts and Instruments was established in the District of Columbia and given the responsibility to manage the Navys charts, chronometers, and instruments.

1831 The post of the British Superintendent of the Nautical Almanac was established and the Office of the Nautical Almanac became administratively under the Greenwich Observatory.

1842 Lt. Mathew Fontaine Maury, USN, was appointed Head of the Depot of Charts and Instruments. He proposed to Congress the establishment of an observatory and hydrographics office, authorized by the Mallory Act.

1842 Construction of a permanent building for the Navys Depot of Charts and Instruments was authorized with the passage of Bill No. 303 of the 27th Congress.

1844 Secretary of the Navy, John P. Young, proposes to Congress that the observations of the new Naval observatory be used by naval officers to calculate a nautical almanac. The proposal was not adopted at that time.

1844 The Depot of Charts and Instruments was reestablished as The Naval Observatory, located in Washington on a hill north of where the Lincoln Memorial now stands. Lt. Maury was appointed Observatory Superintendent.

1845 The U.S. Naval Observatory begins continuous observation of the planets, sun, moon, and selected stars.

1846 The first volume of celestial observations was published by the Naval Observatory.

1846 Representative Frederick P. Stanton (Tenn.) proposed an amendment to the Naval Appropriations bill that would designate $5000 for computing and publishing the American Nautical Almanac. The proposal was not adopted, largely based on the position that the British Nautical Almanac was sufficiently accurate and useful.

1849 Congress establishes the Nautical Almanac Office, located in Cambridge, Massachusetts, and independent of The Naval Observatory in Washington. A congressional appropriation of March 3 provided authority for the preparation and publication of an American nautical almanac. Late in the year, preparation of the first volume of the *American Ephemeris and Nautical Almanac* began at the Nautical Almanac Office in Cambridge under the direction of Lt. C. H. Davis, USN, the newly appointed Superintendent of the Nautical Almanac Office.

1850 Congress adopts a joint resolution that the Observatory at Washington would serve as the prime meridian for astronomical and geographical purposes and that part of the Nautical Almanac used by navigators would be based on the prime meridian at Greenwich.

1852 The Depot of Charts and Instruments published the first *American Ephemeris and Nautical Almanac* for the year 1855. The *American Nautical Almanac* for 1855 was extracted from this larger publication for the convenience of navigators.

1854 The Depot of Charts and Instruments was renamed the U.S. Naval Observatory and Hydrographical Office.

1858 The *American Nautical Almanac* was routinely published without the ephemeris.

1866 The Nautical Almanac Office moved to rented quarters in Washington, D.C. An Act of Congress separated the Hydrographical Office from the U.S. Naval Observatory and established it as a distinct entity.

1871 A table of logarithms of small arcs in time or space was added to the almanac.

1882 The ephemeris for mercury was included along with the ephemerides of the seven planets already included in the almanac.

1883 The Nautical Almanac Office relocated to the State, War, and Navy Building.

1884 New tables for the reduction of mean and sidereal time were included as well as tables for finding latitude by observation of the altitude of Polaris.

1889 The Nautical Almanac Office relocated to the Washington Navy Yard.

1893 The Naval Observatory moved to its present location on Massachusetts Avenue, Washington, D.C. The Nautical Almanac Office relocated to new quarters at the Naval Observatory.

1894 The Nautical Almanac Office became a division of the U.S. Naval Observatory.

1903 The Nautical Almanac Office began production of *The Nautical Almanac* and *The Abridged Nautical Almanac.*

1911 The number of stars listed in *The Nautical Almanac* was increased from 150 to two hundred. Tables for lunar distances were deleted.

1912 Data for lunar distance calculations were omitted from *The Nautical Almanac.*

1916 *The Nautical Almanac* was extensively revised to compute critical data for every hour of the year. The apparent places of 55 navigational stars for the first day of each month and the mean places of 110 stars were tabulated.

1919 Tables showing times of sunrise and sunset and moon rise and moon set were incorporated.

1925 Civil Time, with the day commencing at midnight, was adopted in place of the astronomical time with the day commencing at noon.

1928 Lt. Cmdr. P. V. H. Weems, USN, suggests the tabulation of Greenwich Hour Angle instead of Right Ascension for celestial bodies.

1929 The U.S. Naval Observatory publishes the *Lunar Ephemeris for Aviators* for September 1 to December 31, 1929, the first almanac based on Greenwich Hour Angle.

1931 The *Aeronautical Supplement to the Nautical Almanac* appeared, providing the Greenwich Hour Angle and Declination of the Moon.

1932 The *Air Almanac*, developed at the Hydrographic Office, was published for the year 1933 by The Naval Observatory. The Greenwich Hour Angle of the moon was included in *The Nautical Almanac* for the first time.

1934 *The Nautical Almanac* incorporated the data previously published in the *Air Almanac* and the *Air Almanac* was discontinued.

1936 The first edition of the British *Air Almanac* was published for the last quarter of 1937 by the Nautical Almanac Office at Greenwich.

1940 Publication of the American air almanac resumed. The Naval Observatory published the *American Air Almanac* for the year 1941. Punched cards were used for tabulation and sorting for improved accuracy of the data.

1950 A cooperative effort of The Nautical Almanac Office, IBM and Yale University used electronic computing to produce improved calculations of the orbits of selected planets.

1953 The British and American Air Almanacs were combined in a single publication. Mean Time was used in place of Civil Time.

1958 The British *The Abridged Nautical Almanac* and the *American Nautical Almanac* were combined in a single publication. Published by The Nautical Almanac Office in the United States and by H.M. Nautical Almanac Office at Greenwich in England.

1960 The *American Nautical Almanac* was renamed simply *The Nautical Almanac* as was the British issue.

1977 *Almanac for Computers* was published annually through 1991.

1986 *The Floppy Almanac* was published annually through 1996.

1990 The Naval Observatory created two departments, The Orbital Mechanics Department and the Astronomical Applications Department. The latter, incorporating The Nautical Almanac Office, was and still is responsible for developing and publishing the almanacs and related software.

1993 The *Multiyear Interactive Computer Almanac* was first released, providing rigorous, real-time calculations of almanac data.

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NEWSLETTER INDEX

Index 92 (1-35) published with IssueThirty-five (Spring 1991) is an index covering Issue One through Thirty-five.

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Index to History of Navigation (3-54), published in Issue Fifty-four (Winter 1996-97), covers history articles in Issues Three through Fifty-four. This includes articles under the heading Navigation Notes in Issues Three through Seven.

Index to Navigation Notes (1-56), published in Issue Fifty-six (Summer 1997), does not include the navigation problems and history articles previously published in the Navigation Notes section.

Index to Navigation Basics Review (13-58), published in Issue Fifty-eight (Winter 1997-98), covers those articles written as reviews of the basics of navigation in Issues thirteen through Fifty-eight.

Index to Navigation Foundation Peary Project (23-42), published in Issue Fifty-eight (Winter 1997-98), covers articles and comments on the analysis of the data of Robert E. Peary's expedition to the North Pole in 1909 in Issues Twenty-three through Forty-two.

Index to Marine Information Notes (3-60), published in Issue Sixty (Summer 1998), covers only those notes of more lasting interest in Issues Three through Sixty.

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Index to DO YOU KNOW. . .? (36-63), published in Issue Sixty-three (Spring 1999) covers questions in Issues Thirty-six through Sixty-three.

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Sixty-one Fall 1998	The Peter Ifland Collection of Navigation Instruments	John M. Luykx
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	Closed Form Solution of Lat. and Long. With Two Sights	James O. Muirhead
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	Checking Index Error by Sighting on a Terrestrial Object	Richard Preston
Sixty-Six Winter 1999-2000	A Chronology of the Development and Publication of Ephemeredes and Almanacs Used for Navigation	Peter Ifland

A

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1848.

PRICE SIXTEEN SHILLINGS BOUND.

(See "Lewis and Clark's Equal Altitudes"
by Bruce Stark on pages 9-12.)

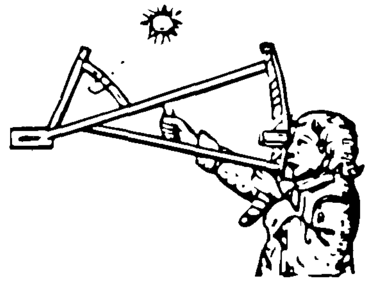
ANSWER TO DO YOU KNOW . . .?

(from page 1)

In his letter of September 7, 1941, to the U.S. Navy Hydrographic Office, George G. Hoehne, a navigation instructor at the Pan American Airways Navigation School in Miami, Florida, reported that he had constructed Star Tables for 15 stars for latitude band 24°N to 27° N and that he had used the tables in a number of night flights. On submission of his tables (the basic H.O. 249 method for stars) to the Hydrographic Office the following month, George G. Hoehne again advised the Hydrographic Office that he had found them very handy in night training flights.

The entering argument for stars Antares, Arcturus, Spica, Vega, and Regulus for latitude 26°N was LHA Aries and was clearly labeled as such in the October 11, 1941 submission.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-SEVEN, SPRING 2000

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Issue #66 Winter (1999-2000) has been lauded by many members as being one of the best yet. We have Director John Luykx and our editor, Ernest B. Brown, to thank for the fine articles and other content. If it were not for these two navigation experts and the excellent articles and letters from members, the Newsletter would not be so interesting, informative and educational.

This time of year brings dozens of e-mails each week from students who are doing term papers on celestial navigation. I try to answer each one as it is received and attempt to help them with the technical facts, lists of publications and at times a fax or attach the information to an e-mail of information that may not be available in their area. I do this with not only the pleasure of helping younger people understand navigation but as one of the purposes of The Navigation Foundation. It is a great delight to communicate with these exceptional youngsters.

We get a number of orders and letters from members who sign them with only their first name and no return address on the letter or envelope. If I can read the cancellation stamp I can usually find the member in our data base, but sometimes it is very difficult. I implore every member to at least sign their name the same way it is listed on their membership label. This will help me expedite any orders you may have or answer any question. I also get some e-mails whose address or server has been changed and not changed in the message address data file. A quick check and a correction if necessary will help us. We can then answer your query and not get a return message telling us we have an incorrect address at the server.

My wife and I are still in the Spring travel mode. We just returned from 2 weeks in Japan and Korea. I served on carriers in the Western Pacific in the 1950's, 1960's and 1970's but had not returned to Japan since 1973. The changes were most startling. The small wooden farm houses are all gone and replaced by western style houses. In Kyoto a section of old homes and an inn have been set aside to preserve some of the old traditions. The area was and still is the Geisha area of Kyoto. It looked like the older Japan that I knew and was a treat for my wife, son and daughter-in-law.

Korea was new to me. I had not been inland so it was not as startling as Japan. We did see a folk village, museums, including the War Memorial Museum, and the DMZ. We were able to descend into one of the tunnels that the North Koreans had dug under the DMZ. In all a great experience and is highly recommended for those who are planning a trip to the Western Pacific. May will bring a 2 week trip to Budapest, Hungary. It is a trip to help celebrate a friend's son's graduation from high school.

A reminder: NOAA/NOS no longer publishes Tide Tables, and Current Tables. The Navigation Foundation is a dealer for both Reed's Nautical Almanac and International Marine. Reed publishes an almanac that includes Tide Tables, Current Tables, U.S. Coast Pilot Information, U.S.C.G. Light Lists, Navigation & Communications Resources and Nautical Ephemeris with Sun, Moon, and Stars Data. All of this necessary information is available in one book. They come as Caribbean, North American East Coast and North American West coast at $29.95 list price. Reed also has Reeds Captains Pack for each of the above areas for $39.95. International Marine has the Tide Tables and the Current Tables each in a sepa-

DO YOU KNOW . . . ?

By Ernest Brown

When the Royal Observatory at Greenwich became the Royal Greenwich Observatory (RGO and where RGO was located?

(*See page 15 of this issue*)

rate book at $19.95 list. Nautical Almanacs are available at $19.95 for the Commercial Edition and $31.00 for the Government Edition. Members discounts apply. When a member needs a chart or publication think of The Navigation Foundation first. Our telephone and Fax number is 301-622-6448 and our e-mail address is navigate@ix.netcom.com.

The year 2000 winner of the Dutton Award at the U.S. Naval Academy is Midshipman Alexander Goodno, USN. The presentation will be made on May 20 at the Academy.

READERS FORUM

Edited by Ernest Brown

Member Kieran Kelly wrote from Australia:

"As a new member of The Navigation Foundation I felt others might be interested in my recent experiences recreating one of the journeys of the greatest navigator and land explorer my country –Australia—has produced.

"In 1988 I was selected by the Government of the Northern Territory to command and navigate the North Australian Expedition which sought to duplicate part of Sir Augustus Charles Gregory's 1855/56 pioneering trip into the Tanami Desert then right across the top of Northern Australia's gulf country and down to Brisbane.

"The objects of the expedition were numerous: to see if modern men could undertake a long distance packhorse trip in desert country the way it was done 150 years ago; could navigation still be made with traditional navigational instruments? Was it still possible to ride from Timber Creek on the mighty Victoria River to Gregory's desert base camp at Depot Creek, through the fearsome Wickham Gorge? Gregory was the only man to have taken packhorses through the gorge since the white settlement of Australia. Finally we hoped to compare Gregory's achievements with those of the better-known Meriwether Lewis and discover who was the better explorer — the Australian or the American?

"The party of twenty riding and packhorses and five men assembled for training in April 1999 in the township of Timber Creek on the Victoria River. The wet season had drawn to a close but it was fearsomely hot. Horses and men were quickly bashed into shape and the group left Gregory's Principal Camp with its historic carved boab tree on May 1, 1999.

"As navigator I carried the following instruments:

C Plath *Professional* sextant Pocket short wave radio (for GMT) Dolland artificial horizon (London c1850) Weems & Plath Star Finder Mirrored artificial horizon with level Francis Barker military prismatic compass 1999 Nautical Almanac Silva baseplate compass Copies of Gregory's 1855-56 charts Topographical maps

"The charts and maps were carried in a map case along with my journal on the pommel of my saddle; the compasses were carried in a specially designed case attached to the kneepads of the saddle along with a Garmin GPS 12 unit. Everything else went in the pack bags.

"Navigational challenges arose almost immediately. Gregory was a consummate cartographer and surveyor, who sketched as he rode drawing landmarks, marking rivers, taking back bearings all from a binnacle compass mounted on the pommel of his saddle. This ingenious device, which he later patented, left his hands free to sketch and take bearings as he rode. I was not so lucky.

"The timber is much denser than in 1855 as traditional aboriginal burning declined following white settlement. We could no longer see the mountains he sketched until we were almost on top of them. I also discovered, much to my surprise, that the GPS would not operate. The dense timber and deep gorges we rode through combined with what appears to be a back hole of satellite coverage over the deserts of northern Australia rendered electronic navigation impossible.

"I was however getting good results with the sextant and when combined with the topographical maps could usually work out position by climbing hills and gorge walls near the evening campsites. The dry season sky was inky black and the big navigational stars of the southern hemisphere shone like diamonds.

"There were other problems: the first was the Dolland artificial horizon. Although it stood only six inches high and about the same wide, it weighed 9.5 lbs. The weight of the iron mercury flask, the mercury, the iron plate and timber box made this an extravagant amount of weight to carry in the pack bags when food was so vital. Pouring the mercury out and getting it back in the flask without spilling any was a problem as was bringing the star down into the mercury pan without losing it in the frame of the glass cover. I eventually decided not to use the horizon and instead shot off the top of a pannikin of black tea. This was an idea I gleaned from Gregory's journal and gave excellent results especially on still nights.

"The sextant performed well despite being bashed around as the horse carrying it collided with trees, other horses and on one occasion, fell in a river while crossing. But the modern aluminum box it came in was impractical being 16" wide by 12" inches deep taking virtually all the space in one pack bag. Doing the complex calculations at night after being in the saddle from before dawn, I used stars higher than 15° and lower than 60° due to the double alt. I was shooting. This meant the same stars, Rigel Kent, Acrux, Antares, Arcturus and Procyon were usually the targets as they were in the right position about 8:30 pm. It was tiring at the end of a long day when I also had to write up the journal and plot the route for the following day while attending to the myriad needs of horses and men.

"For the push into the desert I took only Gregory's charts, the two compasses and the topographical maps. The desert is very low relief which gave me many anxious moments trying to pick up scarce landmarks but a horse, unlike a yacht, walks at a constant speed - 6 km per hour - making dead reckoning navigation, on a compass bearing a surprisingly accurate undertaking. This method was justified as after a journey of nearly 44 km and surviving the horrors of Wickham Gorge and a major bushfire on the Wickham plains which had horse and rider fleeing for their lives, we cut Depot Creek only 300 metres east of Gregory's 1856 campsite.

"The trip answered many questions. The major one being that Gregory was an extraordinary navigator, The campsites and waterholes, the hills and rock art sites which he laid down 145 years ago are right where he said they would be. Unlike most of his contemporaries, he could calculate longitude and on most nights did so. He was familiar with lunars, shooting them often. He seldom shot noon sights as the daytime halt wasted time and left the party vulnerable to aboriginal attack. He preferred the greater accuracy and convenience of star sights. His love of horology came to his aid when, on numerous occasions, while deep in the bush he was forced to strip and repair his chronometers. Another question we answered was how he recorded his sextant sights and read the scale of his Troughton sextant in the years before battery powered torches. Simple. He took the instrument over to the campfire and read by the firelight.

"If you wish to read more about Australia's greatest land explorer or the trip we took to emulate him, I have written a book *Hard Country Hard men,* which will be published by Hale & Iremonger, Sydney in March 2000."

— *Kieran Kelly*, Commander/Navigator, North Australian Expedition 1999 kjkelly@bigpond.com

Claude deWinter sent the following e-mail from Manaus, Brazil on 28 August 1999:

"Being also from the navy and now working in the hinterland of the Amazon nobody can better understand the necessity of celestial navigation and better archeonavigation than when you are at night in the middle of a lake at 200 miles from Manaus with no batteries for the GPS to find a little by-river which is the outlet. Electronics since the old ADF, DECCA and later on OMEGA made navigation easier but also the niveau of seamanship dropped down vertically. Even living here in Manaus, I should be very happy to keep in touch with The Navigation Foundation and hear something from you."

— *Claude deWinter*

In response to an inquiry from the navigator of an expedition going to the North Magnetic Pole in April 2000 as to which chart projection is best for celestial navigation, at the Pole's latitude (about 80°N) the following information was provided:

The polar stereographic projection is ideal for celestial sight reduction for latitudes above 75°; the Mercator projection is quite unsuitable.

Volume 6 of H. O. Pub. No. 229, *Sight Reduction Tables for Marine Navigation*, provides the means for constructing the polar stereographic plotting sheet for the area in which one is operating from about 75° latitude to the geographic pole.

Member Frederic C. Kapp received the following letter of recommendation:

"As you know, I used the services of Ocean Navigator to find a celestial navigator for the last Marion-Bermuda Race. I was fortunate to find Fred Kapp, who resides down in Georgia and who did a great job for us in the Race. There is no need for me to recite his many accomplishments as a navigator aboard a number of significant yachts — all that is in his resumé which you have on file

"As you will recall, I have decided to go electronic next year and thus will not be needing Fred's help. I therefore wanted to append to his file a letter of recommendation based upon our campaign.

"Fred's strengths as a crew member were many. He has a great sense of humor, has a great deal of experience (you don't become a member of Storm Trysail because you can handle a 30 kt breeze) and was not one of those 'I'm the Navigator or – don't bother me — I will tell you where we are when I please'guys — rather he shared (as I wanted him to do) all pertinent info with anyone who asked.

"As a sight taker, he was incredible. Some might say he was almost monkey like in his ability to find a perch, snap a sight, repeat it, repeat it again and then move on to the next body — hanging on with one hand or wedging in between whatever was convenient. We did morning and evening stars/planets, sun lines and LAN. He is a student of navigation and has had two (that I know of) pieces published in the Foundation for the Promotion of the Art of Navigation — the latest of which was in issue sixty-six, winter of 1999-2000 about the last MBR aboard *Seaflower*.

"When I settled on the crew and offered Fred the job of navigator, he quickly offered to fly up to Marion for one of our practice sails which helped fit him into the crew. He also arrived two days before the start so we could check out the compass, calibrate the instruments and get all of his navigator gear correctly stowed. As you can imagine, I was very pleased with his efforts."

Member Oscar W. Underwood III sent the following e-mail April 24, 2000:

"A recent retirement project was to figure the best way a H.P. 32SII hand held calculator could be programmed to reduce a sun sight with its own built-in almanac. This H.P. is very reliable, compact, and inexpensive. Obviously it takes up a lot less room on a small sailboat than a laptop PC. The amount of memory available for programming is quite small. I ended up with three programs:

1. Almanac data (Greenwich Hour Angle and Declination for any year.
2. Sight reduction with GHA and Declination from another source.
3. Almanac data and sight reduction using one program.

"Each of the first two programs requires all of the available memory in the H.P. Using these two programs would require two calculators.

"The third program was written in condensed form with every effort to save memory. This program is not as 'User Friendly' as the first two, but the results are just as accurate.

"Years ago I reduced sights aboard a small sailboat using an Almanac and a Hewlett Packard Model 35, the first one to have full trig functions. This was very time consuming and error prone because of the large number of key strokes required. I saved a number of my old work sheets, and reworked them using Method 3. The amount of time and effort saved is considerable.

"If any Foundation members should be interested in the programs I have described, let me know and I'll try to send them by letter, e-mail attachment, or whatever."

—*Oscar W. Underwood* III<underwoodpg@juno.com>

NAVIGATION NOTES

Millennium Madness: 2000 or Bust!

By Peter Ifland (*Issue Sixty-Five, Fall 1999*)

Author's note:

I did not do the calculations in the article "Millennium Madness" but accepted the calendar information I cited from David Duncan's article "Calendar" in the February 1999 issue of Smithsonian Magazine, *pp 48-58.*

Here is some further clarification:

The complete, modern leap year rule is: "Years divisible by four are leap years unless they are divisible by 100. In that case they are not leap years but if they are divisible by 400, then they are leap years.: I provided the version of the leap century rule decreed by Pope Gregory XIII in 1582 that "cancels out three of the four leap years falling at the turn of each century ... so that 2000 is a leap year but 1700, 1800 and 1900 are not." (Duncan p. 56) Ultimately this led to the centuries divisible by 400 are leap years, others are not" part of the rule.

Just how slow is the calendar running relative to the tropical year? The key issue is the length of the tropical year - the time between subsequent passages of the sun over the equator at the vernal equinox. This is not a simple question but is the subject of sometimes heated ongoing debate. See "Error in Statement of Tropical Year" at http://www.magnet.ch/serendipity/hermetic/cal_stud/cassidy/err_trop.htm. A broadly accepted value is the one I cited, 365.242199 days (Duncan p 51). A 1991 study gives 364.2424 while other experts have cited 365.2422. The value is relevant when compared to the length of a calendar year, 365.2425 days, in predicting when an additional leap day will be required to keep the calendar year in sync with the tropical year. Duncan (p 58) calls the modern Gregorian calendar 26 seconds slow. I erroneously cited 11 seconds, which was the error in the old Caesar's calendar. Duncan notes that the calendar already is about three hours slow and calculates that an additional leap day will be needed in 4909. Using the value 365.2422 leads to a correction of one leap day in the year 4882. In any event, it won't be for a long time.

When did the Chinese adopt the Gregorian calendar? 1912 is the date of official adoption by the Chinese government but according to Duncan (p 50), it did not come into common use in China until 1949 when Mao Tse-tung decreed that it would be used throughout the country as the official calendar.

There is a small correction in the first sentence of the next-to-the-last paragraph. The sentence should read: "If you are unusually fond of the twentieth century and the second millennium. . ."

For anyone interested in calendars, a particularly informative source is:

http://astro.nmsu.edu/~lhuber/leaphist.html. A lighter version is at http://calendarzone.com.

The Development of Sight Reduction Tables for Air Navigation

By Ernest Brown

(Continued from Issue Sixty-five, Fall 1999)

The following is an excerpt from page 580 of the 1977 edition of Pub. No. 9, American Practical Navigator (Bowditch):

> "Hoehne, In October 1941 George G. Hoehne, then a navigation instructor at the Pan American Airways Navigation School, Miami, Florida, submitted a set of Star Air Navigation Tables to the U.S. Navy Hydrographic Office which were superior to the star section of H.O. Pub. No. 218 in basic design. His manuscripts included the tabulation of the altitudes and true azimuths of carefully selected bright stars arranged in a format such that this data could be rapidly extracted for at least ten stars from two facing pages with but one opening of the tables. The use of LHA Aries instead of the LHA of each star as a table argument simplified the sight reduction by: (1) eliminating the need to apply the SHA of

a star to the GHA Aries to obtain the LHA of a star; (2) enabling the optimum arrangement for rapid extraction of tabular values of altitude and true azimuth; and (3) providing for the selection of the best stars for observation for a given LHA Aries at an assumed position. The use of LHA Aries as a table argument with the data arranged in parallel columns so that the stars would be tabulated, from left to right, in increasing numerical order of true azimuth served to make the tables a star finder. The same basic format was later used with 360° of LHA Aries per table opening for volume I of Pub. No. 249, *Sight Reduction Tables for Air Navigation*."

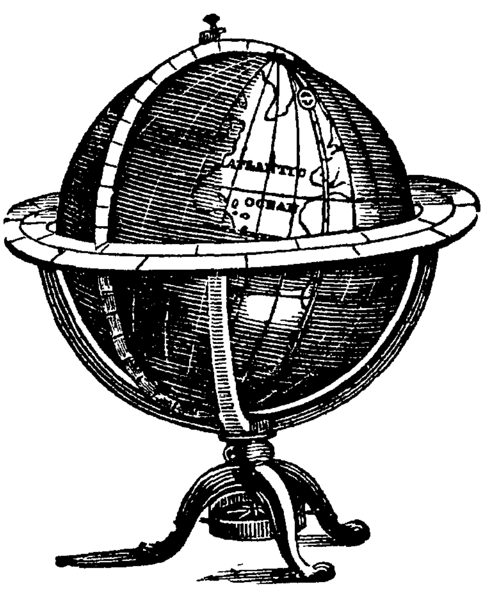
The 1958 edition of Bowditch states on page 542 under the heading *"H.O. Pub. No.249"* (see excerpt in Issue Sixty-five, Fall 1999):

> ". . . A preliminary edition of volume I for selected stars was published in 1947 under the title *Star Tables for Air Navigation*, using the general plan conceived by Commander C. H. Hutchings, USN, in 1942." . . .

The 1962 printing of the 1958 edition of Bowditch changed the last phrase of the above to:

> ". . . using the principles and features of tables proposed previously by George G. Hoehne, Commander C. H. Hutchings, USN, and others."

The foregoing was retained in the 1966 printing of the 1958 edition, the 1977 edition, and the 1984 editions of Bowditch. It is a true statement that does not actually detract from the fact that the basic design came from George G. Hoehne. The 1977 edition first established the fact publicly. (To be continued)



Federal Radionavigation Plan

The Secretaries of Defense and Transportation have recently approved the 1999 Federal Radionavigation Plan (FRP). The FRP is the definitive source for U.S. Government policy and plans for radionavigation services provided by the U.S. Government. The 1999 FRP is available on the Internet through the USCG Navigation Information Service (703)313-5900, or http:// www.navcen.uscg.mil. Printed documents are free of charge. (FAX request to J. Carroll, Volpe Center for Navigation, (617)494-2628.

The 1999 FRP includes the recent decision that Loran-C operation will continue in the short- term beyond the previous year 2000 termination date while the long-term need is further evaluated.

Nautical Astronomy in Lewis and Clark's Day

By Bruce Stark

Since present-day celestial navigation is superior in nearly all respects to the old nautical astronomy, you'd think our familiarity with it would help us understand how navigators worked their observations two centuries ago. Unfortunately it doesn't seem to work that way. The trouble is, our brains can't help trying to force the various elements of nautical astronomy into the familiar patterns of celestial, and we end up dismembering the old system without having noticed the logic that held its parts together.

Although present-day celestial is admirably suited to our needs, it would not have suited the needs of navigators in Lewis and Clark's time. Chronometers were outrageously expensive then—too expensive to be in common use. All too often those that were in use changed rate, stopped unexpectedly, or broke. There were no radio time signals, and ships were sometimes months—even years—away from places of known longitude. In those conditions, our way of thinking about and using time would not have been practical.

Navigators of that era had a different way of thinking about time. The way they thought about time is the key to the old nautical astronomy.

In our present system, GMT is at the center of things. For the majority of our observations the accuracy of the Greenwich mean time read from the watch is as critical as the accuracy of the altitude read form the sextant. The word "Time," for us, implies Greenwich time—*accurate* Greenwich time.

Considering the *Nautical Almanac* we use, this is understandable. It gives the east-west positions of the heavenly bodies in Greenwich hour angle. Unlike declination and sidereal hour angle, which are measured from celestial coordinates, GHA is measurement from a meridian on the fast spinning earth. It changes substantially in a matter of seconds.

The old *Almanac* was different. It gave the east-west positions of the heavenly bodies in "right ascension," measured from the vernal equinox. That's why a navigator could be amazingly casual (from our point of view) with the time he used to enter it. Although he needed accurate Greenwich time occasionally—so he could compare it with his own time and correct the dead reckoning longitude—he didn't need it to work his observations.

Local time—not Greenwich time—connected him to the celestial sphere. In those days "Time," unless otherwise labeled, virtually always meant LAT, local apparent time—the local hour angle of the sun.

Getting the correct time was easy: Just take a time sight—or, as it was called in the early days, an "Observation for the time." The difficulty was in keeping track of the time between observations. The kind of watch the average navigator could afford was considered acceptable if, after it had been running for six hours or so, it was within a minute of the truth.

Also—because time was specific to the meridian—course and distance since the last time sight had to be allowed for at the rate of four seconds for every 1' change of longitude.

Nor was keeping track of the date entirely simple either, as there were three ways of reckoning the day. There was the civil day, the sea (or nautical) day, and the astronomical day.

When in port or coasting along in sight of landmarks a navigator used the civil day, the one we are familiar with. Once he'd taken a departure he kept his journal according to the sea day. But to enter the *Nautical Almanac* he used the astronomical day. Bowditch explains these and related matters in his *New American Practical Navigator.* Here is what he has to say in the fifth, 1821 edition, on pages 140 and 141. Note the heading, and what he does—and does not—discuss under it.

> "**To Find the Time at Sea, and Regulate a Watch**
> We have already noticed the difference between the civil, astronomical, and nautical computation of time; but as it is a subject of great importance, it may not be unnecessary again to repeat, that a civil day is reckoned from midnight to midnight, and is divided into 24 hours; the first 12 hours are marked A.M. the latter 12 hours P.M. being reckoned from midnight in numerical succession from 1 to 12, then beginning again at 1 and ending at 12. Astronomers begin their computation at the noon of the civil day, and count the hours in numeral succession from 1 to 24, so that the morning hours are reckoned from 12 to 24. Navigators begin their computation at noon, 12 hours before the commencement of the civil day, (and 24 hours before the commencement of the astronomical day;) marking their hours from 1 to 12 P.M. and A.M., as in the civil computation.

"There are two kinds of time, mean and apparent. *Mean time* is that shewn by a clock regulated to mean solar time. *Apparent time* is that shewn by the sun, estimating the apparent noon to commence at the passage of his centre over the meridian of any place. There is sometimes a difference of a quarter of an hour between mean and apparent time, owing to the unequal motion of the earth in its orbit, and the inclination of its axis. This difference is called the *equation of time*, and is contained in page 2 of the Nautical Almanac. It is necessary to take notice of the equation of time in determining the longitude by a timekeeper or by the eclipses of Jupiter's Satellites; but it is not necessary in any other nautical observation, because the calculations of the Nautical Almanac, except the times of the eclipses of Jupiter's Satellites, are adapted to apparent time.

"We may obtain the apparent time at sea, when the ship makes no way through the water, by observing an altitude of the sun in the morning, and again in the afternoon, when at the same altitude, and noting the times by a watch; for the middle time between these two observations will be the apparent time of the sun's passage by the meridian; hence the error of the watch may be found. A small correction is necessary for the variation of the sun's declination during the interval between the observations, and the method of calculating this correction will be given in this work, but this method cannot often be made use of at sea by reason of the motion of the vessel.

The best method of obtaining the apparent time at sea, is by observing by a fore observation, the altitude of the sun's lower limb when rising or falling fastest or when bearing nearly E. or W. To this altitude we must add the semi-diameter and parallax, and subtract the dip (or instead of these three corrections add 12', which will answer very well for an observation taken on the deck of a common sized vessel;) subtract also the refraction taken from Table XII, and the remainder will be the correct altitude. The ship's latitude must be found at the time of observation by carrying the reckoning forward to that time. The declination must be taken from Table IV, or from the Nautical Almanac, and corrected for the ship's longitude, and the distance of the sun from the meridian by Table V. Then *if the latitude and declination be both north or both south, subtract the declination from 90° and you will have the polar distance; but if one be north and the other south, add the declination to 90° and you* *will have the polar distance.*

"Having thus found the correct altitude, latitude, and polar distance, the apparent time of observation may be found by either of three following methods, of which the first is the most simple..."

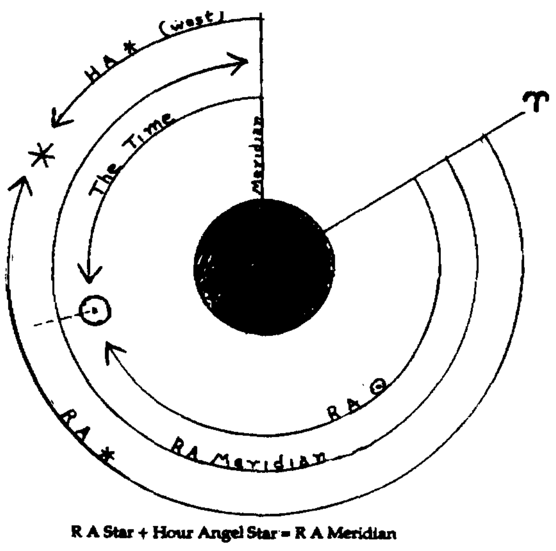
Then he demonstrates, with examples, three different ways of working a time sight.

The Table IV he mentions gave the sun's declination at Greenwich noon each day for four years. Since declination is fairly stable from one leap year cycle to the next, the table would, as Bowditch put it "answer nearly" for sixteen years. The first page was labeled for 1820, 1824, 1828, and 1832, and the other three pages follow a similar pattern, the second page being of 1821, 1825, 1829, 1833. This four page table was a standard feature of the old navigation manuals. It was updated with each new edition.

Table V was a somewhat rough-and-ready four page table devised by Maskelyne to make it easy to adjust declination for longitude, and for time of day.

Another standard feature of navigation manuals was a table giving the right ascensions and declinations of the stars, with yearly variations. There was also a table of the sun's right ascension, but it wasn't particularly accurate. For most purposes the sun's right ascension was taken from the *Nautical Almanac.*

Right ascension, or RA, came into play when it was necessary to get local time from a body other than the sun, or to calculate altitudes for a lunar distance. Like sidereal hour angle, RA is measured from the vernal equinox. But unlike SHA it is measured to the eastward, and is usually given in time, rather than arc. You can think of right ascension as the order in which bodies ascend to the meridian, following the first point of Aries. If the RA of a body is one hour, it is 15° east of Aries. It will come to the meridian an hour later (star time) than Aries. If the RA of another body is two hours, it is 30° east of Aries. And so on, all the way to 23 hours, 59 minutes, 59 seconds.



R A Star + Hour Angel Star = R A Meridian

R A Meridian - R A Sun = Local Apparent Time

Suppose you take a time sight of a star to the west of you and find its local hour angle is 60°—four hours. Your navigation manual tells you (table VII in Bowditch) that the star's RA is sixteen hours. Since you are four hours to the east of the star and the star is sixteen hours east of Aries, you must be twenty hours east of Aries. That is, the "right ascension of the meridian" is twenty hours.

From the *Almanac* you find the sun's RA is thirteen hours. Subtracting the sun's RA from the RA of the meridian you find you were seven hours east of the sun at the moment you took the star's altitude.

Since you were seven hours east of the sun at the moment of the observation, the time was seven hours past noon. The difference between that and what your watch read was the error of the watch. That's how you "regulated" your watch.

If the star had been to the east you would have subtracted its local hour angle from its right ascension. In these particular calculations you can borrow or discard 24 hours as needed without affecting the date.

When starting his calculations the first thing a navigator did was shift to astronomical reckoning. If the sun was on his meridian, noon July 17th civil time, it was noon July 17th astronomical time. The astronomical day began with noon (noon was included as the zero hour) and ran on past midnight—13, 14, etc.—until the instant before the noon of the next day. From noon until midnight the astronomical reckoning was the same as the civil. But from midnight until noon, one day had to be subtracted from the civil day and 12 hours added to the time.

To find Greenwich time for entering the *Almanac* a navigator converted his dead reckoning longitude to time. If it was west he added it to his own time. If it was east he subtracted it.

When the sum of local time and west longitude (converted to time) equaled or exceeded 24 hours he subtracted 24 and added a day to the date. When local time was less than east longitude he added 24 (so he could make the subtraction) and took a day from the date.

It seems odd from our point of view that, while the *Nautical Almanac* gave its data in terms of Greenwich time, it didn't tell where the various bodies were in relation to the Greenwich meridian. Obviously, Greenwich apparent time—of itself—tells where the *sun* is in relation to the meridian at Greenwich. But the purpose of the *Almanac* was simply to keep track of where the various bodies were as they gradually moved around in the celestial sphere. Linking that sphere to the spinning earth was left to the navigator. To do so he found his local time by time sight, and his local time—with a little help from the *Almanac*—told him where the bodies were in relations to HIS meridian.

With this system the nearest five or ten minutes of Greenwich time was, in nearly all cases, abundantly accurate for entering the *Nautical Almanac*. In fact, when dealing with bodies other than the moon, an error of a quarter of an hour threw things off only about as much as would a three second error with our present system.

Navigators occasionally needed accurate Greenwich time to compare with their own time in order to correct their dead reckoning longitude. But in their way of thinking a lunar distance, or a chronometer regulated to Greenwich, didn't give them the time. It gave them the longitude.

Bowditch said nothing about lunars or chronometers under "To Find the Time at Sea and Regulate a Watch." He put lunars under "Finding the Longitude at Sea by a Lunar Distance," and chronometers under "To Find the Longitude by a Chronometer."

Lewis and Clark's equal altitudes observation of July 17th, 1804—worked in issue #66 of the *Newsletter*—gives a sketchy idea of how this way of thinking about time and longitude translates into practical terms. I hope, in future issues of the *Newsletter*, to be able to round out the picture by showing how to work the other observations the captains took on that day

The Future of Almanac Data in the United States

By John A. Bangert, U.S. Naval Observatory

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Introduction

Numerous factors — such as changes in technology, navigation policy, user requirements, and funding levels — make it difficult to predict the future of almanac data in the U.S. In the last few years, there have been detailed discussions of the future of almanacs, both within the U.S. Naval Observatory (USNO), and between USNO and the staff of H.M. Nautical Almanac Office (HMNAO) of the UK. Some definite decisions emerged from these discussions. In some cases, the decisions are already being put into practice. In other cases, the decisions are forming the basis of long-term plans for changes in the products produced by the two almanac offices.

This paper will draw on the discussions mentioned above and present current plans for the future of almanac data produced or co-produced by USNO's Astronomical Applications (AA) Department. This paper will use a broad definition of "almanac data," to include not only printed almanacs, but also software almanacs and almanacs designed for use on the Internet. As with any attempt at making predictions, this paper will inevitably reflect the views and biases of the author.

Future of Celestial Navigation

The future of the navigational almanacs is tied to the future of celestial navigation. In certain respects, the general concept of celestial navigation is more important today than it was ten years ago. The great success and widespread use of the Global Positioning System (GPS) have resulted in the termination or proposed termination of older alternative electronic navigation systems. Prudent navigation practice requires both a primary and a secondary means of navigation, with the secondary independent of the primary. Celestial navigation remains one of the few independent alternatives to GPS.

Celestial navigation can encompass any method that utilizes observations of astronomical bodies — bodies with known positions in a standard celestial reference frame — to determine the position of a platform in a standard terrestrial reference frame. The various methods for performing celestial navigation can be grouped into three general categories. *Traditional, manual methods* require use of the sextant, coupled with manual sight planning and reduction procedures (i.e. printed almanacs and forms). *Traditional, computer-based methods* also require use of the sextant, but sight planning and reduction are performed using a computer program. Finally, *fully automated methods* use some type of automatic electronic sextant or star tracker to make observations, which are then fed to software that performs the sight reduction.

The AA Department plans to be involved in all three of these methods. Prospects and proposals for the navigational almanacs — both printed and computer-based — will be discussed below. The AA Department is also engaged in a study of a fully automated system for celestial navigation[1], although further discussion of this topic is beyond the scope of this paper.

Almanacs for Marine Navigation

USNO's proposed plan for the future role of *The Nautical Almanac* in the U.S. is based on input from fleet navigators and our own vision of the role of celestial navigation in today's Navy. The goal of the plan is to promote a computer-based system for planning and reducing sextant observations as the preferred method for routine use, while retaining manual methods, including use of printed almanacs for backup or emergency use.

Computer-based methods of sight planning and education have obvious advantages: they are much faster than manual methods, they eliminate math blunders, they can be made rigorous, and they allow the navigator to take more sights and improve skills in use of the sextant. Fleet navigators have made these points when commenting on USNO's own computer-based almanac for celestial navigation, STELLA.

However, some navigators have expressed great concern about over-reliance on computers and electronics, especially during hostilities. As one navigator stated in a 1997 survey of STELLA users: "A PC based system won't do me any good if I have to perform sight reduction after battle damage, or heaven forbid, in a lifeboat." Another navigator stated: "Electronics like this ... [are] placing the Navy in serious jeopardy. Electronic warfare and other technology can easily disable these systems. Until you have addressed all of these issues, any decent [quartermaster] will opt for conventional means."

In my opinion, both the advantages of computer-based tools and concerns involving over-reliance on technology are valid issues that must be addressed in any plan for the future of the navigational almanacs. Thus, we have proposed that the U.S. Navy fully approve and promote STELLA for routine use in celestial navigation. We also propose that a manual means of sight planning and reduction be retained, but relegated to a backup role. If this policy is adopted, USNO will likely produce an "Abridged Nautical Almanac" specifically for Navy use. This book will be published every three to five years (to be determined) without the hourly tabular data for the Moon and planets. Discussions with fleet navigators indicate that the Moon and planets are often avoided, due to additional complexities in reducing their observations. Of course, STELLA handles these complexities automatically, and STELLA has the capability to generate lunar and planetary almanac data in standard *Nautical Almanac* format on demand. HMNAO would continue to produce the current *Nautical Almanac* and ensure its availability in the U.S.

It is important to note that this plan is only a proposal at this time.

Almanacs for Air Navigation

The future of the U.S. *Air Almanac* is uncertain. Without a doubt, use of celestial navigation aboard U.S. military aircraft is in rapid decline. New aircraft, replacing existing aircraft, are being built without sextant ports. GPS and inertial navigation systems are becoming dominant. Reflecting this situation, there has been a major reduction in celestial navigation training for military air navigators. "Undergraduate" training has essentially been eliminated, and "post-graduate" training has been reduced to a computer-based course. Furthermore, we have been unable to identify any specific U.S. Navy or Air Force requirements for continued publication of *The Air Almanac*. The AA Department undertook a survey of users of *The Air Almanac* in 1998. The survey results are still being analyzed, but preliminary results indicate that there currently is a need for the book. Furthermore, it appears that there will be at least several types of military aircraft that will use celestial navigation for the foreseeable future. Additional study is needed to understand the requirements. However, it is quite possible that the U.S. *Air Almanac* will be reduced in scope or terminated within the next five to ten years.

USNO has offered to produce for the U.S. military a version of STELLA specifically designed for air navigation, but so far there has been no formal interest.

The Astronomical Almanac

The Astronomical Almanac has not undergone a major review and revision since the edition for 1984. The recent adoption of the International Celestial Reference System (ICRS)[2] by the International Astronomical Union (IAU) will require changes in the book, so there is now an excellent opportunity for a complete review of the contents of the volume. In fact, the AA Department and HMNAO have already begun the process. A survey of users of *The Astronomical Almanac* was undertaken in 1998. While the results are still being analyzed, it is clear that there is strong support for continued production of a printed *Astronomical Almanac*. Numerous survey respondents expressed thoughtful suggestions concerning material in the book that could be added, deleted, or revised. The almanac offices have given, and will continue to give, careful consideration to these suggestions in making decisions concerning the future of the volume.

Changes to *The Astronomical Almanac* will take place gradually, with the first revisions likely to be incorporated into the edition for year 2002. Both content and presentation will be affected. IAU standards will be adopted whenever possible. One of the most interesting changes will be the addition of an "electronic component" to the book. This electronic component will likely take the form of Uniform Resource Locators (URLs) placed throughout the book. These URLs will refer the user to World Wide Web (WWW) sites and services that extend the usefulness of the printed reference data. For example, Section A (Phenomena), which contains extensive tables of sunrise and sunset times, may include the URL of a WWW service that computes times of sunrise and sunset for a specific date and location. Section D (Moon) may include the URL of a File Transfer Protocol (FTP) server from which the lunar ephemeris polynomials can be downloaded and subsequently used in a computer application.

In the long term, the fundamental ephemerides produced by the Newcomb project[3] are expected to form the basis of *The Astronomical Almanac*.

In addition to changes in content and presentation, both almanac offices are adjusting the production schedule for *The Astronomical Almanac*. Our survey results indicate that most users would like to have the book one year prior to the cover year. This is our goal and we have already made great progress in attaining it.

The AA Department and HMNAO are also considering replacing *Astronomical Phenomena* with an expanded publication aimed at a more general market.

Computer-Based Almanacs

At first thought, it may seem as if computer-based almanacs and printed almanacs are competing products. I am often asked if our computer-based almanacs, MICA[4] and STELLA, will allow us to stop production of their printed counterparts. I view the computer almanacs and the printed almanacs not as competing products, but as complementary products. There are many instances when it is much more convenient to look up a value in a book, rather than obtain it from a computer program. Books also stand the test of time, transcending changes in technology that can render a computer program useless. On the other hand, computer almanacs can provide information that is difficult to obtain from a printed book. For example, the topocentric coordinates of the Moon are much easier to obtain from a computer program – they are computed on demand for a specified location and time – than from a book, where tabulated geocentric values must be interpolated and transformed to the location of interest. Furthermore, the long time span of a computer almanac makes it very useful for planning purposes.

Also, in my opinion, the widespread availability of astronomical data on the Internet does not eliminate the need for or the usefulness of computer almanacs, although this situation could change as technology advances. Computer almanacs are still usable when an Internet connection is not available. Furthermore, a richer set of user interface features is available in a modern personal computer (PC) program than is currently available in an Internet data service. This allows the almanac developer to create easier and more powerful methods for interacting with the user, and more flexible options for presenting the computed data.

Thus, the AA Department plans to continue improving and supporting MICA and STELLA. They will continue to be targeted to operate on PCs, which enjoy widespread use throughout the world. We are currently engaged in projects to convert the programs from their current MS-DOS underpinnings, to full compliance with the latest Microsoft Windows operating systems. The printed almanacs generally provide high-precision data in tabular from, and our computer almanacs will continue to follow this prescription. No attempts will be made to compete with the numerous planetarium-type programs that are currently available, although graphics may be introduced if deemed appropriate.

The AA Department also produces another type of specialized computer-based almanac that I will call an "almanac engine." An example of this is the Solar-Lunar Almanac Core (SLAC) available only to our U.S. military customers. In recent years, there has been an increasing demand for illumination data, largely to support planning for night operations and for use in simulators. SLAC is a self-contained, integrated set of C-language functions that computes all important quantities related to illumination: times of sunrise, sunset, moonrise, moonset, twilight, and transit, fraction of the Moon illuminated, and an estimate of the illuminance. SLAC is not a stand-alone program – rather, it was designed for incorporation into larger software systems, such as ones that do operations planning, mission scheduling, or simulations. SLAC has been quite popular and will continue to be supported and improved. The AA Department will also consider developing similar specialized almanac engines to support specific requirements.

Almanac Data on the Internet

The AA Department has already developed a strong presence on the Internet, and that presence will almost certainly increase. We use our Web site for several key tasks. First, we use the site to advertise, and help customers obtain, the printed and computer-based almanacs. Second, we use the site to describe basic astronomical phenomena and to provide answers to frequently asked questions about our products and the information that they contain. Finally, our site offers numerous interactive data services that provide customized almanac data on demand, free of charge. Prior to the establishment of our Web site, the latter two tasks had to be handled by staff astronomers, resulting in less time available for mission work.

As already implied, our Web site will grow by providing services that complement existing products, especially *The Astronomical Almanac.* We also plan to further develop and improve a restricted part of our site that specifically serves the needs of our U.S. military customers.

Use of the World Wide Web as a means of disseminating almanac data is perhaps the most important component of our plan for the future.

Summary and Conclusions

The Astronomical Applications Department of the U.S. Naval Observatory plays a unique role in providing practical astronomical data in the U.S. I am unaware of any other organization in the U.S. that provides high precision almanac data via printed books, computer applications, and the Internet. The department will continue to work toward its traditional goals of providing data of high precision and accuracy, to present those data in useful and usable formats, and to provide those data in a reliable fashion. Furthermore, the department plans to undertake new initiatives to revise its products to meet changing user needs. The key elements of our plans can be summarized as follows:

- Despite the widespread use of computers and the rapid development of the Internet as a mechanism for disseminating data, there are still valid reasons and strong demand for printed almanacs.
- USNO has proposed that the U.S. Navy make our STELLA software the primary tool for routine use in celestial navigation, and relegate manual means of sight planning and reduction to a backup role. If this occurs, the AA Department will likely produce an "Abridged Nautical Almanac" for Navy use, to be published every three to five years. HMNAO would continue to produce the current *Nautical Almanac* and ensure its availability in the U.S.
- The future of the U.S. *Air Almanac* is uncertain. Due to declining use of celestial techniques for air navigation, it is likely that the *Air Almanac* will be reduced in scope or terminated within five to ten years.
- In a cooperative venture between the AA Department and HMNAO, *The Astronomical Almanac*

will be revised. Planned improvement include incorporating the ICRS, a new ephemeris of the solar system, some improved tables and new material, and elimination of outdated material. The book will also include an electronic component, likely in the form of links to WWW services that extend the usefulness of the printed material. The two offices will also explore replacement of *Astronomical Phenomena* with an expanded publication aimed at a broader market.

- The AA Department will continue to improve and support its computer-based almanacs, MICA and STELLA. Both programs are being revised to be fully compliant with the latest PC operating systems, and new features and functions will be added.
- The AA Department is fully committed to making almanac data available via the WWW. Our Web site will continue to be expanded and improved, and will help customers obtain the traditional products, provide answers to frequently asked questions, and provide selected almanac data, especially those data that extend the usefulness of print material.

Last, but certainly not least, the AA Department looks forward to continued successful collaboration with HMNAO and its new parent organization, the Rutherford Appleton Laboratory. Our desire to collaborate has recently been affirmed via a new Memorandum of Understanding between the two organizations to guide our cooperative work.

Acknowledgements

I would like to thank my colleagues at USNO – especially Alan Fiala, George Kaplan, and Ken Seidelmann – for contributing to the ongoing discussion of the future of almanacs. I would also like to thank my colleagues, present and past, at HMNAO – especially Steve Bell, David Harper, Catherine Hohenkerk, and Patrick Wallace – for their contributions to the discussion.

NOTES

1 G. H. Kaplan, "New Technology for Celestial Navigation," these *Proceedings.*

2 For a concise discussion of the ICRS and its practical consequences, see: M. Feissel and F. Mignard, "The Adoption of the ICRS on 1 January 1998: Meaning and Consequences," *Astronomy and Astrophysics,* **331** , (1998), L33-L36.

3 The Newcomb project is an AA Department effort to produce new fundamental ephemerides of major solar system bodies. Additional information can be found in the Research section of the AA Department World Wide Web site (http://aa.usno.navy.mil/AA).

4 MICA is USNO's computer-based almanac for high precision applications. For more information concerning MICA (and STELLA), see J. A. Bangert, "The Astronomical Applications Department Today," these *Proceedings.*

HISTORY OF NAVIGATION

The Tamaya Artificial Horizon Marine Sextant with Six Shot Mechanical Averager

By John M. Luykx

INTRODUCTION

During the 1930s the well-known firm of Tamaya in Tokyo produced a marine sextant for naval use which incorporated a bubble assembly, of the Coutinho type, for night observations, and for use when the natural sea horizon was obscured or indistinct. The design of this sextant was based on the famous C. Plath (Hamburg) "System Gago Countinho" artificial horizon marine sextant, first marketed during the late 1920s, which saw world wide use prior to World War II. (See Issue #27, page 8). The C. Plath artificial horizon sextant in turn was based on the original design specifically devised by Captain Gago Coutinho of the Portuguese Navy for the 1922 transatlantic (east to west) flight from Lisbon to Recife, Brazil.

Prior to, as well as during World War II, the Gago Coutinho sextant design with several modifications was also incorporated in the manufacture of a number of sextants provided by the Tamaya firm for the Japanese Navy. One of the variations of the sextant (in the author's collection) is shown in Figure 1.

A unique feature of this particular Tamaya Countinho type sextant is that, in addition to the artificial horizon a six shot mechanical averager is included in the design. It is the only marine sextant, known to the author, which incorporates a mechanical averager fitted to a micrometer drum marine sextant. An additional and distinguishing feature of this instrument is that the markings on the sextant are limited to two figures: the Tamaya logo and the serial number 1. The serial number probably indicates that the sextant may be a prototype instrument.

DESCRIPTION

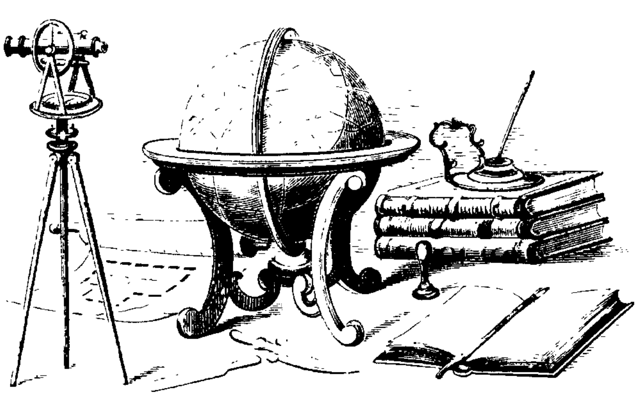
The housing forward of the horizon mirror contains the artificial assembly consisting of two bubble levels and a 45° inclined mirror. The longitudinal bubble element when reflected by the 45° inclined mirror into the optical path of the sextant provides the artificial (true) horizon while the transverse bubble indicates sextant "cant" or "tilt" from the vertical. Figure 2 is a schematic diagram of the sextant and its optical system. Figure 3 shows closeup views of the instrument from various angles. Figure 4 is a closeup of the mechanical averager located on the right side above the handle at the pivot of the index arm.

The arc of the sextant is of 5 inch radius and is graduated from –6° to 90°. A 3 volt lighting system (size D battery in the handle) is provided to illuminate the arc, the micrometer and the bubble assembly. Four index neutral density filters and one horizon filter are included. Two telescopes are available: a 3x Galilean scope which is used for taking altitude observations when the visible horizon is the reference and a 2_ power Galilean scope with vertical focusing lens attached to the objective lens for taking altitude observations when the artificial horizon (bubble) is used as a reference. Two spare longitudinal bubbles, four light bulbs, an adjustment wrench and a telescope eyepiece filter are included as accessories. A hardwood box is provided.

THE AVERAGER

The averager located at the pivot of the index arm is a circular metal device with a circular outer rotating ring graduated in degrees and minutes (with vernier) positioned about the circular inner fixed housing which is similarly graduated in degrees and which acts as the vernier.

When the first observation in a series of six is taken, the lever actuating and rotating the outer ring of the averager is pulled back to the stop. The averager then indicates one sixth of the altitude shown on the arc. When the second observation is made, the lever is pulled back again to a stop. The resulting averager reading is equal to the first averager reading plus one sixth of the altitude shown on the arc at the second observation. For the third observation the averager reading equals the sum of the first two averager readings plus one sixth of the altitude indicated on the arc for the third observation. For the fourth observation the averager reading equals the sum of the first three averager readings plus one sixth of the altitude shown on the arc at the fourth observation. For the fifth observation one sixth of the sextant altitude reading is added to the sum of the first four averager readings. Finally, at the sixth observation the averager reading is equal to one sixth of the sextant altitude reading added to the sum of the first five averager readings.



The averager reading at the end of the sixth observation is equal to the mean value of the six altitudes observed in the series.

If the time of observation of each of the six observations is recorded, then an average of the six times of observation will equal the mean time of the series of six observations. If, however, only the times of the first and sixth observations are recorded, then the average of these two times will be equal to the "mid" or "median" time for the series of six observations.

To illustrate the operation of the averager for the purpose of this article, an averager accuracy test was conducted with the sextant. The following results were obtained:

Table 1: Averager Accuracy Test

1 Obs.	2 Altitude set on sextant	3 Actual averager reading	4 True averager reading	5 Actual averager reading	computation
1	30°00′	05°00′	05°00′	00°00′	30°00′ / 6
2	31°00′	10°11′	10°10′	05°00′	+31°00′ / 6
3	32°00′	15°32′	15°30′	10°11′	+32°00′ / 6
4	33°00′	21°00′	21°00′	15°32′	+33.°00′ / 6
5	34°00′	26°41′	26°40′	21°00′	+34°00′ / 6
6	35°00′	32°31′	32°30′	26°41′	+35°00′ / 6

Notes:

a. Column 2 shows the altitude set on the sextant for each one of the six observations in the series.

b. Column 3 shows the actual reading of the averager after each observation.

c. Column 4 shows what the averager should have read after each observation.

d. Column 5 shows a mathematical computation of the data provided by the averager after each observation.

e. The figures in Column 3 show that after the second altitude observation, the averager was in error by +1.0; after the third observation, the error was +2.0,; after the fifth observation, the error was +1.0; and that the mean averager error after the series of six observations was +1.0.

ACCURACY TESTS

In order to check the accuracy of the sextant, the mirrors and bubble assembly were first aligned and calibrated. A test of the sextant was then conducted to confirm I.C. It consisted of eight observations using the horizon as a reference. The results are shown in Table 2.

Following this test, the altitude of the horizon, using a series of five observations with the bubble assembly, was determined to check the combined I.C. of the sextant and bubble assembly. The results are given in Table 3. The final test of combined sextant and bubble accuracy was conducted in a series of 15 sun observations (3 groups of 5 each). The results of this final test are given in Table 4.

Table 2. Sextant I.C.

Obs. No.	I.C.
1	–1.'0
2	–1.'5
3	–1.'0
4	0.'0
5	+0.'5
6	0.'0
7	–1.'0
8	–0.'0
	8/-4.'0
	Mean I.C. -0.'5

Table 3: Test of the combined accuracy of the sextant and bubble attachment and bubble assembly using the horizon as reference. (Ht. Of Eye: 10')

Obs. No.	Hs (Horizon)
1	-3.'0
2	–3.'5
3	–2.'0
4	–2.'5
5	–3.'5
	5/-14.'5
Mean Altitude:	-2.'9
Dip Error:	-3.'1
IC:	-0.'2

Table 4: Test of the combined accuracy of the sextant and bubble assembly using a celestial body as a reference

Date: 22 July 1999 WC: 0 seconds
Position: N38°03.'5 W76°19.'5 Weather: Warm, cloudy
Body: Sun (C) Instrument: Coutinho type sextant w/averager

Obs. No.	Time (+4)	Hs(Sun)	Error
1	18-23-46	21°29.'0	-3.'8
2	18-24-26	21°20.'0	-5.'0
3	18-25-06	21°16.'0	-1.'3
4	18-25-36	21°04.'0	-7.'5
5	18-26-08	20°58.'0	-7.'3
6	18-27-06	20°51.'0	-3.'0
7	18-27-41	20°44.'0	-3.'3
8	18-28-27	20°31.'0	-7.'4
9	18-29-14	20°29.'0	-0.'3
10	18-29-43	20°19.'0	-4.'7
11	18-30-24	20°15.'0	-0.'7
12	18-30-54	20°08.'0	-1.'9
13	18-31-31	20°03.'0	0.'0
14	18-32-08	19°57.'0	+1.'3
15	18-32-37	19°49.'0	-1.'0
		Total:	15/-45.'9
		Mean Error	-3.'1:
		I.C.:	+3.'1

Note: To avoid further production delay, figures 1, 3, 4 will be in the Summer Issue.

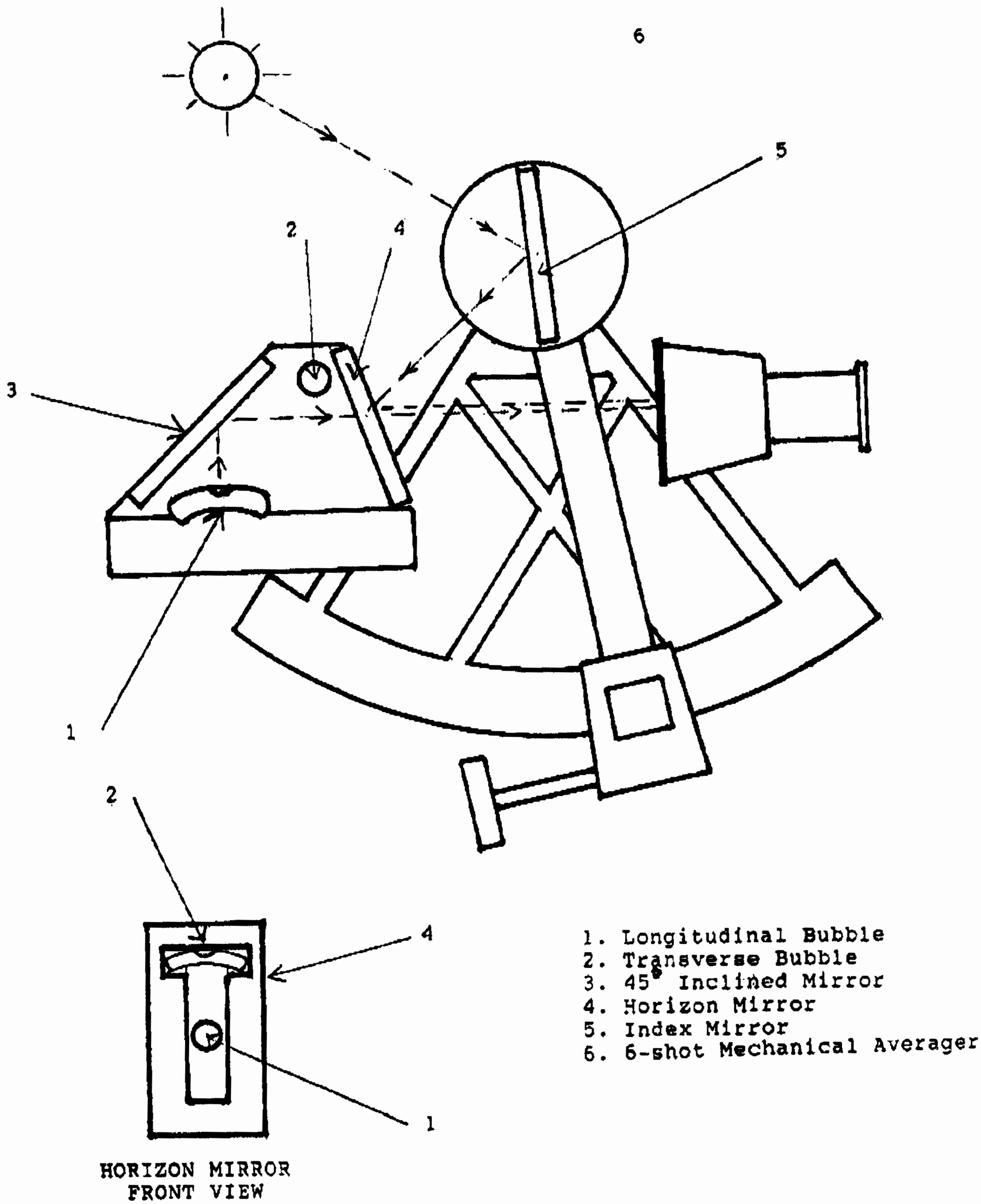


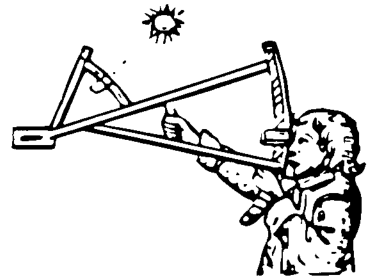
Figure 2. Schematic diagram of Tamaya Artificial Horizon Marine Sextant with Six Shot Mechanical Averager.

ANSWER TO DO YOU KNOW...

(From page 1)

The Royal Observatory at Greenwich became the Royal Greenwich Observatory (RGO) in 1949 after it relocated to Herstmonceux Castle near the English Channel in Sussex. H.M. Nautical Almanac Office (HMNAO), then located at Bath, moved there as well. When the Science Research Council took over the RGO from the Ministry of Defence in 1965, HMNAO became a department of the RGO. Several organizational changes and relocations followed. One change was the closing down of RGO in October 1998.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION ISSUE SIXTY-EIGHT, SUMMER 2000

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

The year 2000 winner of the Thomas D. Davies, USN award for excellence in navigation at Tabor Academy is Emil John Peinert. He was awarded a plaque and a check for $100.00.

The Foundation is still receiving bank drafts from members banks but without any members name. Most times I can associate the bank's ZIP code to a member's address if there is only one member in that area. If you have the bank send a draft for membership renewal have them please provide us with your name. A membership number would be very helpful.

All travel is off until cool weather. Members can rest assured that I will be here to process their chart, publication and book orders. Remember your Foundation when you are looking for a book or chart. Our E-mail is navigate@ix.netcom.com. Our telephone and fax number is 301-622-6448. If you call between 1800 and 1900 weekdays you may find me still at the computer.

READERS FORUM

Edited by Ernest Brown

Member Eric B. Forsyth wrote from Brookhaven, New York on 5 June 2000:

"Dear Friends, The time has rolled around again for another of my two-yearly circular letters. So, as usual, Merry Christmas and a Happy New Year.

"This cruise starts in a week and will take *Fiona* to Canada, Iceland, the Arctic near Spitzbergen, Norway, Scotland, Ireland and Portugal. I hope to fly home for a couple of weeks from Lisbon in early November. On my return we will sail to Madeira and St. Martin in the Caribbean. Brenda plans to join the boat there for Christmas. Early in the New Year we will head downwind to the Virgin Islands, Puerto Rico, the Dominican Republic, Cuba and then Bermuda. I hope to arrive back in the U.S. in early May, 2001.

"The newsletters for this cruise can be downloaded from website managed by Brenda. Its address is: www.yachtfiona.com, which also has some newsletters from previous trips. Color pictures can be downloaded at your discretion, the discretion is due to the size of the file, not the content! This is a family newsletter . . . Have a great year." —*Best wishes, Eric*

January 2000

***FIONA'S* Tentative Timetable, 2000 to 2001**

DATES	ROUTE/PORT	
FROM		TO
12 June 2000	13 June 2000	Patchogue to Block Is
14	16	Block toProvincetown
17	20	Provincetown to Lunenburg, Nova Scotia
21	25	Lunenburg to St. Johns, Newfoundland
28	13 July	St. Johns to Reykjavik, Iceland
18 July	27	Reykjavik to Spitsbergen
3 August	9 August	Svalbard to Lofoten Is
10	23	Cruise W. Coast of Norway
23	25	Stavanger to Moray Firth, Scotland
26	27	Transit Caledonian Canal
28	6 September	Cruise W. Coast of Scotland
7 September	9	Scotland to Ireland
10	22	Cruise W. Coast of Ireland
23	29	Cork
30	4 October	Cork to Portugal
5 October	19	Cruise W. Coast of Portugal
20	18 November	Lisbon
27 October	16 November	Fly to NY and return

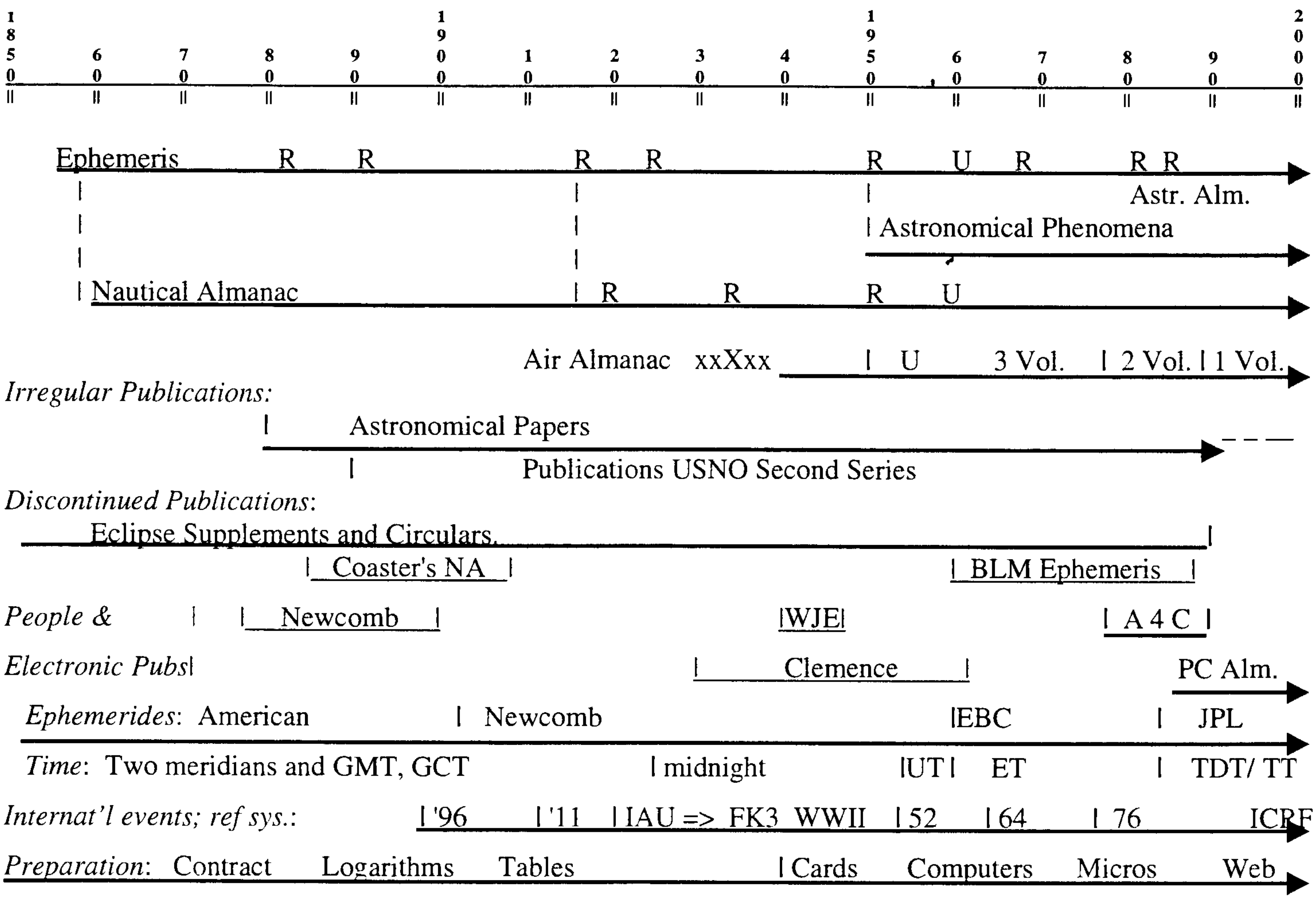
DO YOU KNOW . . .?

By Ernest Brown

Why Amelia Earhart did not succeed in the use of her radio direction finder for a landing at Howland Island on July 2, 1937?

(See page 11 of this issue.)

19 November	22	Lisbon to Madeira
24	20 December	Madeira to St. Martin, W. Indies
21 December	3 January 2001	St. Martin
4 January 2001	5	St. Martin to Virgin Is
18	20	Virgin Is to Vieques
21	27	Vieques
28	29	Vieques to Fajardo, Pto Rico
30	10 February	Fajardo to Mayaguez
11 February	12 February	Mayaguez to Dominican Rep
13	23	Cruise N. Coast of Dominican Rep
24	27	Dominican Rep to Cuba
28	18 March	Cruise N. Coast of Cuba
19	21	Cuba to Exuma, Bahama Is
21	31	Cruise Bahamas
1 April	10 April	Bahamas to Bermuda
11	27	Cruise Bermuda
28 April	3 May	Bermuda to Newport, RI
6 May	8 May	Newport to Patchogue



Abbreviations:

R = Revision
U = Unification
X = Experimental

WJE = Wallace J. Eckert
EBC = Eckert-Brouwer-Clemence Integration and Brown's Lunar Theory
A 4 C = Almanac For Computers
PC Alm. = Floppy Almanacs, MICA, STELLA, etc.

Figure 1. Timelines for Publications, People, and Major Influences

NAVIGATION NOTES

Evolution of the Products of the Nautical Almanac Office

By Alan D. Fiala, U.S. Naval Observatory

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory March 3-4, 1999. Courtesy of the author.

Introduction

My career of nearly 37 years has been spent almost entirely in the Nautical Almanac Office, and I now head the small division that still proudly bears the name. The invitation to review the products that the office has produced gave me the opportunity to step back from the details and look at a broad perspective. Rather than define the history in terms of the products, I'd like to look at some parallel factors in astronomy and navigation, their interaction with the Nautical Almanac Office, and the products that resulted.

Most of you are familiar with either *The Astronomical Almanac* or the navigational almanacs. The first product of the office, *The American Ephemeris and Nautical Almanac for 1855*, superficially bears little resemblance to *The Astronomical Almanac for 2000*, its direct descendant published last month. That first edition was the only product of the office, whereas *The Astronomical Almanac* is just one of several products. The concept of a product, especially within a mission-oriented institution, also means there has to be a demand or requirement for it.

Figure 1 (on the facing page) displays the parallel timelines and significant milestones. The lines in the top part show the evolution of annual printed products. The middle part shows some important people and electronic products. The bottom part shows some of the trends and requirements driving the evolution of the products. This paper will describe the relationships among them.[1]

National Almanac Offices

"Almanac" and "ephemeris" have imprecise definitions. "Almanac" derives from the concept of calendar and almanacs have existed for centuries. It now commonly refers to similar information in an annual publication. The earliest almanacs often had two components, a calendrical one for listing dates and festivals, and an astronomical one for configurations of the Sun, Moon, planets, stars, phases of the Moon, weather predictions, and other such "useful" information. "Ephemeris" derives from the Greek for something lasting a very short time. The current usage is in the sense of tabular representations of the positions of celestial bodies as a function of time. The distinction between an almanac and an ephemeris is therefore somewhat blurred.[2]

In the 15th century, great voyages of exploration and discovery out of the sight of land made the determination of longitude a problem of paramount importance. Many methods were proposed, but few were practical. The most notable schemes required observations of events that could be observed simultaneously from many locations: solar and lunar eclipses, occultations of stars, and the eclipses of the satellites of Jupiter. The drawback was that these events occurred at wide intervals, rarely at times convenient to a navigator, and were difficult to observe because of inadequate instruments and the motion of a ship. The method known as lunar distances was the most attempted, but rarely successful because the lunar theory was so inaccurate.[3]

National offices were intended to assure that accurate information was reliably available to navigators for that country. In France, a private almanac called *Connaissance desTemps* was taken under the auspices of the French Academy beginning in 1679. That publication provided the earliest explanations of finding longitude using the Moon. The British Nautical Almanac Office was established with the main purpose of providing the information for the application of the method. The first issue appeared in 1767. The time was right, as Tobias Mayer had just completed a new, more accurate, theory of the Moon. Germany and Spain soon established their own similar offices and publications.[4]

The United States Nautical Almanac Office

There were, inescapably, political considerations behind the founding of the American Nautical Almanac Office and its development.[5]

The young United States of America used the British Nautical Almanac for navigation and surveying, as well as astronomical purposes. As the country grew geographically and also became a maritime power, there was increasing need felt for a national almanac. Even before establishment of a national observatory in 1842 there was talk in the astronomical community of a federally supported national almanac. In 1844, John Y. Mason, Secretary of the Navy, noted our dependence on foreign nations. There was a dilemma, however. Matthew Fontaine Maury, the Superintendent of the new national observatory, was of the opinion that an American almanac should be wholly American in both calculation and observations. There was fear that such a product might be so inaccurate as to be dangerous. On the other hand, if the product merely duplicated the British work, why expend the funds? There was also a division between those who thought a national almanac should be solely for navigational purposes, and those who wanted to do a service to astronomy in general.[6]

At last, on Saturday, 3 March 1849, the last day of the administration of James K. Polk, an appropriations bill passed by Congress for the Naval Service provided

> ...That a competent officer of the navy, not

below the grade of lieutenant, be charged with the duty of preparing the Nautical Almanac for publication, and that the Secretary of the Navy may, when in his opinion, the interests of navigation would be promoted thereby, cause any nautical works that may, from time to time, be published by the hydrographical office, to be sold at cost,...[7]

Despite the wording, this authorization was not construed as placing the almanac under the hydrographical office. A Nautical Almanac Office was established at the beginning of the next fiscal year, 1 July 1849. Separate from the national observatory, it was located in Cambridge, Massachusetts, next to the Harvard College Observatory, the best research observatory in the United States. Benjamin Peirce was there, and served as *de facto* scientific director. The first Superintendent of the Nautical Almanac Office was Navy LT Charles Henry Davis. He had experience with navigation, but also strong ties to the scientific community. He was a protégé of Peirce.[8] Davis' view was that the almanac should serve for both navigation and astronomy. In navigation, it would make the United States independent of Britain, and in science it would be more perfect than any existing almanac.

Production of the American almanacs was, for at least the first century, considered to be extremely important for the government and for astronomy. Eventually the missions of the Nautical Almanac Office and the Naval Observatory intertwined. The Nautical Almanac Office was moved to Washington in 1866, and then located on the new grounds of the Observatory in 1893. Administratively, it was separate until sometime between 1897 and 1907, when it was taken under Observatory administration.[9]

When CAPT W. J. Barnette assumed the duties of Superintendent of the Naval Observatory in December 1907, wishing to have more information on the workings of the department of Astronomical Observations, he appointed a board to evaluate staff suggestions on the plan and scope of work. The board worked from May to July 1908, and its recommendations were issued as an instruction by Thomas Newberry, Secretary of the Navy, in March 1909:[10]

There is hereby formed an astronomical council composed of the following members: The Superintendent (ex officio), the Assistant Superintendent, such assistants in charge of the astronomical divisions as the Superintendent may designate, and the Director of the Nautical Almanac.

The council should be guided by the fact that the most important astronomical duty of the Government is the publication of a nautical almanac, and as that is intended not only for the use of navigators, but also of astronomers in the most delicate investigations known to their science, it should be kept up to the highest attainable pitch of accuracy. To that end, continuous fundamental meridian observations upon the Sun, Moon, planets, and stars are absolutely necessary and constitute the astronomical essentials.

The astronomical work of the Naval Observatory shall be so planned and executed as best to subserve the following purposes, and no others, to wit:

To furnish to the Nautical Almanac Office, as far as may be possible, such observations and such data as may be needed for carrying out the purpose of the law under which the appropriations for that office are made from year to year, which is as follows:

For * * * [sic] preparing for publication the American

Ephemeris and Nautical Almanac and improving the tables of the planets, moon, and stars ***.

The principal work of the observatory shall be in the field of the astronomy of position as distinguished from astrophysical work, and shall be the continued maintenance of observations for absolute positions of the fundamental stars and of stars which are to be made fundamental, and in addition the independent determination by observations of the Sun, of the position of the ecliptic, and of the equator among the stars, and of the positions of the stars, Moon, and planets with reference to the equator and equinoxes.

Creating and Managing an Almanac

In starting up a new product, Davis was faced with basic questions that are still valid today: What is its application, what information should it offer, how should information be presented, how should it be calculated and by whom, what medium should be used, how should the product be produced, how should it be distributed, and so forth.

Management of change after creating a product is a policy decision. As Eckert[11] reports, many suggestions on change are received by an almanac office. A decision on which improvements to adopt and when to adopt them is difficult and can be made only on the basis of all the factors involved, and in accordance with a consistent long-range policy. The almanacs cannot be used lightly for experimentation or to reflect personal whims. Each modification must be examined not only for intrinsic worth, but also for consistency with the almanac as it exists or is planned for the future. The saving brought about by an alteration must more than offset the inconvenience caused by the change. There is a history in the office of consulting outside experts for advice, or for comments on proposed changes, both in existing products or new ones.

There is an inherent time lag in making changes. From the establishment of the office, a goal was to have the navigational information available for use three years in advance, to supply ships going on the longest voyages. This means that preparation must begin even earlier, the amount depending on the methods. Consequently, this defines the time lag between making a decision and seeing the result appear in the finished product.

In the first edition, as mentioned earlier, for navigational purposes the almanac had to provide at minimum sidereal time for the Greenwich Meridian, lunar distances, and ephemerides of the Sun, Moon, and planets. For astronomical purposes and surveying, and observations for improvements of the theories, it contained transit ephemerides of the Sun, Moon, planets, and many stars for Washington. Occultations of stars by the Moon and eclipses of the Sun provided important opportunities for checking the accuracy of the ephemerides. This was the basic content for several years.

Examples of the most important changes in the navigational portion and their justification are as follows. Ephemerides of more planets were introduced in 1882 as part of a group of changes suggested by Newcomb and approved by the National Academy of Sciences.[12] As altitude-intercept methods were introduced, the method of lunar distances fell into disuse. That portion of the almanac was removed in 1912 after an investigation conducted by the Chief of the Bureau of Equipment in 1907 showed it was little used.[13] When the navigation portion changed from a reprint into a separate publication for navigators in 1916, tabular data were given hourly instead of daily. Rising and setting phenomena of the Sun and Moon first appeared in 1919. From 1929 content and arrangement was influenced by the needs of aerial navigators, as we shall see later. In 1934 the Greenwich Hour Angle of Sun, Moon, and stars was included solely for navigators. Page layout for air navigation influenced the layout for surface navigation.

Examples of changes in the part for astronomy and geography include the following. Davis wanted to include full ephemerides of all minor planets, but as the number grew rapidly, this was impracticable. A century later, a selected few were included for special projects. As more satellites of planets were discovered, better dynamical ephemerides were included. Physical ephemerides of planets and the Moon were added. Longer lists of star positions were always in demand, such that a separate publication was created for them. Pluto was added in 1950, minor planets 1-4 in 1952 for use in studies of the equinox, the ephemeris for the Washington meridian was removed, and so forth. We will not delve deeper into details.

International Cooperation

Let us consider the timeline of Figure 1 for international meetings and other influences.

Today, the American and British Nautical Almanac Offices strive to comply with recommendations of the International Astronomical Union (IAU). There were efforts at some international coordination, if not cooperation, from the beginnings of the American office. Davis, wanting to publish ephemerides of all the minor planets, suggested to the European almanac offices a joint program. They never responded, but the idea was impractical anyway as the number grew rapidly. In 1896 a meeting of directors of national ephemerides was called in Paris. The matter of common planetary ephemerides was somewhat delicate because all the European offices used the work of Leverrier, which in Simon Newcomb's opinion did not incorporate enough observational data.[14] There were some agreements made on which constants to use for the fundamental reference system. They were incorporated into the almanacs for 1901. Newcomb continued to introduce his own theories into the American almanacs.

The next international conference was called in 1911, again in Paris. Although the Conference was primarily concerned with obtaining a greatly increased list of apparent places of stars, it extended its attention to all the ephemerides of bodies in the solar system. The most significant of its comprehensive recommendations was to reduce redundant calculation by distribution of calculations among the five principal ephemeris offices (France, Germany, Great Britain, Spain, United States). It also specified standards of calculation and presentation, arranged for publication of additional data, and fixed the values of some constants to be used in the ephemerides.

Official approval was in some cases necessary for the adoption of these recommendations. The resolutions were distributed to American astronomers, and 84 responded, generally favorably. The naval appropriations act passed by Congress on August 22, 1912 had three provisions that influenced the American almanacs. The one of interest for international cooperation authorized exchange of data with foreign almanac offices. The Nautical Almanac Office expressed willingness to adopt the program of exchanges of data recommended by the Congress, with understanding that it could be terminated upon one year's notice, and with the conditions that it was not committed to printing extra decimals of precision in the ephemerides of stars, nor to cease publishing ephemerides for the meridian of Washington. The changes accepted were introduced into the volume for 1916, at the time that *The Nautical Almanac* became a separately prepared publication.

In 1919 the IAU was established. Commission 4 on Ephemerides provided the formal contacts by which the previous agreements could be continued and extended. The agreements made in 1911 had been directed to reduction of the total amount of work by avoiding duplicate calculation. In 1938 Commission 4 recommended that the principle should be extended to the avoidance of duplicate publication. As a first step the apparent places of stars then printed in all the principle ephemerides would be collected into a single volume. This was implemented in 1941 by the publication of the Apparent Places of Fundamental Stars. That material was removed from the national almanacs, relieving the office of some burden of calculation.

After the disruption of World War II, the Director of the Paris Observatory convened a conference in Paris in March 1950 to discuss the fundamental constants of astronomy. The most far-reaching consequence was in the recommendation that defined ephemeris time and brought the lunar ephemeris into accord with the solar ephemeris. These recommendations were adopted in 1952 and implemented in the almanacs for 1960.

In 1963 at IAU Symposium 21 in Paris, it was concluded that a change in the conventional IAU system of constants could no longer be avoided. At the Twelfth General Assembly in 1964 a list of constants proposed by a working group was adopted and recommended for use at the earliest practicable date in the national and international astronomical ephemerides. This was done in the almanacs for 1968. Further study by IAU groups led to recommendations for far more substantive changes in the constants, reference system, and ephemerides. The recommendations were adopted in 1976 and fully implemented in the volumes for 1984. The volumes for 1981 were united under a single title, and the format was changed.

The selection of a standard reference system for stars was always an important topic at these international conferences. Newcomb was pleased with the work of Arthur Auwers at Berlin, but noted a systematic difference in the right ascension from the stars used in the *American Ephemeris*. Therefore he decided to construct his own catalogue for right ascensions, while adopting the work of Lewis Boss for declinations.

In 1938, the German office finished the FK3, about the same time that the U.S. Naval Observatory finished its zodiacal catalogue. The latter was not printed for lack of funds, and in 1941 the FK3 was adopted as an international standard.[15]

Source of Theory

It is frequently supposed, even these days, that our ephemerides are the direct result of a set of formulas evaluated as functions of time. In fact, they are the concluding step in a sequence of three distinct processes. The first is construction of a theory, defining the problem in mathematical terms and solving the equations of motion. This includes comparison to observations for refinement. The second is construction of an intermediate device that reduces the evaluation of a theory to a series of arithmetic operations. Until mid-20th century, that was a set of tables. Nowadays it is most often the output of a numerical integration. The third is extraction of the data, conversion of coordinates, and arrangement of numerical results.[16]

There have been few major changes in the basic ephemerides of the almanacs, but they occurred more frequently over time. By directing the attention of American astronomers to the need for improved theories of the lunar and planetary motions, the *American Ephemeris* became an important factor in the contributions to celestial mechanics and astrometry made in America.[17]

At the founding of the office, the theories and tables employed at the several national almanac offices were a patchwork collection, with additions, corrections, and adjustments which enabled predictive accuracy for only a few years in advance. They were based on only 50 years of accurate observations. Davis had to use the best and most recent theories, while starting work to produce new ones. Even before the first volume was begun, special new theories and tables were worked out for several bodies. As a test, predictions for the solar eclipse of 28 July 1851 were prepared from the American, British, French, and German ephemerides and compared to observed timings. Davis was obviously proud to report that the American calculations were far superior to the others in accuracy. The British almanac was the furthest off, with an error up to 85 seconds of time, corresponding to an error in longitude of 15-20 miles.

Davis laid out a plan for development of new tables, and his successors kept it up. However, Davis and Winlock both noted in their annual reports, in a theme that continues to this day:[18]

> While the importance of such investigations are admitted in the work of the office, they are subordinate to the current duties necessary for the preparation of the annual volume, and the almanac must be indebted to the devotion of the astronomers to their science for the voluntary contribution of much time and labor to the class of subjects here referred to; the gentlemen engaged upon these are also actively employed on the current duties of the office.

Simon Newcomb was appointed Superintendent in 1877, and in his first annual report, he states "The most urgent want of the office at the present time is a set of tables of the Moon and planets, corresponding in accuracy to the present state of practical astronomy, and founded on entirely homogeneous data."[19]

He began a program to determine fundamental astronomical constants from all available observational data, and to discuss all the observations of the Sun and planets made worldwide since 1750. From this, he and G. W. Hill constructed new planetary theories and tables, and a catalogue of 1,596 fundamental stars. Through the Secretary of the Navy, in December 1877 Newcomb submitted a proposal of fifteen suggested changes in the astronomical ephemeris to the astronomers of the country that were referred to a committee of the National Academy of Sciences. Most were sustained, some modified, and they were incorporated into the volume for 1882. After the international conference in 1896, his new theories were introduced into the American and other almanacs starting with 1901. At the time, he predicted that they would only be good for 70-100 years.

Another provision of the Act of Congress in 1912, referred to earlier, authorized personnel to conduct this research if time permitted.

Starting in 1938, extensive discussions of accumulated observations of the Sun and planets indicated appreciable discordances. Gerald Clemence, Director of the Nautical Almanac Office, reported that the various defects and inadequacies indicated that a new attack on the whole problem of the motions of the principal planets was needed. The accumulation of observations since Newcomb's time was massive, and extensive theoretical and computational work was needed to utilize it and to improve the form of the theory.[20] In 1947-50, Wallace Eckert, former director of the NAO, Dirk Brouwer of Yale, and Gerald Clemence, then current director of the NAO, undertook to reconstruct all the planetary theories, based on still more observations, using computers to do a numerical integration for comparison. The principal result was a numerical integration of the outer planets that covered the span 1653-2060. In 1952-54, Brown's lunar theory was evaluated from theory rather than the tables. The results were incorporated into the almanacs starting with 1960.

After the war, more observations flowed in, including the new dimension of distance and using non-optical detectors. Driven by requirements of the space age, the Jet Propulsion Laboratory (JPL) developed extensive new theories of planets and satellites, based on but not completely conforming to IAU guidelines adopted in 1976. Their development and lunar ephemerides DE200/LE200 were taken as the basis of the almanacs starting with 1984.

In 1994 the IAU adopted a new International Celestial Reference System (ICRS). JPL has a new Development Ephemeris that conforms to the ICRS, and we contemplate introducing it into our almanacs for 2003 or 2003. (To be continued)

NOTES

1. *Unless otherwise noted, all information on the almanacs and their contents is taken from annual reports of the Nautical Almanac Office, annual reports of the U.S. Naval Observatory, prefaces in the annual volumes, or reports of Commission 4 on Ephemerides within the transactions of the International Astronomical Union that are published after each General Assembly.*

2. *David A. Kronick, "Almanacs and Annuals", in A History of Scientific & Technical Periodicals, The Origins and Development of the Scientific and Technical Press 1665-1790, Second Edition, Scarecrow Press, Inc., 1976.*

3. *See "Finding the Longitude" in* Greenwich Time and the discovery of longitude, *Derek Howse, Oxford University Press, 1980, Appendix I, pp.192-198. Also, Seymour L. Chapin, "A Survey of the Efforts to Determine Longitude at Sea, 1660-1760, Part II: The Use of Celestial Bodies", NAVIGATION,* Journal of the Institute of Navigation, *March 1953, p. 242.*

4. *P. K. Seidelmann, P. M. Janiczek, and R. F. Haupt, "The Almanacs - Yesterday, Today and Tomorrow", NAVIGATION:* Journal of the Institute of Navigation, *Vol. 24, No. 4, Winter 1976-77, pp. 303-312.*

5. *Craig Waff, "Navigation vs. Astronomy: Defining a Role for an American Nautical Almanac, 1844-1849", These proceedings.*

6. *Ibid.*

7. *9 Stat. L., 374, 375, CHAP.CLIL. - An Act making Appropriations for the naval Service for the year ending the thirtieth of June, one thousand eight hundred and fifty. Text and background taken from "U.S. Naval Observatory [1809-1948]", a typescript first narrative prepared by Commodore J. F. Hellweg. QB82 U7U8 in the U.S. Naval Observatory Library.*

8. *Marc Rothenberg, "Observers and Theoreticians: Astronomy at the Naval Observatory, 1845-1861",* Sky With Ocean Joined", *Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U.S. Naval Observatory, Washington, D.C. 1983.*

9. *According to Hellweg,* op. cit., *"On September 20, 1894, the Secretary of the Navy, availing himself of the authority granted in the act of March 3, 1857, issued a regulation making the Nautical Almanac Office a branch of the Naval Observatory. In a departmental decision rendered January 19, 1905 (File 9449-04 and 17626 Navy Department), it was held that the Nautical Almanac Office is not a separate shore station, and since that time its status has been that of a department of the Naval Observatory."*

10. *Synopsis of the Report of the Superintendent of the United States Naval Observatory for the Fiscal Year Ending June 30, 1909.*

11. *Wallace J. Eckert, "Air Almanacs",* Sky & Telescope, *Vol. IV, No. 1, Nov. 1944.*

12. *Edgar W. Woolard, "The Centennial of the American Nautical Almanac Office",* Sky & Telescope, *Vol. XI, No. 2, pp. 27-29, Dec. 1951.*

13. *Synopsis of the Report of the Superintendent of the United States Naval Observatory for the Fiscal Year Ending June 30, 1908, p. 14.*

14. *Arthur L. Norberg, "Simon Newcomb's Role in the Astronomical Revolution of the Early Nineteen Hundreds",* Sky With Ocean Joined", *Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U.S. Naval Observatory, Washington, D.C. 1983.*

15. *Report of the Office of "The American Ephemeris" to Commission 4, Transactions of the International Astronomical Union, Vol. VII, Seventh General Assembly held at Zurich, August 11 to August 18, 1948. Cambridge University Press, 1950.*

16. *Seidelmann, Janiczek, and Haupt,* op. cit.

17. *Woolard,* op. cit.

18. *Annual Report of the Secretary of the Navy, Nautical Almanac Office. November 10, 1857.*

19. *Arthur L. Norberg, "Simon Newcomb's Role in the Astronomical Revolution of the Early Nineteen Hundreds",* Sky With Ocean Joined, *Proceedings of the Sesquicentennial Symposia of the U.S. Naval Observatory, Edited by Steven J. Dick and LeRoy E. Doggett, U.S. Naval Observatory, Washington, D.C. 1983.*

20. *G. M. Clemence, Report of the Office of "The American Ephemeris" to Commission 4,* op. cit., *p. 78-79.*

The Personal Error

By Wilson Van Dusen

Bowditch just mentions the personal error (Bowditch 1995, p. 802). It is a systematic error the navigator inadvertently puts into a sextant observation. A series of simple experiments helped me find and correct my own error. My sights are taken from a fixed and known position on the coast using a sea horizon. GPS gives my exact position which is used as a D.R. Time is taken from a clock that adjusts itself to the Naval Observatory time signal. A navigational calculator makes sight reduction so simple a matter that it encourages experimentation. Under these circumstances it was easy to examine the accuracy of my own sights taken ten or twenty at a time. It could also be done at sea if the GPS and sight were at the same time. My situation encouraged a closer examination of the accuracy of my sights.

If I had no systematic error my mean sight intercepts should vary around zero equally toward (+) and away (-). But quite consistently I get a mean intercept of .4 miles toward whether rising or setting. With a navigational calculator it was a simple matter to try varying the sight time and altitude until +.4 miles was eliminated from the intercept.

It turns out that taking 3 seconds off all sights would give me a mean intercept of zero. So my personal correction is -3 seconds off the observed time.

What does a personal error -3 seconds mean? It means that on average I take 3 seconds trying to make sure the body has touched the sea horizon. If I continue to function in the same way simply taking 3 seconds off all sights would improve sight accuracy. There is a satisfaction in measuring what one is doing and in getting greater accuracy. But if a student of mine came up with this I would say view sextant observations within a mile of your position as good ones and within 2 miles as tolerable. The sextant has that kind of accuracy. It is useful to bring one in sight of land. Then you shift to the more accurate piloting based on land that can be seen. There is a certain satisfaction in actually finding and understanding one's own error. In the last seconds of taking a sight I am aware of the anxiety of determining whether the body is just touching the horizon or not, so a personal correction of -3 seconds makes good sense. Now I can proceed as before and easily subtract 3 seconds off the time. If the personal error remains the same the mean intercept will be closer to 0 with an equal tendency toward and away. Though I had heard of a personal error, until now it was unclear if it was real and how one would derive it. But my playing with accuracy led to finding it.

Artificial Horizons, Octants, and Back Observations as Used by Lewis and Clark

By Richard Preston

The astronomical observations of Lewis and Clark have been mentioned in several recent articles in the *Newsletter.* Readers may be interested in knowing how these explorers used artificial horizons and an octant equipped for back observations for measuring apparent altitudes. Although artificial horizons are still in use today and many readers of the *Newsletter* are familiar with them, it is possible that some are not. Perhaps less familiar to modern navigators is the octant, which was the principal tool used by Lewis and Clark for measuring the noon altitude of the sun. (They had a sextant, but usually reserved it for other uses.) Finally, back observations with an octant are probably unfamiliar to most readers. In this article, I outline the basic principles of the liquid artificial horizon, the octant, and back observations.

The Liquid Artificial Horizon

The apparent altitude of an astronomical body — its apparent height above a horizontal plane at the observer's location — is the most basic measured quantity in celestial navigation. At sea, finding this altitude starts with a sextant measurement of the angle between the body (or one of its limbs) and the horizon. Corrections of varying importance can be applied to this raw sextant reading to obtain the required apparent altitude of the body (or its limb). But two corrections are essential. Obviously there must be a correction for any index error. In addition, there must be a correction for dip to account for the fact that the horizon is below the horizontal by an amount that depends on the height of the observer's eye above the water.

Inland, no true horizon is available except on fairly large bodies of still water. Use of a liquid artificial horizon is a simple way to compensate for this lack. The validity of results obtained with such an artificial horizon depends on two facts:

- an undisturbed liquid surface is a horizontal plane surface which partially reflects light like a mirror
- in mirror reflections from a plane surface, the angle of incidence equals the angle of reflection

A liquid artificial horizon is simply some liquid, often water, in a pan on the ground, or, in a pinch, a natural puddle of water. In freezing weather, Lewis and Clark used spirits (whiskey or rum) instead of water. Figure 1 shows how an observer would use a sextant to measure the angle between light rays coming directly from the star and light rays from the same star after reflection by the surface of the liquid. In this figure only two rays from the star are shown. One represents the multitude of parallel rays that arrive directly at the sextant from the star and the other represents all the parallel rays from the same star that arrive at the surface of the liquid. These two representative rays are, of course parallel to each other, and the choice of any other two rays as representative rays, one reaching the sextant and the other the surface of the liquid, would make no difference to the following geometrical argument

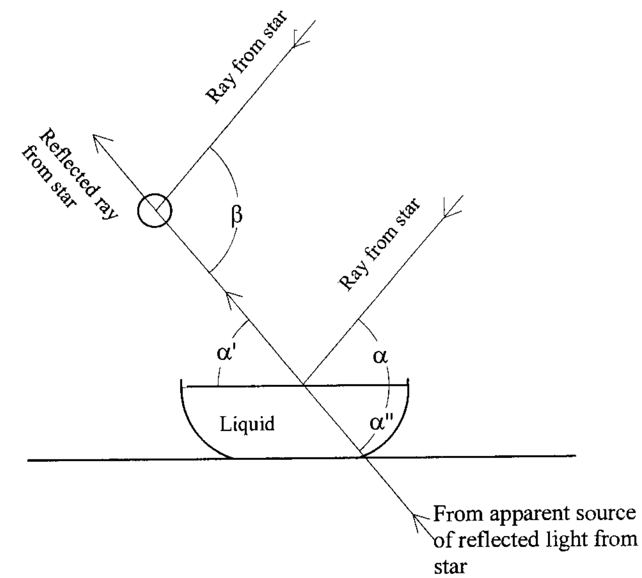


Figure 1. Use of an artificial horizon. The reflected light appears to come from below the reflecting surface. A sextant or octant at O measures the angle β between the direct and reflected rays from the star.

The navigator wants the value of α, the apparent altitude of the star. Because the angle of incidence equals the angle of reflection,

$\alpha = \alpha'$ (1)

To the observer, the reflected light *seems* to be a ray coming from below the surface of the liquid and making an angle α″ with the surface. By elementary geometry,

$\alpha'' = \alpha'$ *(2)*

Combining equations 1 and 2 gives

$\alpha = \alpha''$ (3)

The navigator uses a sextant or octant to measure the angle β. The ray from the star directly to the sextant is parallel to the ray incident on the liquid so that, again by elementary geometry,

$\beta = \alpha + \alpha''$ (4)

Combining equations 3 and 4 yields

$\beta = 2\alpha$ (5)

Thus, when β has been measured, the apparent altitude is easily calculated from

$\alpha = \beta/2.$ (6)

No correction for dip is necessary because the altitude measurement was to the truly horizontal surface of the liquid, and not to the horizon. In order to maintain a good reflecting surface, the liquid must be shielded from the wind and vibrations. Liquid artificial horizons are useless at sea because the liquid surface is disturbed by the irregular motion of the vessel.

There are two situations where the artificial horizon cannot be used with a sextant, even on land

- For stars low in the sky, α and α′ are small, so the sextant must be held close to the ground or far back from the artificial horizon. At some low value of α either the walls of the container get in the way of light arriving at or leaving the liquid surface, or the observer must lie prone with the sextant touching the ground. For any smaller value of α the measurement is then impossible.
- Nominally, the maximum angle a sextant can read is 120°. Thus the maximum altitude that can be measured using a sextant and an artificial horizon is, nominally, 60°. This can be a serious limitation. For instance, at latitude 40° the noon altitude of the sun is greater than 60° during the longest days of the year.

Despite these limitations, however, the artificial horizon is still useful for measuring altitudes lower than 60° when inland, and it eliminates the need for a dip correction. Furthermore, the restriction to altitudes less than 60° can be overcome by substituting for the sextant an octant equipped for back observations.

The Octant

Figure 2 is a 19th century engraving of an octant. The octant was a predecessor of the sextant. This one reads angles from a little less than 0° to 95°. The octant derives its name from the fact that its scale is nominally one eighth or 45° of a circle. However, it is also known as a quadrant because nominally the largest angle it can measure is twice this, or one fourth of a circle. It is also called a Hadley's quadrant or, colloquially, a Hadley. Lewis and Clark referred to their Hadley as an octant, and I follow their usage here. A sextant might be thought of as simply an octant whose scale has been extended beyond 45° to 60° or more, and can therefore measure angles up to 120° or more. (The sextant whose name reflects the fact that its scale is nominally one sixth of a circle, has not acquired a popular alternative name, like "quadrant" for "octant", that would reflect the fact that the maximum angle it can measure is, nominally, twice one sixth or one third of a circle.)

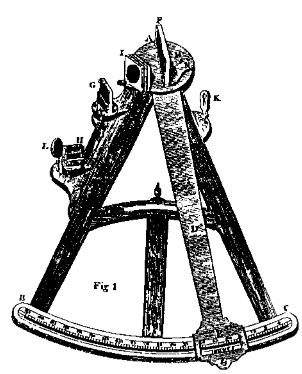


Figure 2. An octant fitted for fore and back observations. From the 20th edition of Bowditch (1851).

This octant is fitted with two horizon glasses, G and H. The upper one is used only for fore observations and the lower one only for back observations. The term "fore observation" refers to the kind of altitude measurement that is made with an ordinary sextant where both the horizon and the sun, moon, or star are *before* the observer during the measurement. In an altitude measurement by back observation, light from the astronomical body comes to the index mirror from in *back* of the observer, while the horizon is still in front, as will be described. Thus, compared with a fore observation with the same instrument, the octant is being used *back*wards. The sighting vanes L and K serve the same purpose as a sighting tube on a modern sextant. As usual, the index mirror F rotates as the index is moved to different readings on the scale. The index mirror is large enough that after reflection by it, light from a given star can reach both horizon glasses at the same time.

Figures 3 and 4 show a 90° octant that is fitted with two horizon glasses and is being used to measure the apparent altitude of a star. For simplicity, the sighting vanes and shades have been omitted.

Fore Observations with an Octant

Figure 3 portrays a fore observation of the apparent altitude of a star when that angle is no more than 90°. Only the first horizon glass, G, is used in a fore observation, which is carried out exactly as it would be with an ordinary sextant. In Figure 3 the direct ray from the horizon and the reflected ray from the star are depicted as parallel when they emerge from the horizon glass toward the observer's eye. According to ray-optics theory, this signifies that the images of the horizon and the star are superimposed in the observer's eye, as is also depicted in the figure. Therefore, the scale reading at this point, after correction for index error, is the apparent altitude of the star.

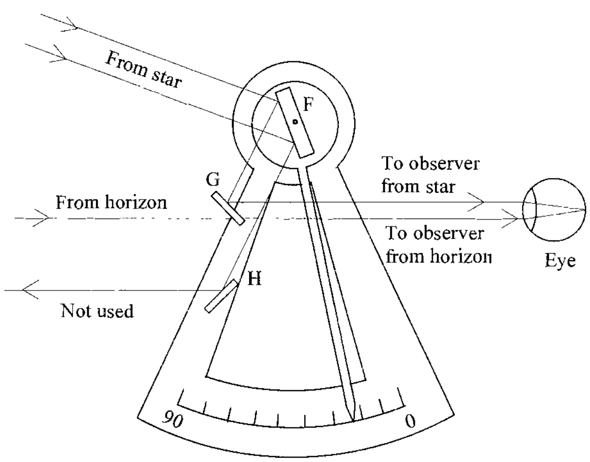


Figure 3. An octant being used to measure the altitude of a star by a fore observation.

As with a sextant, the index mirror is exactly parallel to the horizon glass when (1) the angle between two far distant objects is exactly zero and, (2) at the same time, the two images are superimposed in the observer's eye.

Back Observations with an Octant

Figure 4 shows the same octant being used in a back observation of the apparent altitude of a star. A back observation uses horizon glass H, but not horizon glass G. (The shades at I in Figure 2 have to be moved to position O.) In Figure 4, as in Figure 3, the fact that the rays from the star and from the horizon are parallel as they emerge form the horizon glass toward the observer's eye signifies that at this point the two images are superimposed in the observer's eye, as shown. Thus, again, the apparent altitude of the star is the scale reading at this point, after correction for index error.

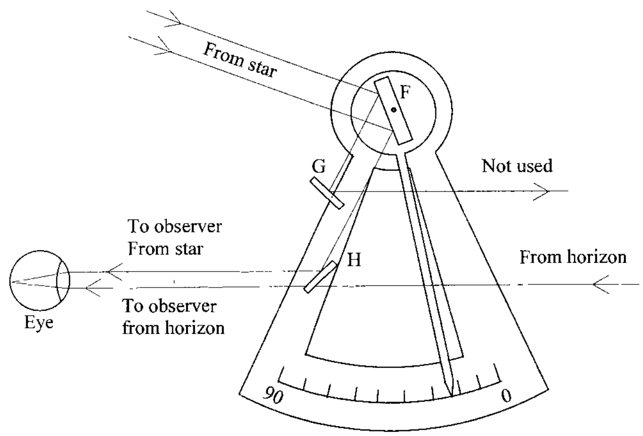


Figure 4. An octant being sued to measure the altitude of a star by a back observation.

At sea, back observations for apparent altitude are worthwhile only on the rare occasions when the horizon directly below the astronomical body is obscured while the opposite horizon is visible. Inland, back observations can be indispensable for measuring altitudes using a liquid artificial horizon when the angle β of Figure 1 is too large for measurement with a fore observation by octant or sextant.

By inspection of Figure 4 it is clear that the apparent angular distance from the star in back of the observer to the horizon in front of the observer is the supplement of the apparent altitude. From this it follows that, in a back observation, the apparent angle between any two distant objects is the *supplement* of the scale reading after correction for index error. Thus the value of β from a back observation with an artificial horizon (Figure 1) is the supplement of the scale reading after correction for index error in the conventional way. The apparent altitude is then half of β.

Altitude Measurements Using an Artificial Horizon and Back Observations by Octant

Figure 5 shows an octant being used with an artificial horizon in a back-observation measurement of the apparent altitude of a star. The direct and reflected images of the star coincide in the observer's eye, so in an ideal situation where the index error is zero, β is the supplement of the scale reading, and is twice the apparent altitude. Since the scale reading is about 42°, the apparent altitude must be about (180°-42°)/2 or about 69°.

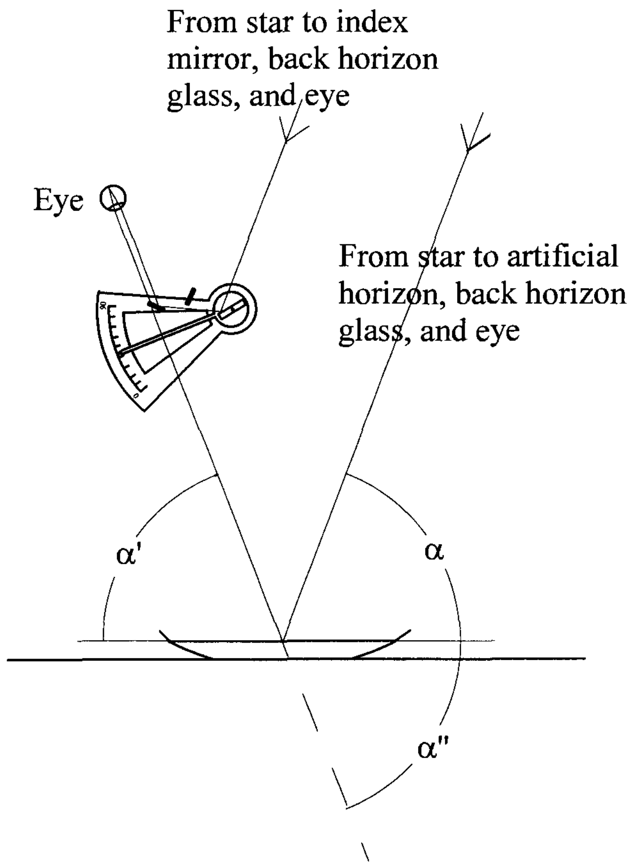


Figure 5. Apparent altitude of a star by back observation with an octant, using an artificial horizon (see Figure 1).

With its combined capability for both fore and back observations, the octant can be used to measure angles all the way from zero to 180°. Thus it can be used with an artificial horizon to measure altitudes over a range from near zero to 90°. Lewis and Clark had both a sextant and an octant, but they made almost all their noon measurements of the sun's altitude with the octant, usually by back observation. (Their octant must have had a second set of shades to protect their eyes from the direct view of the sun through the back horizon glass.)

In a back observation the index mirror is exactly perpendicular to the back horizon glass when (1) the angle between two far distant objects is exactly 180° and, (2) at the same time, the two images are superimposed in the observer's eye. Since the index mirror is exactly parallel to the fore horizon glass at this point in a fore observation, it follows that the two horizon glasses would be exactly perpendicular to each other if there were no index error for either the fore or back observation (or if they had exactly the same index error).

In general, the index error for back observations is different from the index error for fore observations. The index error for fore observations is best determined, as for a sextant, by reading the scale when the two images of a single star are superimposed. Inland, the index error for back observations can be obtained by measuring the angular separation of two stars and clearing the measured stellar separation for refraction using a procedure that is identical to that for clearing a lunar distance, except that the parallax is zero. The difference between this result and the stellar separation calculated from data in the *Nautical Almanac* is then the index error.

For their back observations using an artificial horizon, Lewis and Clark chose to use a value of the index error that was half the conventional value. Their final value of the altitude was unaffected by this choice because they applied this correction to *half* the supplement of the scale reading.

I am grateful to Bruce Stark for encouragement and for a number of suggestions which have improved this article.

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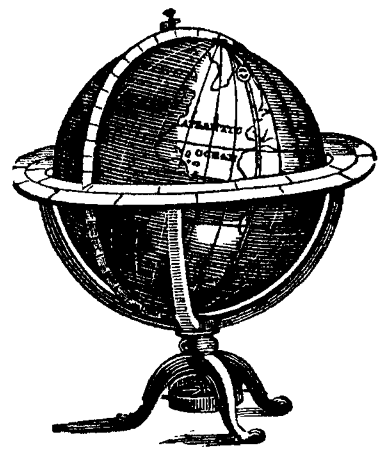

ANSWER TO DO YOU KNOW. . .?

(From page 1)

The navigator of the 1967 commemorative flight, Major William L. Polhemus, in commenting on the 1937 Amelia Earhart flight in The Quarterly Newsletter of the Institute of Navigation, Summer 1998, refers to a paper by Roy Blay, a Lockheed Corporation engineer, which indicates that the DF receiver installed in Amelia Earhart's Lockheed Electra L-10 was limited to the range of frequencies 200-1430 kHz.

Earhart requested transmission of reference signals of 7500 kHz as well as 3105 kHz and 6210 kHz. She reported to the USCGC *Itasca* that she could not receive an identifiable signal. *Itasca* advised her to transmit on 500 kHz but apparently she was unable to do so.

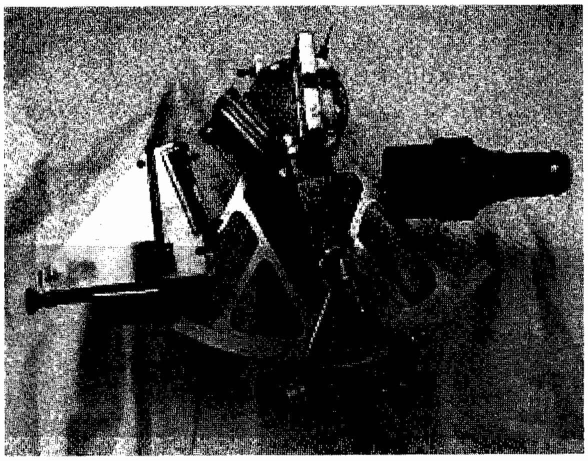

Figure 1. Tamaya sextant in author's collection.

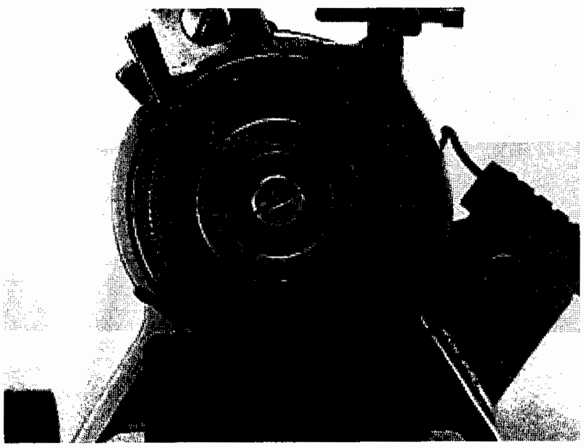

Figure 3. Closeup views of the sextant from different angles.

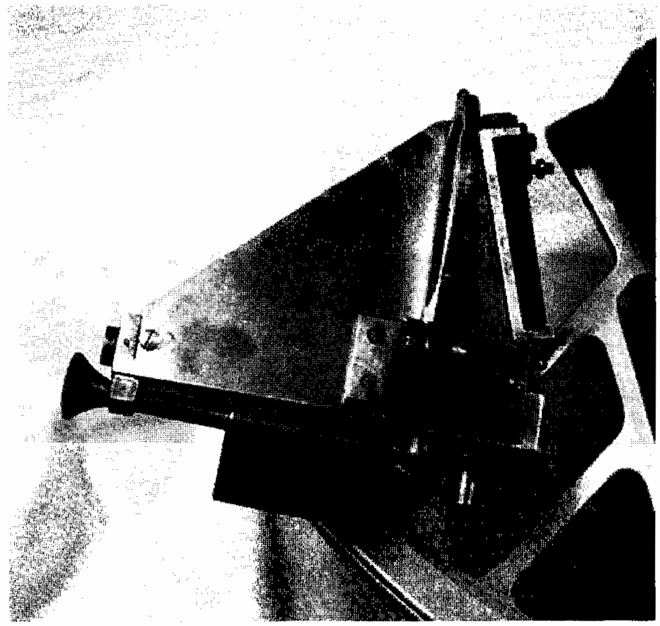

Figure 4. Closeup views of the mechanical averager.

These three images for "The Tamaya Artificial Horizon Marine Sextant with Six Shot Mechanical Averager" by John M. Luykx did not run in the last issue due to technical problems.

// THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SIXTY-NINE, FALL 2000

THE NAVIGATOR'S NEWSLETTER

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

This Summer has been relatively quiet in terms of new members. We still get queries concerning membership but only a few follow up by joining. We do get numerous requests for help from students who are writing term papers or trying to write a technical paper for their class. As usual, we answer all requests with as much explanation as can be sent via e-mail. Some we have to turn down when they ask us to send them everything there is on navigation. We do ask them to be more specific in their requests and ask us questions. We then answer these questions and add enough additional information to provide clear answers to novice navigators.

NOAA/NOS has commenced a new system for ordering charts. The change does not affect the way our members order charts. Members continue to order through The Foundation by telephone or FAX at 301-622-6448 or e-mail to navigate@ix.netcom.com. The orders will be billed by an invoice enclosed in the package except books/publications or products that are sent directly from the publisher. Do not pay the publisher; send your payment to the Foundation to get your discount.

The new NOAA/NOS ordering system is now via e-mail rather than telephone or FAX. We hope it improves some aspects of their system. Last Fall The Foundation ordered one copy of PUB 249, Vol. 1, EPOCH 2000 for a member. The order included a note just below the Publication description stating this order is for one copy. When the order had not arrived in a reasonable time, we called to check on the order. We were informed that a truck was on the way with our 2000 copies of PUB 249, Vol. 1. After recovering from the shock we tried to stop the order but were unable to have it returned to the warehouse. The only recourse was to refuse the shipment. Our next NOAA statement had us charged for the 2000 copies. After several complaints the charge was replaced by a credit for the same amount. Again complaints, but to no avail. It seems the computer would not accept a change. Our last statement seems to have the problem corrected.

NOAA tells us that sometime in the near future that we can supply you with Nautcial Charts on Demand. In other words the chart will be printed when ordered. They should be up to date with all corrections already entered. We do not have a time frame nor prices for these charts but will keep you informed as to the progress of this program.

READERS FORUM

Edited by Ernest Brown

Member Oscar W. Underwood III wrote from Winter Haven FL on June 17, 2000:

"Re the article by John M. Luykx under 'History of Navigation', Issue 67, his detailed description of the Japanese sextant which had a marine horizon as well as averager with a bubble was interesting and I'm looking forward to a continuation in the Summer Issue. Re Table 4, concerning accuracy using the bubble with the averager, it appears from the coordinates that the location of the test was at or very near Pt. Lookout in the Chesapeake Bay. Maybe I've missed the obvious, but I wonder if the observer was on a stable land position or

DO YOU KNOW . . .?

By Ernest Brown

What navigation equipment Navigator Fred Noonan had aboard the Lockheed Electra 10-E during Amelia Earhart's attempt to fly around the world in 1937?

(See page 19 of this issue.)

on a boat in the Bay? If the Bay, what were the surface conditions?

"The U.S. Navy had an aircraft sextant with many similarities, the Mark V. It had an averager for aircraft use and a micrometer reading marine horizon for use aboard ship. I do not know how successfully the Mark V was used aboard ship with the bubble and averager. I bought one with the averager removed from Celestair in the sixties. I used it for backyard practice with the bubble, and with the marine horizon on my sailboat. The accuracy with the bubble on land was not very good, sometimes off 10 nautical miles. (If I had used an averager, as with aircraft use, I suspect the results would have been better.) Aboard my boat, even in very flat water, the bubble was useless. The marine horizon, on the other hand, was very accurate. I could often get an LOP within a mile or two of a known location, and the maximum error was hardly ever over 5 or 6 miles.

"I particularly liked the complete image of the sun that could be brought down to the horizon rather than the half-image typical of the Navy sextants I had used. (I served briefly aboard ship in the Navy, and didn't realize until after I left the service that there was such a thing as the Mark V.) John S. Letcher describes his use of this sextant in his well written book 'Self Contained Celestial Navigation with H.O. 208', International Marine Publishing Co., Camden, Maine.

"The main disadvantage of the Mark V was its bulk and weight. In its sturdy wooden box, the box with sextant inside weighed 15 pounds. However, it was easy to use, and as John Letcher pointed out in his book it could take more abuse than the typical sextant. It was made by the Pioneer Division of Bendix Aviation some years before World War II." — *Sincerely, Oscar W. Underwood III.*

Director John M. Luykx responded as follows:

"Thanks for your interesting letter of 17 June which was recently forwarded to me for reply. With regard to the Japanese Tamaya sextant article in Issue 67 of the Navigator's Newsletter, the three missing figures will appear in Issue 68 soon to be published.

"For the purpose of the article in the Newsletter, I took observations on 'Terra Firma' just about a mile or so north of Point Lookout and about 20 yards from the water line.

"You refer to the U.S. Navy Mark V aircraft sextant in your letter which of course has some similarities with the Tamaya sextant I described in the article. The Mark V is primarily an aircraft sextant and becomes quite handy and less difficult to use once the averager has been removed. Accuracy with the Mark V is significantly improved when used both on land and sea if a series of 10 to 20 observations are made and the mean value of time and altitude computed. With practice an observer on land should be able to obtain mean values of altitude to 1-3 miles.

"Developing skill in using an aircraft sextant requires constant practice, a procedure analogous to the training involved in the development of top notch rifle and pistol shots.

"There exist many aircraft sextants as well as marine sextants fitted with an artificial horizon which are superior to the Mark V sextant you used at sea. Some of these are described in a series of 3 articles published in Issues 26, 27 and 28 of *The Navigator's Newsletter* in 1989, 1990. If you are interested in the information, I will gladly forward to you zerox copies of these articles. In addition, if there is any other information you require, please let me know." —*Sincerely, John M. Luykx*

NAVIGATION NOTES

Evolution of the Products of the Nautical Almanac Office

By Alan D. Fiala, U.S. Naval Observatory

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory March 3-4, 1999. Courtesy of the author.

(Continued from Issue Sixty-eight.)

Time and the Almanacs

Davis stirred up another controversy when he was planning the first issue of the *American Ephemeris*. He asked what meridian to use — Greenwich, or one in North America? It had not been specified in the Act that authorized the office. To use the Greenwich meridian would be to redo the British Almanac, and surely an American product was wanted.[21] The question was taken to the American Association for the Advancement of Science and referred to a committee of eminent astronomers and mathematicians. In February 1850 the House Naval Affairs Committee took up the issue. On 2 May it proposed a joint resolution that was adopted in an appropriations bill on 23 September:

> that hereafter the meridian of the Observatory of Washington shall be adopted and be used as the American meridian for astronomical and geographical purposes, and such part of the computations of the Nautical Almanac as may be designed for the exclusive use of navigators, shall be adapted to the meridian of Greenwich.[22]

This was a compromise, but also recognition by the Congress that the Almanac was not only for navigators, but also astronomers and geographers. The division of material into parts for navigation and astronomy permitted a reprinting of the first part separately, which commenced in 1858. The provision for two meridians was repealed by the previously mentioned Act of Congress of August 22, 1912. Nonetheless, despite international pressure to use the Greenwich meridian, two meridians were used in *The Nautical Almanac* until 1934 and the *American Ephemeris* until 1950.

Until 1925 there was continued international effort to standardize on the use of a common term for the time argument of the ephemerides. The astronomers wanted to use Greenwich Mean Time with the day starting at noon, but some places still used Greenwich Civil Time with the day starting at midnight, and there was confusion over whether the day started at midnight or noon. In 1925 everyone agreed that the day would start at midnight. In the volumes for 1939-1952 time is listed as both Greenwich Civil Time and Universal Time. In 1953, the term Greenwich Civil Time was discontinued. The term Universal Time was adopted for astronomical use, while the term Greenwich Mean Time was adopted for navigational use. The latter was converted to Universal Time over 1985-1990. Meanwhile, in 1950, Clemence proposed the introduction of Ephemeris Time as the independent argument, separate from Universal Time. This was adopted in 1952 and implemented in 1960 with the Eckert-Brouwer-Clemence integrations. That was superseded in 1984 by the introduction of Dynamical Time with the JPL ephemerides, and that concept is still being refined.

Presenting the Data: Calculation, Typesetting, and Proofreading

We mentioned earlier that there are three distinct steps in preparing an ephemeris for presentation. Clemence wisely observed that there is also a fourth, keeping out mistakes.[23]

During its earliest years, the NAO had no permanent staff beyond the Superintendent and a few clerks and proofreaders. The superintendent contracted with various astronomers and mathematicians throughout the country for the computations. Some of the most eminent American astronomers of the time took part in this work, and without their cooperation it is doubtful whether the project could have been successfully accomplished. Davis felt that it also created general interest in the character and prosperity of the work. Newcomb, early in his tenure as Superintendent, noted that two-thirds of the ephemeris calculations were done by piecework. This took extra lead time in the preparation of copy. He thought it would be more efficient to have the planetary work done by one expert. Newcomb also noted in an early annual report that typographical and other errors in the published *American Ephemeris* were frequently reported. Knowing that he had to maintain trust in the integrity of the publications, he put proofreading under the supervision of a single responsible assistant, Mr. D. P. Todd. Only in 1950 was the use of pieceworkers outside the office entirely discontinued.

The naval appropriations act passed by Congress on August 22, 1912, provided:

> That any employee of the Nautical Almanac Office who may be authorized in any annual appropriation bill and whose services in whole or in part can be spared from the duty of preparing for publication the annual volumes of the American Ephemeris and Nautical Almanac may be employed by said office in the duty of improving the tables of the planets, moon, and stars, to be used in preparing for publication the annual volumes of the office.

It was a continuing thread of comment throughout the annual reports that it was difficult to find competently trained staff, and even more difficult to hire them when the authorized pay was so low — lower than that of a common clerk. The annual report for 1938 laments the loss by retirement or death of experienced astronomers all over the world, and adds:[24]

> At the last three meetings of the IAU, decisions were made over the protest of experienced astronomers, and then had to be reversed at the next meeting. Many observatories have ceased fundamental astronomical work, as the younger generation seeks something more attractive, less monotonous, and less arduous. Maintaining staff for fundamental work is expensive.

Astronomers welcomed any development that promised to relieve the amount of calculational labor and increase the reliability of the results. L. J. Comrie, Director of the British Nautical Almanac Office, started working with calculating printers as early as 1929, and Wallace J. Eckert was working with punched card equipment by 1933. He was brought in as Director of the American Nautical Almanac Office in 1940, to introduce punched card equipment and apply it to the production of the newly created *Air Almanac*. The machines helped compensate for a wartime shortage of staff. Machines calculated the data and generated tables; the tables were photo reproduced and also proofread by machine methods. The resulting almanac was the most reliable and accurate yet produced. By the time war urgency passed, there was a commitment to continue using tabular equipment to produce the almanacs. Starting in 1945, a specially built card-operated typewriter was producing camera copy for *The Air Almanac,* a method later applied to *The American Nautical Almanac* and other publications. Introduction of the same equipment into the British office in the 1950s enabled unification of the British and American Nautical Almanacs from 1958. The Air Almanacs had already been unified in 1953. Similarly, the Ephemerides were unified in 1960, with each office preparing half the publication. We are now working with HMNAO to make it look like a uniform product.

Programmable computers were installed and utilized from the late 1950s onward, and used for both calculation and typesetting. In the mid-60s, the Government Printing Office began using typesetting equipment driven by computer-generated tapes, and went through several generations until the late 80's. Though they were generally more accurate than the old conventional methods of setting cold type, they weren't always any faster or easier! Right up until 1995-1996, preparing copy for an annual volume for reproduction and printing might be spread out over several years. Now, all the camera copy is produced right in our office and delivered to the printer ready to reproduce. Unfortunately, overconfidence in the reliability of computers without considering the human factors had led to some embarrassing errors and oversights, and we are paying particular attention to proofreading and examination again.

Distribution

The mainline printed products of the office produced as directed by law and through congressional appropriations have not generally been aggressively marketed in the United States. As a result, there was no incentive to make changes to appeal to a wider audience. For the first 60 years or so, the office itself handled sales, either directly or through designated agents. The Bureau of Equipment handled distribution to the Navy and other military components. Around 1908-1910, public sales were turned over to the Government Printing Office, but distribution to the Navy, military units, and exchange libraries came back to the office. In 1980, an agreement was reached with the Defense Mapping Agency to have them do distribution for the Department of Defense, and this has been passed on to the Defense Logistics Agency as of last year.

The office has distributed data in camera copy since the 1940's, and in machine readable forms for special purposes ever since computers were introduced. Participation in international exchanges tended to discourage changes. Since about 1986, we have been exploring the use of computer disks, the Internet, and the World Wide Web for distribution of not only products, but also services.[25]

Special Considerations for Navigational Almanacs

The Nautical Almanac was a reprint of the nautical portion of *The Astronomical Ephemeris and Nautical Almanac* from 1855 to 1915. In 1916, because the speed of ships had increased enough that the process of taking sights had to be expedited, the presentation of the data was completely redesigned. The original book had to be opened to too many different places to collect all the information required. The new arrangement reduced the number of openings required, and with accuracy only to the number of places required.

Development of an air almanac began in the late 1920's. As aircraft began making long flights, it was discovered that it took too long to extract data from the American Nautical Almanac to get a fix. P. V. Weems suggested that a big burden of computation could be transferred from the navigator to the almanac office if the Greenwich Hour Angle in arc replaced the right ascension in time.[26] In spite of limited staff, the office published supplements and made minor additions into the American Nautical Almanac beginning with 1929 and continuing through 1934. An experimental air almanac was issued in 1933. In 1940 permission was given to increase the staff of the NAO and start a crash program to design and publish an almanac to meet the needs of air navigators. There had been enough aerial navigation to find out what was required of an almanac, and the aerial navigators were in general a small group of carefully selected and highly educated young men. It was therefore possible to make an almanac on the basis of what was then considered the ideal almanac without much regard to the past. The desirable features included having all the astronomical data for a single day on a single sheet, tabulated at a suitable short time interval, and with convenient interpolation tables. The emphasis was always on doing as much calculation for the navigator as possible. When the American and British Air Almanacs were unified in 1953, there were some minor adjustments that did even more.

An annual Air Almanac was issued starting in 1941. It was first issued in three volumes per year of four months each (with patriotic red, white, and blue bindings[27]); in 1977 it was issued in two volumes per year for six months each, and as of 1987 it has been issued as one annual volume. Sky Diagrams were issued separately for a few years, and were so enthusiastically received that they were incorporated into the volume.

Surface navigators quickly adopted *The Air Almanac* because of its ease of use.[28] This suggested that a changed design might improve the ease with which *The Nautical Almanac* could be used. In order to study this subject, the Naval Observatory included in the *Nautical Almanac for 1947* a questionnaire for mariners. The U.S. Institute of Navigation had an Almanac Committee. It considered the comments received and a sample of pages from the Observatory. In October it sent a report to the Naval Observatory. In December the USNO began to prepare a preliminary sample of current ideas for a 1950 Nautical Almanac. This was sent to as many members of the ION as were deemed interested, for reaction, constructive criticism, and suggestions. Clemence was in charge.[29]

As a result *The Nautical Almanac for 1950* and onward was designed along the same lines as *The Air Almanac*; all the data for three days presented on facing pages, lookup tables to reduce the GHA in a separate section, and correction tables in critical value format on the inside covers.

As of 1998, at the direction of the RAF, HMNAO ceased publication of *The Air Almanac* for navigation and created a new one that serves an entirely different purpose, providing information on illumination and light levels.

Other Products: Printed

We have now discussed our three "mainline" continuing annual products. There is currently a fourth printed annual publication entitled *Astronomical Phenomena*. According to the annual report for 1951, "extracts from The American Ephemeris, with a small amount of supplementary material, are now published separately under the title Astronomical Phenomena. The contents consist primarily of material of interest to the general public, which was formerly supplied in mimeographed form or by correspondence; the separate publication is primarily for economy, permitting the users instead of the observatory to bear the cost of distribution." The first issue was for 1951 and coincided with the revision of *The Nautical Almanac*. The intent has been to publish it three years in advance of the cover date for planning purposes, but right now it is just two years ahead. It was for some time a joint publication with HMNAO, but they have now stopped marketing it separately.

There are other products with a significant lifetime, but are issued irregularly or have been discontinued.

When Newcomb began his grand project to redo all the planetary theories and to redetermine all the astronomical constants, in 1879 he started a series to publish the results, titled *Astronomical Papers Prepared for the Use of the American Ephemeris and Nautical Almanac*. Generally known as "The Astronomical Papers", the most recent part was published in 1987, and while it is not officially terminated, it seems unlikely to continue. In parallel, *Publications of the United States Naval Observatory, Second Series* started in 1900 to publish astrometric observations and data, the most recent part appearing in 1992.

The Coaster's Nautical Almanacs were devised as an experiment by Newcomb to meet a perceived need, but are so obscure that they are mentioned only in a few annual reports.[30] Before the American Nautical Almanac Office was established, American ships used reprints of the British Nautical Almanac made by a Mr. G. W. Blunt. It had many errors in it, which was one reason justifying establishing an official American office. In 1857, a contract was made with him to cease publication of his almanac and become an exclusive agent of our official one. When he retired in 1867, sales agents were appointed in major seaports, and later sales were opened up to any dealer, although keeping the accounts was a major burden to the NAO. Sales fell off by a third from 1876 to 1883, supposedly because fewer American ships were in service, but Newcomb suspected it was actually because numerous companies were reprinting portions of the official almanac to sell cheaply for advertising purposes, and they were popular on ships plying a coastal trade.

Newcomb felt that since the Government had established the Hydrographic and Nautical Almanac Offices for the purpose of supplying navigators with all necessary scientific data for navigation, an almanac for the coastal trade should be issued. But in order not to compete with private enterprise, all known publishers of private almanacs had to agree to cease publication if an official almanac were issued. All but one did, that one being John Bliss & Co. of New York, nevertheless in 1884 an experimental American Coaster's Nautical Almanac was issued, followed by separate Atlantic Coaster's and Pacific Coaster's Nautical Almanacs in 1885. In addition to astronomical data, they contained information on tides, lists of lighthouses, and other information of use for coastal navigation. By 1891, it appeared that the experiment had failed, as the private publishers continued to produce cheap or free reprints for advertising and sales of the official almanac were never the great quantity expected. They were never discussed in the annual reports after 1891, though they appeared in the annual publications list until 1907 or 1908. The story is of interest to us now because we are today in a similar situation where copies of *The Nautical Almanac* are being reprinted and sold privately even though British authorities hold the copyright.

The Ephemeris for the Bureau of Land Management (BLM), Department of the Interior, is the next discontinued publication. The annual report for 1959 stated that the Nautical Almanac Office had undertaken its preparation beginning with the issue for 1960. This was a publication founded in 1909-1910, and formerly prepared within that agency. Federal cadastral surveyors using solar attachments needed the data contained in *The Ephemeris* for determining bearings from astronomical observations. The BLM asked the NAO to take it over, apparently because their expert retired or died. In 1985, changes in our computer systems required major changes in the computational software, and the BLM decided that since use had declined so far, and other devices and calculator software on the market (such as *The Almanac for Computers* described later) could do the job, they would no longer support it. The last edition was for 1987-88.

Supplements and Circulars on solar eclipses are the final discontinued series. Even before the first volume of the Ephemeris was published, the NAO published predictions of a solar eclipse in 1851. Solar eclipses were of great value because the observations gave valuable information on the orbital elements of the Moon, up until the mid-1950s. After that, they gave valuable information on the limb of the Moon and the diameter of the Sun. The Navy sent expeditions to all total solar eclipses that could be profitably observed before World War II, and some afterwards. The American Nautical Almanac Office had charge of the eclipse work for all the almanac offices of the world until recently. Before the era of personal computers, the calculations for predictions were quite long and tedious, but a natural outgrowth of the work of the NAO. To encourage observations, supplements to the *American Ephemeris* were issued. The USNO began an irregular series of Circulars in July 1949, and many of them contained the information on solar eclipses previously issued in the supplements. The number of eclipse Circulars and the quantity of detail therein increased over the years, then they were discontinued in 1989 as a cost-saving measure. Only the basic information still appears in the annual almanacs.

There have also been important publications for navigators and astronomers that are not periodical, such as the two sets of Sight Reduction Tables for Marine Navigation (H.O. 229) and for Air Navigation (H.O. 249)[31], done for the Hydrographic Office in cooperation with the British Nautical Almanac Office, and *Planetary and Lunar Coordinates* that is done every 20 years or so.

Other Products: Electronic

In consideration of the availability of computers and the Internet, we have started rethinking how we supply not just information, but services to the community. Other speakers will cover this in more detail, but for completeness I want to include here a mention of some of them. A more thorough discussion will be the topic of other papers in this Symposium.[32]

Since the introduction of mechanical calculators, the NAO had distributed data on punched cards, and then magnetic tape. We also did some types of specialized calculations. As personal calculators and computers began to appear, there was a need to provide information tailored for them. The *Almanac for Computers*, 1977-1990, was designed to facilitate the applications of digital computers and small calculators to problems of astronomy and navigation which require coordinates of celestial bodies.[33] Fixed-interval tables, requiring interpolation, are replaced by concise mathematical expressions for direct calculations. The expressions were polynomial approximations fit to the tables, both navigational and astronomical. In the second edition, expressions were introduced to allow calculation of certain quantities for intervals greater than the current year. It was primarily a printed product, but the coefficients were also available on floppy disk or magnetic tape. It was discontinued when technology permitted the distribution of data and an executable file together.

The first computer almanacs of this form were introduced around 1986-1988, and were designed to do calculations using a supplied ephemeris that defined the valid time interval. The Floppy Almanacs,[34] good for just a few years each, were first, followed by the Interactive Computer Ephemeris (ICE) that had a longer ephemeris. Although they are still available from private sources, the NAO ceased supporting them when we introduced better products in 1993 and 1995. Two products were developed for certain microcomputer systems. MICA (Multi Year Interactive Almanac)[35] is the computerized complement to *The Astronomical Almanac*, while STELLA, (System To Estimate Longitude and Latitude Astronomically),[36] for DoD use only, is a counterpart to *The Nautical Almanac*. Each has a limited ephemeris.

As of 1996, the Astronomical Applications Department has a public Web site that provides information on our products and services, and can automatically handle many of our correspondence requests. As this seems to be an important future medium of communication both for DoD and general use, we are investigating ways to expand and tailor our site to complement our printed publications.

In the continuing spirit of consulting with our customers before making changes, we enclosed a mail-back survey with *The Astronomical Almanac for 1999*, and also had a very detailed version up on the Web. We were interested not only in what portions of the publication are being used, but also whether an electronic complement or substitute would be acceptable. The results from several hundred responses indicate an overwhelming desire to retain the printed version no matter what. The respondents do not yet trust electronic media for ease of use, nor stability of the technology, in particular for archival purposes.

Conclusion.

The products of the Nautical Almanac Office have changed quite a lot over the long run. The evolution of our products is accelerating, and we are often asked whether we are keeping up with the evolution of technology. We place our mission at the highest priority. I close with some words from my predecessor, LeRoy Doggett.

> By the 1980s some people regarded ephemeris offices as obsolete producers of paper products in an age of electronic information. Electronic methods of navigation were becoming much easier and, in many cases, more reliable than traditional celestial navigation. But at the same time, the offices were facing ever increasing public demands for information.
>
> Today, with the market awash in astronomical software, someone needs to set a standard for scientific excellence. It is a role the ephemeris offices are uniquely qualified to fulfill.[37]

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The Marine Super Integrating Bubble Sextant

By John M. Luykx

INTRODUCTION

The Marine Super Integrating Bubble Sextant manufactured by H. Hughes and Son following World War II is the first of the aircraft type artificial horizon sextants to be designed specifically for marine use. It was developed in England during the latter stages of the war, but was not marketed until after the war when the Hughes firm became associated with the firm Kelvin Bottomley and Baird and later known as Marine Instruments Ltd.

The design of the Marine Super Integrating Bubble Sextant is based on the famous MK IX series manufactured by Hughes during the period 1940-1945. The original MK IX (1940) incorporated a 6 shot mechanical averager while the MK IXA had a 2-minute observation (clockwork) averager. Later in the war, the MK IX BM was developed to include a selective 1 or 2 minute chronometer averager with the addition of a 2X optical telescope.

Although the design of the marine super integrating bubble sextant (super sextant) closely paralleled the Hughes MK IX series of instruments, the mechanical and clockwork averagers were replaced by an integrating system of completely new design in 1945. Figure 1 shows three (3) aspects of the exterior of the sextant as well as some basic nomenclature.

THE AVERAGER

To increase the accuracy of observation when using a bubble sextant in air or marine navigation and to eliminate the errors caused by ship ro aircraft motion, i.e. pitch, roll and yaw averaging devices of various types were incorporated in bubble sextant design by all the belligerent nations during World War II. Early averagers consisted of median types simple mechanical devices and clockwork mechanisms.

The German firm of C. Plath of Hamburg was the first to include an integrator averager in the design of a bubble sextant. This advance resulted in the famous SOLD sextant first issued in 1939 and later issued during the war in 1945. The SOLD gyro stabilized artificial horizon sextant was used in submarines.

In the U.S. and Britain, the integrator averager did not become available until the latter stages of WWII. In the U.S. integrators were developed in 1944-5 for the Bendix A-15 sextant and by Kollsman following the war for their MA-1 and MA-2 hand held aircraft sextants and the periscope sextant. In England following the war, Henry Hughes was the first to develop an integrator averager for use with a bubble sextant. It is this sextant which is the subject of this article.

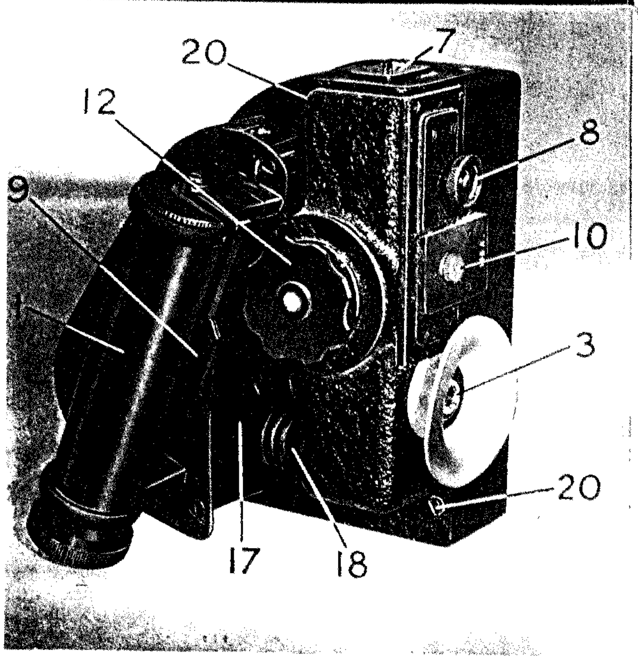
OPERATION

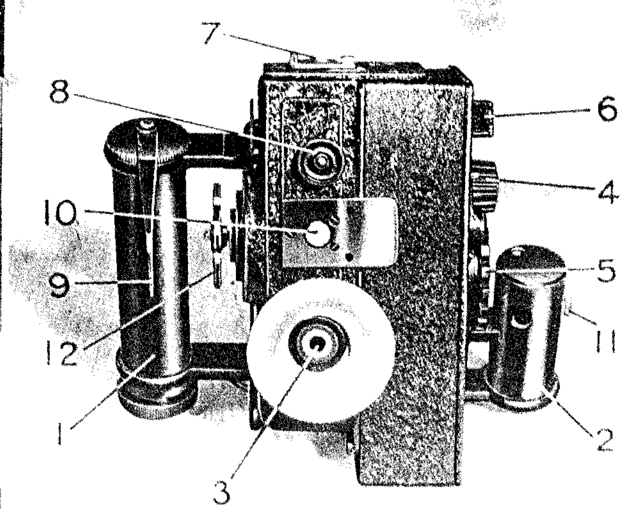
The Optics System

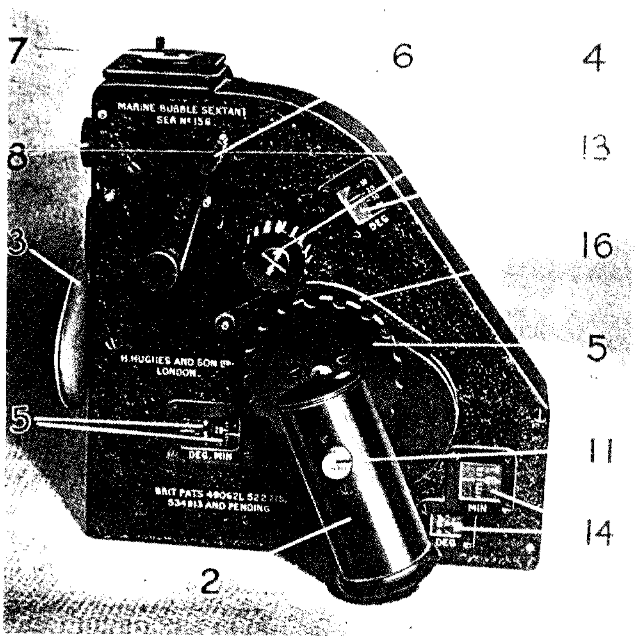
The sextant employs the double reflection principle of the typical marine sextant which includes an index mirror, a horizon mirror and associated filters. These optical assemblies, however, are enclosed in a compact metal housing which differentiates this instrument significantly from the typical marine sextant. No telescope is provided. The bubble assembly incorporated in the sextant is the exact duplicate of those associated with the MK IX series of air sextants. What sets this instrument apart is the averager, the heart of which is the integrator mechanism which is operated from the right side plate of the instrument (Figure 1).

Figure 2 shows various aspects of the interior of the sextant.

MARINE
SUPER INTEGRATING BUBBLE **SEXTANT**





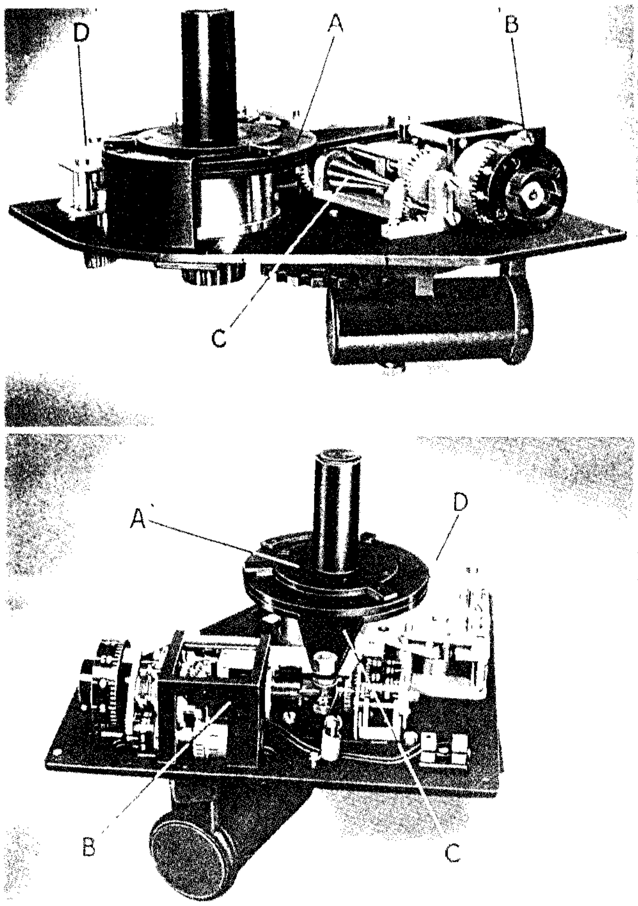


1 Left Handle 2 Right Handle 3 Eyepiece 4 10 altitude adjustment 5 Altitude fine adjustment 6 Winding lever 7 Daylight lighting cover 8 Night lighting intensity control 9 Lighting switch 10. Bubble lamp 11 Scale lamp 12 Bubble control knob. 13 Tens of degrees scale 14 Degrees and Minutes scales (instantaneous reading) 15 Degrees and Minutes scales (average over 2 minutes) 16. Starting lever 17 Automatic shutter 18 Shades. 19 Window of bubble box 20 Screws securing bubble box to sextant

FIGURE 1.

MARINE INSTRUMENTS LTD
GLASGOW LONDON

Figure 1.



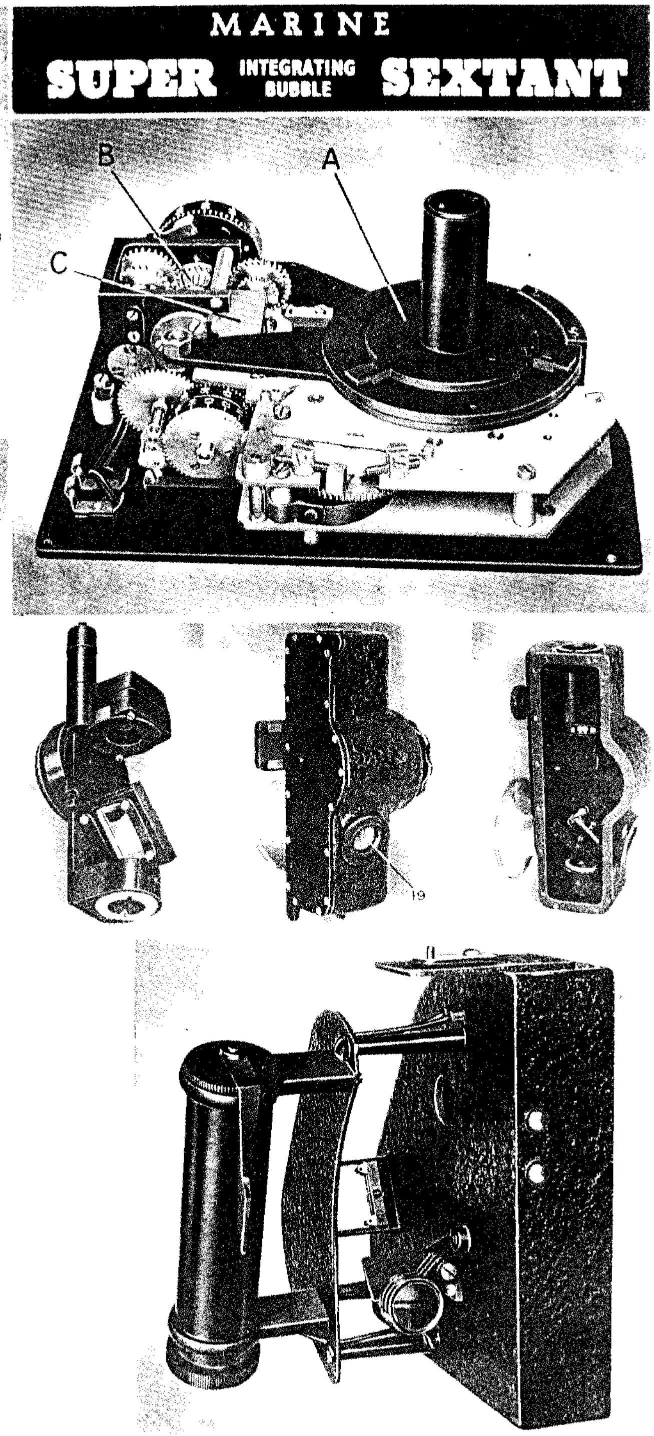


FIGURE 2.

MARINE INSTRUMENTS LTD

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Figure 2.

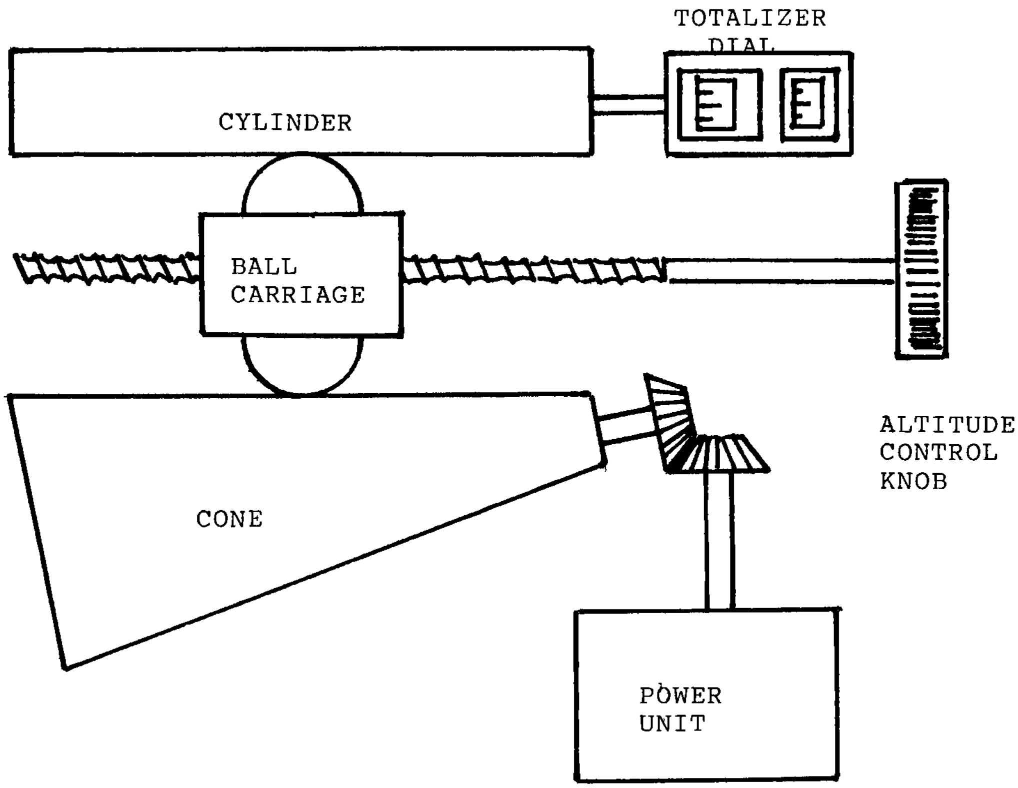


Figure 3.

Integrator Averager

The integrator assembly is constructed of a rotating cone and a cylinder with its axis parallel to one edge of the cone (See Figure 3). Contact is made between the cone and the cylinder by a carriage containing two balls so arranged that the contact points between the cone and ball, ball and ball and ball and cylinder are in a straight line. The carriage containing the 2 balls is driven by gear wheels connected to the altitude control knob operated by the observer during observation. Secured to the end of the cylinder of the integrator is a totalizer dial showing degrees and minutes indicating the mean value of the altitude observed during the 1-minute period of observation.

The Observation

A clockwork mechanism in the power unit is wound prior to observation and set in motion by depressing a lever on the right side plate of the sextant as the altitude control knob is rotated to keep the bubble and celestial body in collimation. During the 1-minute period of observation, the ball box or carriage moves across the rotating cone causing the ball to rotate. The cylinder in contact with the upper ball is caused to rotate and indicate on the averager (totalizer dial) the mean value of the altitudes measured during the observation. At the end of one minute a shutter moves across the optical path of the instrument indicating the end of the period of observation. At this point the observer records the time. The *mean time* of the observation is obtained by subtracting 30 seconds from the time recorded at the end of the period of observation. The mean altitude of the observation is read from the totalizer dials.

SUMMARY

The advantages of the marine super integrating sextant over the standard marine sextant are:

1. The altitude of a celestial body can be obtained above the true horizon when the natural sea horizon is indistinct due to fog, weather or darkness of night.
2. The errors of observation associated with the artificial horizon bubble sextant are significantly reduced by averaging them out over a period of 1 minute of continuous observation.

Although this instrument is a substantial improvement over the bubble sextants of the World War II period, it rarely, however, can provide the order of accuracy of the marine sextant when that instrument is used with a clear horizon.

The results of early accuracy tests of this sextant conducted by the author are recorded in Pages 5 and 6 of the Winter 1990 (#31) issue of *The Navigator's Newsletter*. More recent tests conducted from shore on Chesapeake Bay in July 1999 near Point Lookout, Maryland provided the following results:

Table 1: Index Correction by altitude observation of the visible horizon

10 single (non-averaged observations Height of Eye: 10 feet

Observation N.	*Altitude of Horizon (Hs)*
1	-2.'0
2	-5.'0
3	-1.'0
4	-2.'0
5	-1.'0
6	-1.'5
7	-1.'0
8	+0.'5
9	-1.'5
10	-2.'2
	10/16.'7
Mean Error:	-1.'7
Dip Error:	-3.'1
Bubble Sextant I.C.:	-1.'4

Table 2: Index Correction by altitude observation of the sun from a known position: 10 observations using integrator averager.

Date:	15 July 1999	W.C.:	0 seconds
Position:	N 38°03.'4	Weather:	warm, clear
	W 76°19.'6	Instrument:	Hughes Super Marine Sextant
Body:	Sun (C)		

Observation No.	Time (+4)	Hs	Error
1	17-04-18	31°45.'5	+3.'5
2	17-07-47	37°04.'0	+3.'1
3	17-10-15	36°34.'5	+2.'8
4	17-12-37	36°05.'0	+1.'2
5	17-14-56	35°41.'0	+4.'5
6	17-17-19	35°09.'0	+0.'7
7	17-19-35	34°42.'0	+0.'4
8	17-22-04	34°13.'0	+0.'7
9	17-24-27	33°47.'5	+3.'3
10	17-26-50	33°17.'0	+0.'0
			10/+21.'1
		Mean Error:	+2.'1
		I.C.:	-2.'1

The data shown in Tables 1 and 2 (taken from a position ashore) indicates the inherent accuracy of the Hughes Marine Super Integrating Bubble Sextant.

Instrument accuracy is best determined by observations of celestial bodies or objects of known height from a fixed position on shore, while accurate observations recorded at sea are more the result of observer skill than instrument design.

HISTORY OF NAVIGATION

History of the American Nautical Almanac Office

By Steven J. Dick, U.S. Naval Observatory

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory March 3-4, 1999. Courtesy of the author.

The American Nautical Almanac Office is rich in history from many perspectives: as one of the oldest scientific institutions in the U.S. government; for promoting American navigation; for its many scientists, mathematicians and "computers" who deserve to be better known; for its leading role in international cooperation in science; and, not least, for its role in advancing astronomy in areas including planetary theory, astronomical constants, ephemerides and related fields. Although it is not possible in this brief paper to touch on all these subjects, there is perhaps merit in attempting a coherent account of the highlights of the 150 years that we celebrate today.

In order to provide an overview, I divide the history of the Office into three broad eras: the Founding Era (1849-1865), the Transition and Newcomb era (1866-1897), and the Twentieth Century,. These three eras were played out, respectively, in Cambridge (Massachusetts), Washington, D.C., and at the U.S. Naval Observatory's present location on Massachusetts Avenue in Washington.

Cambridge, Massachusetts: The Founding Era, 1849-1865

An obvious first question is why the Americans required their own Nautical Almanac when the British had been publishing a *Nautical Almanac and Astronomical Ephemeris* since 1767. Clearly one reason was grounded in patriotism. Already in his report of November 15, 1844 — two months after he appointed Matthew Fontaine Maury Superintendent of the Depot of Charts and Instruments (soon to transform into the Naval Observatory) — Secretary of the Navy John Y. Mason noted that the Depot's new astronomical instruments were "well selected, and may be advantageously employed in the necessary observations with a view to calculate nautical almanacs. For those we are now indebted to foreign nations. This work may be done by our own naval officers, without injury to the service, and at a very small expense." In his first annual report as Superintendent, Maury himself argued for an American almanac as part of his goals: "If we attempt to compute the 'American Nautical Almanac' — and this we can do at no greater

Frontispiece, *Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Abservatory, March 3-4, 1999.*

expense than we pay the English for computing theirs for us — from our own data, it is highly desirable that the data should be wholly American." Mason renewed this call for action on an almanac in 1846 and 1847, and in 1848 submitted estimates of $6000 "for calculating, printing and publishing the Nautical Almanac, including pay of superintendent of the same." As Waff documents in detail in his paper in this volume, during this time Maury played the leading role as advocate of an American Nautical Almanac, shepherding it through a tortuous political process. Finally in 1849 — in the closing days of Mason's tenure as Secretary of the Navy, and on the last full day of James Polk's tenure as President of the United States — the Nautical Almanac was approved.[1]

The naval appropriation act of 3 March, 1849 authorizing the preparation and publication of the Nautical Almanac was part of a paragraph relating to Maury's Hydrographic Office. It provided only "That a competent officer of the Navy not below the grade of lieutenant, be charged with the duty of preparing the nautical almanac for publication;" the remaining clause referred to the other business of the Hydrographic Office.[2] As the wording made clear, however, the Nautical Almanac was to have its own Superintendent, and when the appropriation became available the next fiscal year (beginning July 1), Lt. Charles Henry Davis (Frontispiece) was officially placed in charge effective July 11.

Although the act said nothing about the establishment of a distinct office, not only was the Nautical Almanac Office formed separately from the Naval Observatory and Hydrographic Office, it was founded in an entirely different city. Though one might have thought the new Office would immediately be associated with the Naval Observatory, or at least located in its proximity, there was considerable rationale for its location in Cambridge. Davis (1807-1877), a Boston-born 1825 graduate of Harvard, had lived in Cambridge (when not on sea duty) since 1835, engaged in the Coast Survey work. Harvard University was near, with Benjamin Peirce and other mathematical talent, and its library, enriched with the library of Bowditch, was important. The mathematical work of the Nautical Almanac Office different significantly from the observational work of the Naval Observatory, requiring only the data from the latter and not a physical presence at the Observatory. And although Maury from the beginning had said that his observations would be useful for a nautical almanac, the two functions of observing and predicting could be separated.[3]

One of the first issues that had to be decided related to the question of an American Prime Meridian, a subject already broached during the struggle to establish the Almanac Office. Not only was Davis convinced of the need for an *American Ephemeris* because of his work with the Coast Survey, he also wanted to reference his survey work to an American prime meridian rather than one that lay far away across the ocean. Once raised, the idea was supported by the leading American scientists of the day — Alexander D. Bache, Joseph Henry and Maury himself. But the issue of the establishment and location of an American prime meridian was contentious, and resulted in an interesting and well-documented debate. I will note here only that the issue went all the way to Congress, and the House Committee on Naval Affairs, with all of the debate documentation in hand, recommended to Congress a compromise solution by proposing the adoption of an American prime meridian for astronomy and geography, while retaining the Greenwich meridian for the navigational part of the Almanac.[4] As a direct result of this decision that the meridian of Greenwich would be used for navigators and the meridian of Washington for astronomers, the *American Ephemeris* had a peculiar bipartite form, one part of more use to astronomers and the other part tailored for navigators. The ephemeris for the meridian of Greenwich gave the ephemerides of the Sun, Moon and Planets together with lunar distances. The ephemeris for the meridian of Washington gave the positions of the principal bright stars, the Sun, Moon and larger planets, and other phenomena predicted and observed including eclipses, occultations and motion of Jupiter's satellites. This, of course, would be most useful for observers in the United States.[5]

From the beginning, Davis considered the work of the Nautical Almanac Office broader than publishing rows of useful numbers. Most generally, Davis wished "to advance that which is, and has always been, the principal object of astronomy; and that is, in the language of Bessel, to supply precepts by which the movements of the heavenly bodies as they appear to us from the earth, can be calculated." This, he considered, was the highest calling of astronomy, much more important than mere descriptive astronomy. It was an activity designed not only to improve the safety of navigation but also to contribute to astronomy, compensating American mathematicians for their often unsung labors, and proving a credit to the country that supported this highest form of intellectual endeavor. An Astronomical Ephemeris, Davis added, "was something more than a book of mere results of calculations based upon rules furnished elsewhere; it should itself help to investigate the theories it is obliged to employ."[6] This is one of the central themes throughout the history of the Office. As evidence of Davis's commitment to this ideal, already in 1952 the Navy Department published essential sections of Davis's translation of Karl Friedrich Gauss's classic *Theoria Motus Corporum Coelestium* [Theory of the Motion of the Heavenly Bodies Moving about the sun in Conic Sections, 1857][7]

While waiting for a resolution of the problem of the meridian to which the almanac would be referred, and for the lunar and solar tables of Peter Hansen that would improve the predicted positions of the Sun and Moon, In the amount specified as the expenditure for the fiscal year 1851–'52, is included the cost of printing up to the 12th of October, 1852, because it is a part of the regular expenditure for that year.

I have the honor to transmit, also, a statement detailing the current expenses of the office during the present year.

Very respectfully, your obedient servant,

CHARLES HENRY DAVIS,
Lieutenant, Superintendent Nautical Almanac.

Hon. JOHN P. KENNEDY,
Secretary of the Navy, Washington, D. C.

Estimate for the Nautical Almanac for the fiscal year 1853–'54.

For salaries of computers	$16,200 00
For the purchase of paper, printing, &c., in order to publish, in the year 1854, the Nautical Almanac for the year 1857, and for other occasional printing	2,200 00
For clerk	500 00
For contingent, (including rent, servant hire, &c.)	500 00
Total	19,400 00

The amount of this estimate is the same as that of the preceding year.

Respectfully,

CHARLES HENRY DAVIS,
Lieutenant, Superintendent.

CAMBRIDGE, *October* 14, 1852.

Detailed estimate of the current expenses of the Nautical Almanac for the fiscal year ending June 30, 1853.

COMPUTERS.

Professor Peirce	$1,500
Professor Shubert	1,200
Professor Winlock	1,200
J. D. Runkle	1,200
Nathan Loomis	1,000
John Downs, as computer	600
John Downs, as corrector of the press	800
J. M. Van Vleck	1,000
B. S. Hedrick, as clerk	500

B. S. Hedrick, as computer	$500
Professor E. O. Kendall	900
C. H. Sprague	800
J. E. Oliver	600
W. C. Kerr	600
E. J. Loomis	500
J. G. Runkle	500
Dr. B. A. Gould	500
M. Mitchell	500
J. B. Bradford	400
C. A. Runkle	400
Professor A. W. Smith—off	300
J. A. Wilder	300
Chauncy Wright	300
Charles Hale—off	300
E. C. Bache, copyist	300
	16,700
Deduct	600
	16,100

MISCELLANEOUS.

Printing almanac	2,150
Occasional printing	50
Rent of rooms	378
Books	50
Stationery	150
Fuel	127
Servant	120
Contingent	275
Total	19,400

Very respectfully,
CHARLES HENRY DAVIS,
Lieutenant, Superintendent.

CAMBRIDGE, *November* 2, 1852.

Fig. 1. (Left and above) Budget estimate for the Nautical Almanac Office for the fiscal year ending June 30, 1853. "Computers" are ranked by salary, which was by far the largest expense item in the total budget.

Davis had four computers begin a new set of tables of the planet Mercury based on the theory of the French astronomer U. J. J. Leverrier. Even using such classical European work in celestial mechanics, one can imagine the problems that Davis faced: "it has been necessary to train the computers for a work such as has never before been undertaken in this country," he wrote. Nevertheless, following his own precept, Davis set about not only producing an Almanac, but also revising theories of the planets on which it was based, including the theory of Neptune that "belongs, by right of precedence, to American science."[8] By 1852 he had recruited a variety of people, whose rank may be gathered from their pay (Figure 1) and their division of work (Figure 2). Figure 1 also shows how labor intensive Almanac production was. Arriving at Cambridge in 1857, Simon Newcomb entered the happy ambiance of the young Almanac office that he described in his *Reminiscences*. He took well to the life of a "computer", which paid him $30 per month.[9]

Already in his *Annual Report* for 1851 Davis boasted of the practical results of the American *Nautical Almanac* — they reduced to one third the average errors of the Moon's place given in the British *Astronomical Ephemeris*. A crucial test was the solar eclipse of 28 July, 1851. According to Davis, the British almanac was 85 seconds in error at Cambridge and the American Almanac 20 seconds; at Washington the British Almanac was in 78 seconds for beginning of eclipse, 62 seconds for the end, while the American Almanac erred only 13 and 1.5 seconds respectively. Davis pointed out that the French and Berlin almanacs used the same tables as the British, and so were also in error by the same amount. In practical terms this meant 15-20 miles error in determination of longitude at sea by lunar observations.[10]

Called upon by a member of the U.S. Senate to defend his work in 1852, Davis appealed to the scientific reputation of the country, "already established and widely extended by the coast survey and the national observatory." And he took the opportunity to summarize the nature of the volume: to embrace all the information necessary to determine at any time the absolute and relative positions of the sun, Moon and planets, and some of the brightest stars; the phenomena for determination of longitude, including occultations, lunar distances, transits of the Moon and stars, and eclipses of Jupiter; also places of the minor planets, rules and tables for nautical astronomy, tables of tides and geographical position. The geographical extent of the U.S. he argued, :"makes it apparent that neither the authorities nor standards of Europe can satisfy our demands."[11] The work of the Nautical Almanac Office, Davis concluded, also serves the advancement of science and the diffusion of knowledge in the United States.

In January 1853 the first volumes of a total print run of 1000 copies of The *American Ephemeris and Nautical Almanac* (Washington, 1852) were transmitted to Washington. Undoubtedly in part because of its success, in 1854, after 31 years in the Navy and 23 in the grade of Lieutenant, Davis was promoted to Commander. In November 1856, he accepted a new command, and although Davis would return to head the office from 1859-1861, as the founding Director of the Office, he had placed his indelible stamp on the most creditable American mathematical feat to date. By 1860, supporters of the *American Ephemeris* argued that "hardly a single civilized nation considers its naval equipment complete without a Nautical Almanac. Six thousand copies of this year are spoken for; ten thousand will soon be the annual sale. The sale is constantly increasing, and he American is fast taking the place of the British Almanac in our own market,."[12]

Davis's successor as Superintendent in November 1856 was Joseph Winlock, who except for a brief period in 1859-61 would head the office for a decade, including the Civil War years. As Figure 3 shows, he was the first in a long line of Professors of Mathematics, USN, to head the office.

Compared to the battles and fundamental decisions of the Davis period, under Winlock's tenure it was relatively smooth sailing, as the office settled down to the routine annual production of the Almanac volumes. With the end of the Civil War in 1865 and the departure of Winlock and the move to Washington in early July, 1866, the Nautical Almanac Office entered a new era. (To be continued.)

NOTES

1. John Y. Mason, *Report of the Secretary of the Navy*, Nov. 25, 1844, 520 and Dec. 5 1846, 385, Matthew F. Maury, in *Report of the Secretary of the Navy*, October 20, 1845, 690-91. Craig B. Waff, "Navigation vs. Astronomy: Defining a Role for an American Nautical Almanac" (this volume) provides the most complete account, with full citations, of the events leading to the founding of the American Nautical Almanac Office.

2. Statutes at Large, 9, 374-375, as cited in Gustavus A. Weber, *The Naval Observatory: its History, Activities and Organization* (Johns Hopkins Press: Baltimore, 1926), 27. The remainder of the clause reads, somewhat ungrammatically, "that the Secretary of the Navy may when, in his opnion, the interests of navigation would be promoted thereby, cause any nautical work that may, from time to time, be published by the hydrographical office, to be sold at cost, and the proceeds arising therefrom to be placed in the treasury of the United States."

3. Already in an 1847 letter to John Quincy Adams, Maury had conceded that he himself would be unable to superintend the production of a nautical almanac in detail, and advocated a "special and subordinate Superintendent, whose duties should be confined to the details of the work and nothing else." The word "subordinate" implied that Maury wished to maintain overall control, but he did not. Maury to Adams, 17 November, 1848, published in *The Southern Literary Messenger*, January, 1848, pp.4-10; see also Waff (reference 1 above). Simon

Notes continue on page 18.

DIVISION OF WORK.

Professor Peirce—The general theory; planets generally; Mars particularly. Mr. J. B. Bradford, assistant.

Professor Winlock—Sun and Mercury, Astraea, Egina.

Mr. J. D. Runkle—Last ninety-two days of moon, Pallas. Mr. C. A. Runkle, assistant.

Mr. Van Vleck—Second ninety-two days of moon, Hausen's theory of Jupiter and Saturn. Mr. E. Loomis, assistant.

Mr. B. S. Hedrick—First ninety-one days of moon, Metis, Ceres. Mr. W. C. Kerr, assistant.

Mr. C. Wright—Third ninety-one days of moon. Mr. J. G. Runkle, assistant.

Mr. J. E. Oliver—Latitudes and longitudes; miscellaneous.

Mr. John Downs—Occultations, Saturn; proof-reading. Mr. J. A. Wilder, assistant.

Miss M. Mitchell—Venus.

Professor E. Shubert—Iris and other asteroids.

Professor E. O. Kendall—Jupiter and Neptune.

Professor A. W. Smith—Flora.

Mr. C. Hale—Clio.

Dr. B. A. Gould—Vesta, Hygeia.

Mr. C. H. Sprague—Fixed stars.

Mr. Nathan Loomis—Star table.

Mrs. E. C. Bache—Copyist.

I transmit with this report a proof copy of the general preface to the first number of the Nautical Almanac, for the approval of the department.

In conclusion, I have the honor to inform the department that, notwithstanding the slight delays referred to in the beginning of this report, the general state and progress of the work under my charge is satisfactory.

Very respectfully, your obedient servant,

CHARLES HENRY DAVIS,
Lieutenant, Superintendent Nautical Almanac.

Hon. JOHN P. KENNEDY,
Secretary of the Navy, Washington, D. C.

Fig. 2. Division of work among Nautical Almanac Office computers in 1852

Superintendents of the Nautical Almanac Office

LT Charles Henry Davis	July 11, 1849 (ordered)—Nov. 23, 1856
Prof. Joseph Winlock	Nov. 23, 1856—August 9/10, 1859
CDR Charles Henry Davis	Aug. 10, 1859—Sept. 18, 1861
Prof. Joseph Winlock	Sept. 18, 1861—May 1, 1866
Prof. John H. C. Coffin	May 1, 1866—Sept. 15, 1877
Prof. Simon Newcomb	Sept. 15, 1877—Sept. 20, 1894

Directors of the Nautical Almanac Office (Title changed Sept. 20, 1894)

Prof. Simon Newcomb	Sept. 20, 1894—Mar. 12, 1897
Prof. William W. Hendrickson	Mar. 12, 1897—June 30, 1897
Prof. William Harkness	June 30, 1897—Dec. 15, 1899
Prof. Henry D. Todd	Dec. 15, 1899—Aug. 24, 1900
Prof. Stimson J. Brown	Aug. 24, 1900—Mar. 25, 1901
Prof. Walter S. Harshman	Mar. 28, 1901—Oct. 1, 1907
Prof. Milton Updegraff	Oct. 1, 1907—Nov. 2, 1910
Prof. William S. Eichelberger	Nov. 2, 1910—Sept. 18, 1929
A. James Robertson	Sept. 18, 1929—May 31, 1939
Walter M. Hamilton	May 31, 1939—Feb. 1, 1940
Wallace J. Eckert	Feb. 1, 1940—Feb. 28, 1945
Gerald M. Clemence	Feb. 28, 1945—Jan. 31, 1958
Edgar W. Woolard	Jan. 31, 1958—Jan. 31, 1963
Raynor L. Duncombe	Jan. 31, 1963—July, 1975
P. Kenneth Seidelmann	Feb. 29, 1976—Sept. 1990

In September 1990 the Astronomical Applications Department was created and the Nautical Almanac Office became a branch of that Department, first under Paul Janiczek (Sept. 1990-July 1997), then under John Bangert (Dec. 1997—present).

Chief, Nautical Almanac Office [under Astronomical Applications Department]

LeRoy E. Doggett	Sept. 1990—April 1996
Alan D. Fiala	April 1996—present

Fig. 3. Superintendents, Directors, and Chiefs of the Nautical Almanac Office

Newcomb, Reminiscences of an Astronomer (Boston and New York, 1903), 62, states that the Nautical Almanac Office was founded at Cambridge to "have the technical knowledge of experts, especially Peirce, see also C. H. Davis [Jr.], "Memoir of Charles Henry Davis, 1807-1877" *Biographical Memoirs of the National Academy of Science*, 4 (1902), 25-55; C. H. Davis [Jr.] *Life of Charles Henry Davis, Rear Admiral* (Boston and New York, 1899), 74-93.

4. "American Prime Meridian", Report No. 286 to accompany Joint Resolution No. 17, House of Representatives, 31st Congress, 1st session, May 2, 1850, 1-2. On Maury's support for a Washington meridian as early as 1847, see Waff (reference 1 above). On the distinction between an ephemeris and an almanac, see Alan Fiala, "Evolution of the Products of the Nautical Almanac Office" (this volume).

5. Newcomb comments on this bipartite form in "The Astro-

nomical Ephemeris and Nautical Almanac," in *Sidelights on Astronomy* (Harper and Brothers: New York and London, (1906), 191-215

6. Lt. C. H. Davis, "On the Nautical Almanac," *Proceedings of the American Association for the Advancement of Science*, fourth meeting held in New Haven, Ct., August, 1850 (Washington, 1851), 56-60.

7. Karl Friedrich Gauss, *Theory of the Motion of the Heavenly Bodies Moving about the Sun in Conic Sections*, A Translation of *Theoria Motus Corporum Coelestium*, by Charles Henry Davis (New York, 1857; reprinted by Dover, New York, 1963).

8. Davis to William Ballard Preston, *Report of the Secretary of the Navy*, Oct. 2, 1849, 443-444.

9. Newcomb's *Reminiscences* (reference 3 above) describes the Office during its early years in the chapter "The World of Sweetness and Light". Also, Newcomb, "Aspects of American Astronomy," in *Sidelights on Astronomy*, 290-1 describes the atmosphere of the office under Davis. See also Davis's reports in *Report of the Secretary of the Navy*, Oct. 12, 1850, 229-230; November 29, 1851, 73-76; and December 4, 1852, 345-348. Figures 1 and 2 are from the latter. Davis summarized the goals of his work at the fourth meeting of the American Association for the Advancement of Science in 1850 (see reference 6).

10. C. H. Davis, *in Report of the Secretary of the Navy*, November 29, 1851, 75.

11. Senate Documents, Ex. No. 78 (1852), reprinted in "Davis's Report on the Nautical Almanac, *The American Journal of Science and Arts*," second series, 14 (Nov., 1952), 335.

12. "Memorandum Concerning the Objects and Construction of a Nautical Almanac," 11-12, and "Memorandum on the American Ephemeris and Nautical Almanac, showing its special and peculiar merit and Utility," in *Two Memoranda on the Objects and Construction of the American Ephemeris and Nautical Almanac* (Cambridge, 1860).

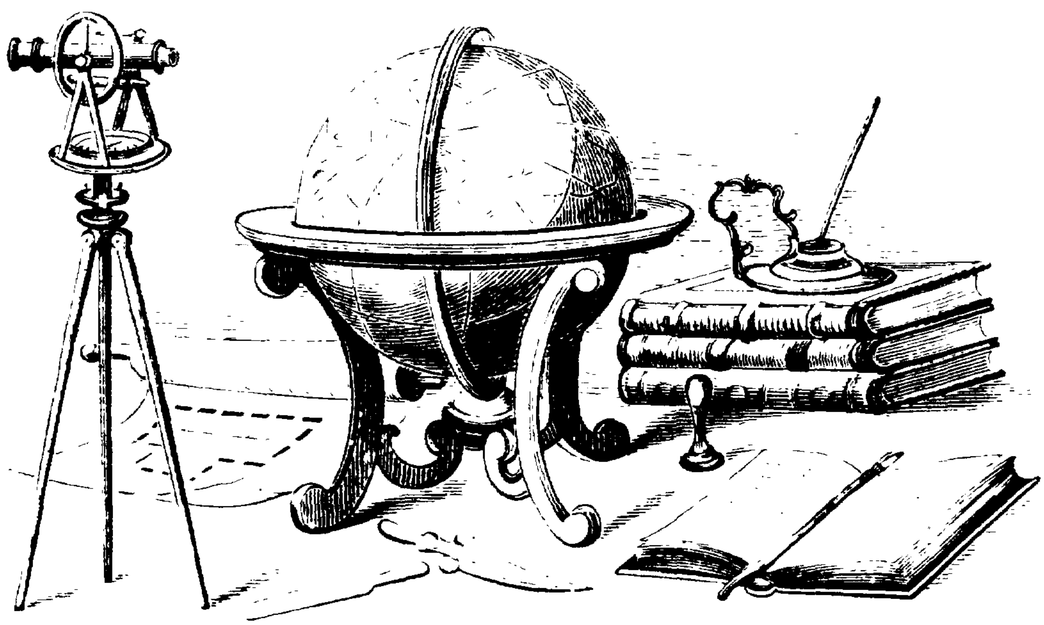
ANSWER TO DO YOU KNOW . . .

(From page 1)

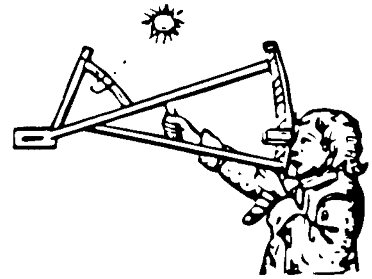
The navigator of the 1967 commemorative flight in a restored Lockheed Electra L-10, Major William L. Polhemus, in commenting on the 1937 Amelia Earhart flight in *The Quarterly Newsletter of the Institute of Navigation*, Summer 1998, lists the navigation equipment available to Navigator Fred Noonan aboard the Lockheed Electra 10-E as follows:

- a hand held bubble sextant
- three chronometers
- a magnetic compass
- an altimeter
- an airspeed meter
- an unstabilized driftmeter
- a pelorus mounted at the side window of the cabin aft

The side window had optically flat glass to permit sextant observation. Noonan's field of view was severely limited. He had no access to the cockpit. Pilot and navigator communicated by written messages passed from one to the other on a pole.



THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY, WINTER 2000-2001

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Now is the time to order your Nautical Almanacs for 2001. The Commercial Edition is available at $22.50 List Price. The U.S. Government Edition is available at $34.00 List Price. Member discounts of 20% on publications apply. There is a shipping and handling charge added to the member cost of the publication.

NIMA and NOS chart prices have increased again this year. Harbor, coastal and approach charts are now $17.00 each. Atlas of pilot charts are $31.50; Sight reduction tables $13.50 and *The American Practical Navigator* (Bowditch) is now $25.75. Member discount for charts *only* is 20% for orders under $50.00 and 25% for orders over $50.00. Shipping and handling is added to the members cost but the cost is still much less than the list price cost of the charts or publications.

If members are interested in other prices for nautical charts, books and publications, ask. We can get your publications from many nautical sources. When you order from The Navigation Foundation do not pay the invoice included from the publisher. Wait for an invoice from The Foundation, otherwise you will not get your discount. If the chart, book or publication is mailed from The Navigation Foundation you can pay the included invoice. This will give you the members discount.

Member John Lewis forwarded the following announcement on 9 January 2001.:

A few members in Seattle interested in the history of celestial navigation will be hosting Bruce Stark for an informal talk with a small group, on topics such as the importance and practice of lunar distance observations in the exploration of the Pacific NW (both by sea and by land), and recent developments in celestial navigation.

The tentative date for this gathering is Friday evening April 27. Space will be quite limited, but we want to make certain that members in Seattle are aware of this opportunity.

For further information contact John Lewis at (206) 521-2784.

The Directors of The Navigation Foundation wish you a "MERRY CHRISTMAS" and a "HEALTHY, HAPPY AND PROSPEROUS NEW YEAR."

READERS FORUM

Edited by Ernest Brown

Member Peter Ifland sent by e-mail on November 12, 2000:

"Last month, Luce and I had the pleasure of traveling to some of the points of navigational highlights in Portugal — Cape St. Vincent where Henry The Navigator had his school in the 1400's, the Maritime Museum in Lisbon (a must see!) And the University of Coimbra. While at the University, I gave a talk entitled The History of the Sextant, at the Science Museum. My sponsor, Professor Alves, Director of the Observatory, has put the text and the slides from my talk on the Internet at the Observatory's HELIOS site. If you are interested in seeing the material, go to *http://www.mat.uc.pt/~helios/index.html*"

— *Peter Ifland*

> DO YOU KNOW . . .?
>
> *By Ernest Brown*
>
> What communications equipment Amelia Earhart had aboard the Lockheed Electra 10-E during her attempt to fly around the world in 1937?
>
> *(Answer at end of issue)*

Member Rollan Perkins wrote from Dexter, OR on October 23, 2000:

"I recently received the Navigator's Newsletter and your kind welcome to the Navigation Foundation.

"I came across the Foundation in the Celestaire Catalogue, and what a wonderful find it was. I'm just a small boat sailor who has been taken with Celestial. It has become a wonderful refuge of sorts, but as you might imagine, being self-taught has produced enormous holes in my level of understanding.

"There are no teachers available (locally) and everyone I know is pushing a button. I've had good results with Mr. Bergins book and some H.O. 249 texts as well (Cunliffe, Milligan, Blewitt) Kelch.

"Using a Grundig Yacht Boy for time and a Davis Mark 15 Sextant, I was able to produce several fixes within 5-8 miles of my D.R. position (my favorite lighthouse). I think the results might have been affected by haze and fog, but being a green-hand with the sextant I still felt very happy with those initial results. Of course it was the AM-PM Equal Angle Method and a Noon Sight, but it was grandly liberating.

"Well, Sir, I was feeling in top form until I took out Dr. Bayless' Tables and promptly found myself to be somewhere near Midway. I thought I understood it. The examples are clear, but I failed. This really bugged me since I have been able to produce a L.O.P. with H.O. 249.

"The problem is that I love that little book and want to master it. Are there any texts re: H.O. 211 available beyond what is described in the Compact Table itself? That book of Compact Tables fascinates me, so I would ask the following questions.

1. Is it possible to use Mr. Gray's "100 Problems" to practice with Dr. Bayless' book?

2. Being interested in some theory, do you think Mr. Turner's book, Celestial for the Cruising Navigator, CMP, would be helpful? . . ."

— Yours truly, Rollan Perkins

Member Kieran Kelly sent from Sydney, Australia on December 10, 2000:

"I have just noticed that on page 3 of *The Navigator's Newsletter*, Issue 67, Spring 2000, the length of the North Australian Expedition's journey from Timber Creek to Depot Creek was incorrectly recorded as 44 kms — if only it had been that easy! It was 440 kilometres — six weeks in the saddle. What a big difference a small zero, when omitted, can make."

— Regards, Kieran Kelly, Commander and Navigator, North Australian Expedition 1999.

Member Eric B. Forsyth posted Newsletter #1 from Alesund, Norway, August 2000:

"*Fiona* will soon be heading for Scotland and as we leave the Arctic Circle it seems an appropriate point to list our adventures so far. On board, as we left Patchogue in mid-June, 2000, was myself, John, an Englishman who flew over specifically to join this caper, and Chris, A German physicist at Brookhaven National laboratory who was squeezing out a month's vacation in order to sail as far as Iceland.. We should have stayed in port: as we sailed out of Fire Island Inlet we encountered a stiff easterly wind that did not let up for a couple of days as we clawed our way to Block Island. Normally this leg takes about 20 hours from Patchogue, this time it took us a day and two-thirds; it was midnight when we picked up a mooring in the Great Salt Pond, Block Island. A good night's sleep, a brisk walk to the Southeast lighthouse and supper at Ballards restored our good spirits. We left the next morning, bright and early, for a sail to the Cape Cod Canal and a mooring at Provincetown, on the top of Cape Cod. Here the best entertainment is to sit on a form in front of the Town Hall and watch the throng passing by. The prize goes to a creation on 6-inch platform shoes dressed in gauzy pink, of indeterminate gender. Probably there is no greater contrast to Provincetown than Lunenburg in Nova Scotia. We tied up there after a three day trip across the Gulf of Maine, mostly in foggy, windless conditions. Lunenburg was one of the leading fishery and shipbuilding ports on the Nova Scotia coast. Now the collapse of the cod fishing has had a dramatic impact. There is an interesting museum devoted to the Atlantic fishing business including a genuine Grand Banks schooner. Tied up at the Scotia Trawler dock we encountered a fascinating yachtie - Bill Butler. He and his wife survived 66 days in a life raft in the Pacific after their sailboat was sunk by a whale (they think). He now has a new wife and a new boat.

"Our next stop was in St. Johns, Newfoundland. St. Johns was England's first colony, a tribute to the enormous value of the cod fisheries, now fished out. It is the capital of Newfoundland, and an impoverished town. The residents are extremely pleasant, one cruising couple invited us over to their apartment for supper. It is unnerving for a New Yorker to step into the street and finding all the traffic grinding to a halt, crosswalk or no. The residents complain a lot about the weather.

"The passage to Iceland took 11 days. The logbook is full of "foggy". The Labrador Current, coming down the Davis Strait on our port gave us plenty of fog, sometimes calm, sometimes winds to 25 kt. The period of darkness fell to 3 or 4 hours as we gained northing. The boom and sail dripped and condensation appeared in the cabin. The seawater temperature fell into the 40's. Chris was not impressed. It reminded me of my first transatlantic passage with John and Barbara Knight aboard *Arvincourt*. When we entered the snug harbor at Reykjavik we found a NATO exercise in full swing with six frigates tied up. The public telephones in the town were very busy with crew calling home. Reykjavik is a pleasant town with striking architecture. Virtually all the buildings are heated by geothermal springs as Iceland lies on a major fault line in the earth's crust. These springs also provide electric power in such abundance that Iceland is a smelter of aluminum using bauxite transported from half way around the world. The thought crossed my mind that when we run out of fossil fuel the Icelanders will still be warm and running cars using hydrogen obtained by electrolysis. In Iceland a friend of a fellow South Bay Cruising Club member, Eli, had been prepped to meet us. He was waiting on the dock when we tied up. He was a treasure. We had a great supper with him and his partner, Hilda, in their modern apartment. On the day Chris flew home he gave us a tour of the southwestern corner of Iceland. Near the coast the terrain is barren; jumbled rock with little vegetation. Inland it is a little greener. We walked through the rift which is slowly tearing Iceland in half. It is in a dramatic setting and was the site of the first parliament when the Vikings settled Iceland in the 900's. It was a society ridden with blood feuds — parliament was a neutral place with weapons laid aside.

"We had an elegant meal with Eli and Hilda in a small restaurant one evening, which was astonishingly expensive by American standards. Perhaps it was the fare: smoked puffin for appetizer. One can only wonder at the energy and productivity of the Icelanders; it is a fully functioning democratic society with good social services, international and national airlines, ferries, a fishing fleet, etc. and virtually free energy (but imported fuel is very expensive), all with a population of 280,000 souls. When Chris left we were joined by Doug, a recently retired professor of oceanography who flew in after just completing a field trip to the Great Barrier Reef. He likes his life to be full of contrast, obviously.

"After leaving Reykjavik we sailed by Surtsey, an island formed in the 1960's by a volcanic eruption off the south coast. After that we tied up next to a trawler in the Vestmann Islands. Legend has it that they were first inhabited by escaped Irish slaves during the Viking period, figuring no one would venture to such a wild place. But the Vikings tracked them down and killed them anyway. The main island, Heimaey, was threatened by an eruption in 1973 when a river of lava might have closed off the harbor. They imported dozens of big diesel driven water pumps and cooled down the flow so now the lava forms a nice breakwater; the harbor was saved. We climbed to the top of the volcano, Eldfel, which is still gently steaming and warm underfoot. Halfway up is a monument to the occasion when the harbor and town were threatened — a rusting diesel engine and pump!

"Our next landfall was Jan Mayen Island, north of the Arctic Circle. We were not sure if we would be able to land — there is no harbor thus one must get ashore by dinghy and, perhaps more of an obstacle, prior permission is required from a Norwegian government office on the mainland. The passage was a study in contracts: high winds, then calm fog, then sunshine. The nights grew shorter. A day before we arrived the first sign of engine trouble surfaced. Early in the morning the smoke detector in the engine room clanged away; there was steam everywhere, the engine had lost its cooling water. The leak was in the water pump, the problem would continue to plague us, as you will learn. Jan Mayen is dominated by a 9000 ft. or so high volcano, permanently covered with snow. When we had it in sight we called on the radio and were directed to anchor in Walius Bay, on the west side of the island. It was late afternoon when we finally got there and conditions were calm. We were formally given permission to land "for two hours" and a knot of people met us on the rocky beach, including the station commander. I think the two hour limit was simply to meet some official directive about admitting strangers to the island; we stayed over five hours. A jeep-like vehicle transported us to the main base 18 km away, dubbed 'Aluminum City' from the style of the clustered buildings there. Twenty-six people live on the island manning radio transmitters and a meteorological station. There is a sprinkling of women. We met a couple in the cozy lounge while being served tea and cake. First our guide insisted we take a shower — towels and soap were ready. Was that for our benefit or theirs? After visiting most of the facilities and a small museum we returned to the beach. Even though ti was after midnight it was quite light. In the museum were some pieces of a German Kondor that crashed on Jan Mayen during WW II. It was probably damaged spotting Allied convoys that were often routed this far north. The pilot obviously hoped for a successful crash-landing on this rocky island but all six aboard were killed, a story we will never learn. It was still clear when we left and we got several snaps of the volcano, Beerenberg, as we left. According to the guide book we carried, the peak of the Beerenberg can only be seen one day in a hundred, so we were lucky.

"We got good ice charts from the met office in Jan Mayen. The pack ice was a little further south than usual this year. The last tendril of the Gulf Stream is deflected along the west coast of Svalbard (also known as Spitzbergen); this causes the pack ice to be further north close to the coast. As we sailed northeast from Jan Mayen we encountered northerly winds which pushed the sea ice to the south. We finally encountered ice at 78°37'N, about 10% sea coverage. Some of the floes were 100 ft. long and perhaps 10 ft. high. John spotted a dark object on one but it slid into the sea on our approach; it was probably a seal. We started the engine to keep maneuverability and took lots of photos. We had no difficulties working free of the ice as we sailed east and a day later we raised Ny Alesund, near the north coast. At 79° N it claims to be the world's most northerly settled town. It was founded in the 1920's as a coal mining village but a series of explosions, culminating in a shocker in the 1960's, shut down mining operations. For the last couple of decades it has been the home of a number of teams interested in high arctic scientific research. It is very busy in summer with visiting investigators, a few hardy ones winter over. I talked to one British scientist who knew Dave Burkett, the chief at Pt. Lockeroy, whom I met in

1999 during the Antarctic cruise — small world. A museum full of mining artifacts and photos testifies to the hard life the miners and their families lead. Some coal mines (mostly operated by Russians) are still in business in other parts of Svalbard. Ny Alesund must be one of the few places on earth where you are not allowed ashore WITHOUT a gun. Doug had put his 12 gauge shotgun aboard before we left New York and it was checked by a policeman on our arrival. The danger is polar bears, which in summer move north with the receding pack ice looking for seals to eat. For some reason a few forget to go north and they hang around the coast looking for something else to eat — you! This is a historic spot in the story of arctic exploration. Many expeditions set out from Ny Alesund, for example the tower for mooring Nobile's dirigible, in which he flew over the North Pole in the 20's, is still there, about half a mile from the dock. We tied up next to a very interesting fellow, Hans, who had built his own steel sailboat which he charters each summer to scientists going further north. The same length as *Fiona*, she weighed 50% more — the bottom and bow were made of steel plate over an inch thick. I asked how far north he had sailed and he replied 83° N in a good year. This must be a record for a yacht, only 420 miles from the Pole. One afternoon as John and I walked into the village an Arctic fox raised havoc among the nesting terns by searching for eggs. Ultimately it found one despite the distracting attacks by the terns and then scampered away.

"After a couple of days we sailed down the scenic Forelandsundet, a spectacular 90-mile journey past high mountains and wide glaciers to Longyearbyen, the capital of Svalbard. This too was a coal mining village and overhead cables and supports dot the rugged terrain. Although the population is under 2,000, the village boasts 'the second best restaurant in Norway', to quote a guidebook. Doug felt a trip there for the crew after all our hardships ought to be his treat and so one evening off we trooped. The room was impressive: gleaming glasses and plates on snowy tablecloths, each setting had four knives and forks, not counting the little fork for dessert. Now it has always been my maxim that the bill is proportional (not necessarily linearly) to the number of forks. In the past I have steered the guys away from places with only two forks. Four forks would be a new point on the curve. The meal was indeed sumptuous, the wine list ran to about six pages. The waitress was disappointed we only ordered one bottle, as each course appeared she suggested the appropriate bottle, which we declined. Doug did pay the bill, for which we thanked him. It was in the stratosphere. On the day we arrived as we walked past the police station on the way into town we noticed the police unloading three dead polar bears from a trailer. Apparently they consisted of a mother and two two-year old cubs. The mother was shot by a Polish scientist at a base out of town when it destroyed some equipment. The police shot the cubs, which appeared fully grown to me, as a precaution based on past experience. It was tragic to see these wonderful animals lying supine and bloodied.

"Alcoholism must be a problem in these northern communities. We discovered residents are rationed as to how much they can buy and they are given a ration card. Unfortunately visitors don't get a ration. We had hoped to add a couple of cases of beer to our dwindling stock. Fortunately, Hans showed up and when he learned of our plight got himself a card (he resides permanently in Svalbard) and went with me to a store to get a case. One evening we went to a pub in town for a quiet drink before returning to the boat. When the owner heard our accents he insisted on setting up tots of vodka on the house, to be downed in one gulp, Russian style. After the fifth round we staggered home in the light of midnight sun. While in Ny Alesund I had called my ship's wife, Red, in Bellport on the phone and asked him to mail a new water pump for the engine to my English friend Derek who is planning to join *Fiona* at the end of August. Since Jan Mayen it had been necessary to add fresh water to the system whenever we ran the engine, but I felt we could live with that for a few weeks. This turned out to be a miscalculation. Shortly after we left Svalbard, while still under power, there was a loud shriek from the engine room followed by the now familiar clamor of the smoke detector. This time it really had detected smoke — the pump had seized up solid and the slipping fan belt had caught fire. Our destination was the Lofoten Islands about 600 miles to the south, but still above the Arctic Circle. After I removed the pump it was clearly past fixing on board — broken ball bearings fell into my hand as I pulled it apart. Thus we decided to head for Bodo (pronounced Buddha), a fairly large town just south of the Lofotens. One problem was that without the engine we had no way of keeping the batteries charged, so we instituted rigorous electrical economy, no heater and only one side of a tape at happy hour. As we sailed south Murphy struck again: the jib fairlead came loose, the sheet chaffed on the after turning block and broke. The subsequent flogging of the jib caused the roller furler foils to separate and the job got ripped. This left us with only the main and staysail as a means of propulsion. Over the next few days we rigged a spare bilge pump so we could run the engine and we stitched the jib so it could be hanked onto a temporary stay. We crossed the south end of the Lofotens near the infamous Maelstrom and tied up at Bodo eight days out from Svalbard. We were able to contact a charming lady sailmaker who bore away the jib for some TLC. Next to us was a 103 year old Colin Archer sailboat owned by an amazing character called Steinar. When we said we needed a new water pump he cell-phoned an acquaintance on a nearby island who ran a diesel repair business and arranged to have a new one shipped to the airport by the local SAS carrier that afternoon. By half past five on the day we arrived I had the new pump in my hands. I was deeply impressed by the demonstration of Nordic efficiency. Not only had I the pump, I had also paid for it at a bank on the waterfront who transferred the money electronically to the vendor's account. The next day I installed the pump while Doug and John took a bus ride to some of the local scenic spots including Saltstraumen, the fastest flowing tidal stream in the world (20 kts). A couple of days later our sail was delivered and we left for an abbreviated cruise to the Lofoten Islands. These islands, lying about 30 miles off the Norwegian coast, are famous for their mountainous beauty and rugged coast line. The night we crossed over the wind piped up and we ducked into the old whaling port of Skrova for shelter. Later in the day we ran downwind to Stamsund, which is Steinar's home port. He was nice enough to pick us up at the boat that evening and give us a tour of Vestervagen Island. On the morrow we caught a bus to the interior to visit a reconstructed Viking long house and ship. Although the coasts of these islands are forbidding and look like the homes of trolls, the interiors are quite gentle, with fertile valleys, farms and grass meadows. A veritable northern Shangri-la. We visited two quite charming fishing villages, one of them, Nusfjord, is a world heritage site. We liked the pub there anyway. Then we left the islands from Reine for the 400 mile leg to Alesund on the Norwegian mainland, crossing the Arctic Circle on our way south. This concludes the arctic phase of the cruise; since leaving New York we have logged 5,483 nautical miles."

— *Best wishes, Eric*

Editor's note: See Fiona's tentative Timetable, 2000 to 2001 and website address in Issue Sixty-eight (Summer 2000)

NAVIGATION NOTES

Artificial Horizons, Lunars and Longitude in Australian Exploration at the Time of Lewis and Clark

By Kieran Kelly, Sidney, Australia

The Journal has recently published several scholarly papers on Lewis and Clark's use of artificial horizons and lunar distance observations during the course of their trans-American expedition (1803-1806). In the years just prior to the Corps of Discovery Expedition, one of Australia's most significant journeys of exploration was undertaken to map the entire coastline - an area larger than the Continental United States. Australia was settled in 1788, much later than the United States and at the time of Lewis and Clark's expedition, the total extent of its landmass and its exact coastline was unknown.

This momentous task was ordained by Governor Hunter when in October 1798 he entrusted Lt. Matthew Flinders with command of the sloop *Norfolk*, 25 tons. The young British naval officer's first command was for a three-month voyage from Sydney to the storm tossed Southern Ocean. The aim of the voyage, to be undertaken in the wild seas that claimed so many lives in the 1998 Sydney to Hobart yacht race, was to discover if Tasmania was an island or connected to the Australian mainland.

Demonstrating the great rarity and cost of chronometers in the early part of the nineteenth century, Flinders' journal on the first night of the voyage laments, "...but a time keeper, that essential instrument to accuracy in nautical surveys, it was still impossible to obtain...."

Undaunted the navigator on October 11, 1798 mentions use of his artificial horizon for the first time and details some of the perils of onshore celestial navigation in the early years of the nineteenth century, "I was preparing the artificial horizon for observing the latitude when a party of seven or eight natives broke out in exclamation upon the bank above us...."

"The approach of the sun to the meridian calling me down to the beach, our visitors returned into the woods. We could perceive no arms of any kind amongst them, but I knew these people too well not to be assured that their spears were lying ready, and that it was prudent to keep a good lookout on the woods, to prevent surprise while taking the observation...."

Taking the artificial horizon onshore for the noon sight became a feature of Flinders' voyages and on November 2, less than a fortnight into the journey, he records his first set of lunars. "We passed close to Stony Head at ten o'clock, when two sets of distances for the sun east of the moon gave its corrected longitude 147°10' east." We know today that Stony Head lies in 147°01' east. Flinders' actual position was about 7 nautical miles west of his observed position — commendable accuracy from the mariner.

Three weeks later he demonstrates not only his knowledge of lunar distances but also the use of eclipses recording, "... there being a lunar eclipse announced in the ephemeris to take place in the following night, I landed to observe it with the telescope of the sextant. The times at which the beginning and end happened by the watch, being corrected from altitudes of the stars Rigel and Sirius observed in an artificial horizon, gave 148°37 1/2' for the uncorrected longitude of Preservation Island."

Flinders is confident enough of the accuracy of his sight to quote longitude to half a minute but cautions on the shortcomings of eclipses as a navigational tool: "The penumbra attending the earth's shadow is usually supposed to render this observation uncertain to two or three minutes of time, or more than half a degree of longitude." How right he was. Preservation Island lies at 148°05', an error of about 24.5 nautical miles on Flinders' observed longitude. Still not too bad, out by about half a degree without a chronometer! The substantially better accuracy of the lunar distance sight at Stony Head compared to the lunar eclipse sight at Preservation Island is however, noteworthy.

Delighted with Flinders' journey through the wild Southern Ocean and his proof that Tasmania was indeed an island, the British Government in 1801 gave him command of the sloop *Investigator* of 334 tons. His mission - to chart the entire Australian coastline.

Flinders left England in July 1801, this time armed with two chronometers by Arnold. However, he still needed his mercury horizon in its mahogany box. The utility of the artificial horizon to a mariner was shown in the first week of February 1802 as Flinders coasted along Australia's southern shore charting as he went. Unable to get a good sea horizon for his sights, he lamented "There was so dense a haze below, that the true horizon could not be distinguished from several false ones, and we had six or seven different latitudes from as many observers; those taken by me to the north and south, differed 19 minutes." Undaunted he took the artificial horizon ashore and through the use of noon sights and lunars was soon able to pinpoint his location and correct his charts. When the real horizon was obscured the maritime navigator had no alternative but to resort to his mercury horizon.

The nineteenth century preoccupation with time and distance in navigation and the ingenuity of these nautical pioneers was shown later in February when Flinders went ashore to lay out the base line for a survey. "Having left orders on board the ship to fire three guns at given times, I went to the South-east end of Boston Island, with a pendulum made to swing half seconds. It was a musket ball slung with twine, and measured 9.8 inches, from the fixed end of the twine to the centre of the ball. From the instant that the flash of the first gun was perceived, to the time of hearing the report, I counted eighty-five vibrations of the pendulum, and the same with two succeeding guns; whence the length of the base was deduced to be 8.01 geographic miles. . . ." Flinders appears to be calculating distance using a presumed speed of sound of 1.142 ft. per second and 6,060 ft. to the geographic mile. Speed of sound and the length of the geographic mile have changed a number of times in intervening years.

The ephemeris was keenly studied and on 14 March 1802 he observed the solar eclipse through "a refracting telescope of forty-six inches focus, and a power of about two hundred. . . ." All through the Northern spring of 1802 as Thomas Jefferson and Meriwether Lewis struggled to formulate their great expedition, and Lewis was tutored in the use of a sextant, the southern coast of Australia was slowly taking shape on the charts of Lt. Matthew Flinders. He arrived in Sydney on May 8, 1802.

In July 1802 he was off on the northern leg of his trip. Up the Queensland coast skirting and charting the Great Barrier Reef, then through Torres Strait, making a detailed chart of the entire top half of Australia before sailing onto Timor. After resupply, he sailed down the Indian Ocean coast of Western Australia into the Great Southern Ocean again, and with the *Investigator* falling apart beneath him, arrived back in Sydney in June 1803 a year after his departure. As Lewis finalised preparations in Washington for his imminent departure to Pittsburgh and the start of his great adventure, Flinders had become the first man to circumnavigate Australia and gave the country the name by which it is known today.

A final note to this great voyage is that it puts to the lie the fact that lunars were discontinued once chronometers were introduced. September 24, 1802 as he coasted through Australia's tropical north Flinders lamented, ". . . on landing at the tents, I found to my no less surprise than regret, that the time keepers had again been let down, and no more than one day's rates had been since obtained. Twenty-five sets of distances of the sun and moon had been taken to correspond with an equal number on the opposite side. . . ." The officer in charge, intent on this large number of observations either side of noon, simply forgot to wind the chronometers. It was back to the artificial horizon and the Lunar Distance Tables. There was simply no other way to establish time or check ratings at that period in history.

It is further worth noting that the chart drawn up by Flinders of the north coast of Australia in 1802/3 and updated later by Capt. Philip Parker King remained in service with the Royal Australian Navy until the 1950's. It was this chart, stitched together with the help of artificial horizon and Lunar Distance Tables, which the Australian armed forces relied on to defend our long coastline as the Japanese pushed south in World War II - a fitting tribute to a great navigator.

Kieran Kelly was Commander and navigator of the North Australian Expedition 1999 on which he used a Dolland mercury pan Artificial Horizon manufactured in London in about 1850. He wishes to thank Bruce Stark for reviewing this paper and making suggestions. Bruce wrote:

"It's interesting to me that Flinders worked out the first way of adjusting a magnetic compass. Here's a quote from page 10 of my 1977 Bowditch: 'But no one knew how to correct a compass for deviation until Captain Matthew Flinders, while on a voyage to Australia in HMS *Investigator* in 1801-02, discovered a method of doing so. Flinders did not understand deviation completely, but the vertical bar he erected to correct for it was part of the solution, and the Flinders bar (art. 720) used today is a memorial to its discoverer.' "

The Lifeboat Sextant in World War II

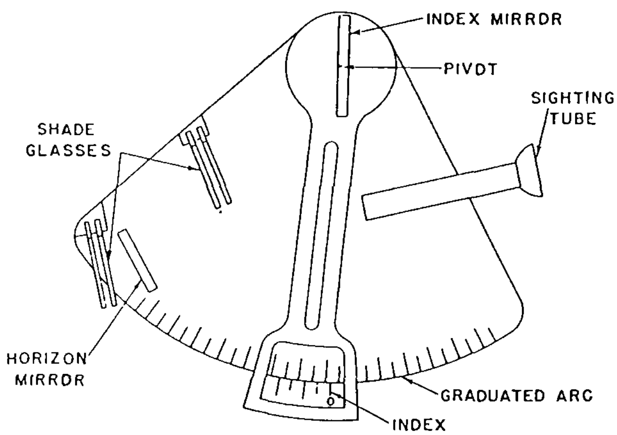
By Captain Warren G. Leback

In late 1943 the Maritime Commission through the War Shipping Administration began to furnish a lifeboat sextant as part of the lifeboat equipment. I am sure there are many of us who remember being trained in its use. More importantly there are probably still alive those who had to use it after their vessels were sunk.

The lifeboat sextant was stored in a more or less watertight box clearly marked as property of the Maritime Commission. Besides the sextant, the box contained:

. One (1) pair of six (6) inch parallel ruler
. One (1) pair of dividers
. Two (2) pencils
. One (1) eraser
. One (1) note pad
. One (1) instruction book

The sextant was constructed out of ribbed gray plastic with two folding handles on the back. In lieu of a telescope, a sighting tube was fitted. An adjustable vernier scale was fitted over the arc. The index arm in addition to the vernier scale carried the index mirror. Two sets of shade glasses were fitted to the arc, one set to reduce sun glare and one set to reduce horizon glare. The horizon mirror was split so as to show the horizon and the reflected image of the sun or star. The sextant is shown below.



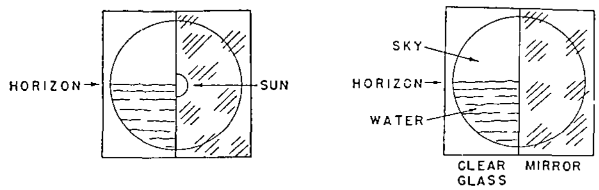
The instruction book was straightforward, concise and written for the novice. The inside of the front cover provided a check off list. On several ships I served on the list was reproduced and posted on the bridge, in the chart room and copies were given to each officer.

The book contained instructions, data, and pertinent comments. The most important instructions covered

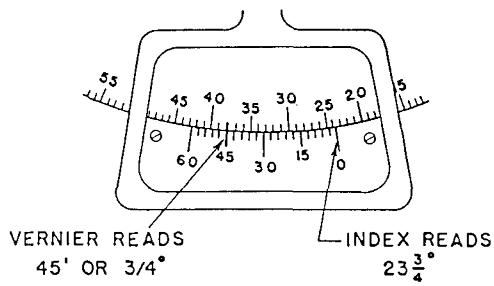
. Latitude from Noon Altitude of the Sun
. Latitude by observation of Polaris (Pole Star)
. Line of Position from observation of the Sun to determine longitude
. Position by observation of two or more stars

If by chance you forgot the chronometer or your watch and the time zone difference east or west of Greenwich, lines of position for longitude position could not be worked. Latitude from observations of the sun's highest altitude and the Pole Star could be determined without Greenwich Civil Time. Bear in mind one could always "run the Latitude down" and reach land.

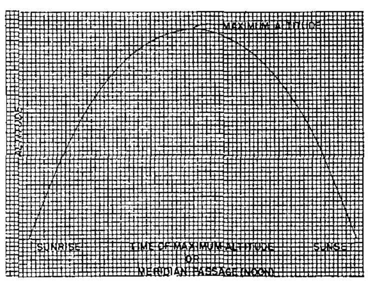
The basic instruction on how to use the sextant was simple and straightforward. The sextant is held in the right hand by the handles on the back of the Arc. Estimate by eye the altitude of the sun or star. An easy method is to look directly overhead then by eye divide the arc into 15 degree segments (total of six segments). Adjust the pivot to the estimated altitude adjusting the pivot until the sun or star is reflected int horizon mirror. Remember the Sun's equator is adjusted to the horizon line. A star is adjusted to the horizon line. This is shown below.



The altitude in degrees is read off the Arc. The minutes are read off the vernier as shown below.



To determine Latitude from the noon local time altitude of the sun, it was recommended the observer take a series of observations of the sun prior to and after the sun reaches the meridian. The observed meridian altitude subtracted from 90° and then combined with the declination of the sun determines the latitude of the observer. The series of observations should be plotted on the graphs provided to insure the maximum altitude is obtained This is shown below.



Latitude can be obtained from observing Polaris's (Pole Star) altitude north of 10 degrees North Latitude. With a one degree error or less the altitude of Polaris equals the observer's Latitude.

Longitude is determined by observing the altitude of the sun or star if the observer knows the correct Greenwich Civil Time at the time of observation. If GCT is not known then longitude cannot be determined. There were several examples of determining longitude which requires considerable practice on the part of the novice navigator.

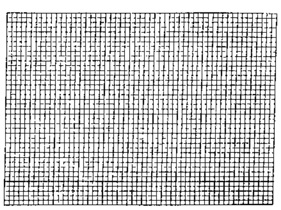
The instruction book provided a simple method of determining direction. Sailing instructions were provided such as how to determine speed of the drifting, rowing or sailing. It also provided the novice on how to determine direction using a compass. All lifeboats had as part of their equipment "Pilot Charts". These charts contained a wealth of information to assist in navigation. It recommended the novice navigator study the charts carefully.

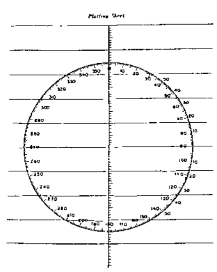
A star chart was included in the book giving the principal stars. This chart provided for star identification. It was useful in determining a rough estimate of the Lifeboat's position.

The following tables were included:

- Table I - Calendar for 1944 and 1945.
- Table II - Declination of the Sun by month and day of month
- Table III - Correction to Sun's Declination at Time of Meridian Passage.
- Table IV - GHA (Greenwich Hour Angle) of the Sun by month and day.
- Table V - Correction to GHA.
- Table VI - GHA by month and day.
- Table VII - Listing of 24 stars giving order of magnitude, their Declination and Sidereal Hour Angle.
- Table VIII - Bearing from north when Rising or Setting for Sun or Stars by month and Latitude
- Table XI - Altitude and Azimuth by Latitude Increments.

Plotting Sheets, Graph Paper and scratch pad were provided. The Plotting Sheet and the Graph is shown below.





There was a check-off list plus some suggestions when abandoning ship. These were

- Your lifeboat should contain for navigation:
  - Charts
  - Compass
  - Sextant
  - Radio

- If time permits you should take the following:
  - Chronometers, watches, charts and sextants from Chart Room.
  - Know the error of the Chronometer and your own watch.
  - Date, time abandoning ship.
  - Last known position of vessel.

The instruction was as before stated straight forward and concise. It however lacked a paragraph on Dead Reckoning and Plane Sailing.

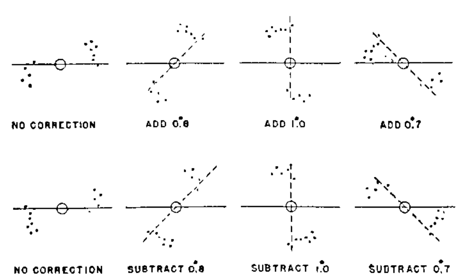
When vessels running in convoy in the North Atlantic were abandoned, ship crews were generally picked up by the Convoy Escorts and Designated Rescue Ships. Vessels sailing in the South Atlantic, Indian and Pacific Oceans generally sailed by themselves. Hence the Sextant and its Navigation Book were useful. When I sailed in the Pacific, we ran by ourselves except for the invasion of Guadalcanal and Okinawa. I sailed with two skippers whose Standing Orders were to post on the Bridge and in the Chart room at the change of each Watch the following:

- Ships' position
- Nearest Landfall, bearing and distance.
- Greenwich Mean Time
- Ship's course and speed

A small roll of charts of the area were readily available when abandoning ship. I am sure many of the merchant marine veterans remember the Lifeboat Sextant. There are occasions on the Internet where lifeboat sextants are listed for sale. The current prices range in area of $150 per sextant. It would be a souvenir from when we were young and sailing in harm's way.

Editor's Notes —

The handbook provided a means of obtaining a more accurate latitude from the Polaris observation by applying a correction to the observed altitude which depends only upon the appearance of the Big Dipper and Cassiopeia. Corrections for the several appearances are shown below.

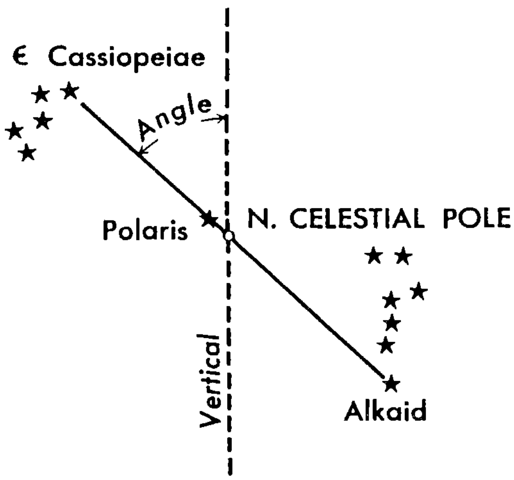


The figures are drawn for angles of 0°, 45° and 90° between the vertical and the line through Cassiopeia and the Dipper. For intermediate positions the angle may be estimated and the correction taken from the following table.

Angle	*Correction*	*Angle*	*Correction*
0°	1°0	50°	0°6
10	1.0	60	0.5
20	0.9	70	0.3
30	0.9	80	0.2
40	0.8	90	0.0

Note that the correction changes very slowly near the time when the correction is greatest, and hence an error in estimation of the position has little effect at this time.

The trailing star of *Cassiopeia* (ε *Cassiopeia*) and Polaris have almost exactly the same SHA. The trailing star of the Big Dipper (Alkaid) is nearly opposite Polaris and ε *Cassiopeia*. These three stars, ε *Cassiopeia*, Polaris, and Alkaid, form a line through the pole (approximately).



When this line is horizontal, there is no correction. When it is vertical, the maximum correction of 56′ (1° in the table above) applies. It should be added to the observed altitude if Alkaid is at the top, and subtracted if ε *Cassiopeia* is at the top.

One of the tables not listed by the author is an inspection type sight reduction table. The entering arguments are latitude in 5° increments from 5° to 60° (Same and Contrary Name); declination in 5° increments from 0° to 30°; meridian angle in 5° increments from 0° to 85°. The respondents are altitude and azimuth angle.

HISTORY OF NAVIGATION

History of the American Nautical Almanac Office

By Steven J. Dick, U.S. Naval Observatory

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory March 3-4, 1999. Courtesy of the author.

(Continued from Issue Sixty-nine)

Washington, D.C.: Transition and Newcomb Era, 1866-1897

The Newcomb era of the Nautical Almanac Office did not begin immediately upon its move to Washington in 1866. Although Simon Newcomb had worked in the Almanac Office in Cambridge beginning in 1857, in 1861 he had transferred to the Naval Observatory, and was busily advancing his career there. But on Joseph Winlock's departure in 1866 to become Director of Harvard College Observatory, Newcomb must have watched with interest as J. H. C. Coffin was made Superintendent of the Almanac Office. One of Maury's earliest recruits to the Naval Observatory in 1845 as a Professor of Mathematics, Coffin had gone on to head the Department of Mathematics at the Naval Academy in 1855, and upon Chauvenet's retirement in 1860 also became head of the Department of Navigation and Astronomy. There was no question at this juncture of the young Newcomb taking the job that eleven years later he would clearly inherit; at the age of 30 he had only nine years of experience and had not yet made a reputation. Thus it was Coffin who would inherit the work of Davis and Winlock at the Nautical Almanac Office, a work that he shepherded over the next twelve years. By one account, as evidenced in the volumes of the Almanac from 1869-1880, Coffin's influence "although appreciable, cannot be called great. New positions of the standard stars were introduced on more than one occasion and 'changes of detail have from time to time been introduced into the work, but the general plan has remained unaltered.'"[13] Coffin's work was reputable, but unremarkable, so one could not speak of "the Coffin Era" in any significant way.

The most remarkable event of Coffin's tenure was not in the Almanac itself, but in the office which was moved from Cambridge to rented quarters in Washington in July, 1866. The reasons, which had little to do with Coffin, were as compelling as those that had determined the original location in Cambridge. The most original work of Benjamin Peirce was finished, and the following year Peirce would succeed Bache as Superintendent of the Coast Survey in Washington. Davis, the founder of the Almanac Office, was now head of the Naval Observatory, and he perhaps persuaded the head of the Bureau of Navigation to relocate the Nautical Almanac Office to Washington. Although still not joined with the Naval Observatory, Newcomb undoubtedly took the opportunity of its proximity to visit the office he would one day head.

On Coffin's retirement from the Navy, on September 15, 1877 Simon Newcomb (Figure 4) was named Superintendent of the Nautical Almanac Office. Born in Nova Scotia, in September, 1853, he made his way to a teaching post at a country school at Massey's Cross Roads in Kent County, Maryland, where his father had settled. The following year he moved on to a small school in Sudlersville, Maryland and finally (in 1856) to a tutoring position some 20 miles from Washington, D.C. During this period Newcomb frequented the library of the Smithsonian Institution, met its Secretary, Joseph Henry, by chance in the library, and was recommended to the Coast Survey Office. J. E. Hilgard at the coast Survey in turn recommended him to Winlock at the Nautical Almanac Office in Cambridge, Massachusetts, where Newcomb arrived in January, 1857. It is remarkable that Newcomb to this point was entirely self-taught in mathematics and astronomy, and although he studied under Benjamin Peirce at the Lawrence Scientific School of Harvard in 1857-1858, he remained largely self-taught throughout his life. Newcomb had obtained his position at the Naval Observatory in October 1861, with the defection of several Professors of Mathematics (as well as Superintendent Matthew Maury) to the Southern cause of the Civil War.

The Nautical Almanac Office at the time Newcomb took charge was "a rather dilapidated old dwelling house, about half a mile or less from the observatory, in one of those doubtful regions on the border line between a slum and the lowest order of respectability." The permanent occupants of the office were Newcomb, his senior assistant Mr. Loomis, a proof reader and a messenger. All of the computers worked at their homes. One of Newcomb's first steps was to secure a new office at the top of the new Corcoran Building. The change from the Naval Observatory, Newcomb later recalled, was "one of the happiest of my life." He was now in a position of "recognized responsibility", and because he had complete control of the office he could now plan and carry out the research he desired.[14]

Fig. 4. Simon Newcomb in the 1870's, when he became Superintendent of the Nautical Almanac Office.

And this is exactly what he did, to the extent that Newcomb more than any other man dominates the history of the Nautical Almanac Office, and indeed has been called "the most honored American scientist of his time, wielding unparalleled influence on both professional and popular astronomy[15] Newcomb's name is associated with his work during the 1860's and 1870's with the transit circle, the transit of Venus and the 26 inch refractor at the Naval Observatory. Newcomb's career, however, may only be understood in terms of the central driving force of his last 30 years: placing planetary and satellite motions on a completely uniform system, and thereby raising solar system studies and the theory of gravitation to a new level. This could be carried out under government funding because it meant reforming the entire theoretical and computational basis of the American Ephemeris, a goal which he carried out as Superintendent of the Nautical Almanac Office from 1877 to 1897. Thus Newcomb's seemingly disparate work on the transits of Mercury and Venus, the velocity of light, the constant of nutation, lunar motion and many other subjects may only be understood as part of this grandiose scheme, which encompassed reform of the system of astronomical constants, determinations of the elements of planetary orbits, and the production of tables of motion of the Moon and planets based on the new data. "To endeavor to build up the theory of our whole planetary world on an absolutely homogenous basis of constants was an almost superhuman task," a fellow European scientist remarked in 1899. "One would have been inclined to predict the failure or, at least, only partial success of such a scheme,: the mathematician G. W. Hill wrote on Newcomb's death in 1909, but Professor Newcomb, by his skillful management, came very near to complete success during his lifetime; only tables of the Moon were lacking to the rounding of the plan."[16] Through sheer perseverance — and a good deal of help from dedicated colleagues like Hill — Newcomb largely succeeded in his life's goal

Newcomb's work traces its lineage to the 18th century continental mathematician — especially the third volume of the *Mécanique Céleste* of Laplace, who conceived the method of finding algebraic expressions for the positions of the planets at any time, giving their latitude, longitude and radius vector as a function of time. This method required that at least six of the seven elements of each orbit (such as period and orientation of the ellipse) be derived from observation. Even once these elements were determined, no algebraic expression could give a rigorous solution. Instead, the expression was an infinite series of terms; by using more and more of the terms, one could approach mathematical exactness, but never reach it. Even then, no general expression was applicable to all cases, so that one was needed for the inner planets, one for the Moon, one for Jupiter and Saturn, one for the minor planets, and so on. These expressions were in each case worked out by individual astronomers and mathematicians focusing on one case. Thus Charles Delauney at Paris Observatory and Peter Hansen at Gotha spent significant parts of their careers on the Moon, Lindenau and Alexis Bouvard produced tables lasting through the first half of the 19th century based on Laplace's formulae, and Leverrier undertook the next complete reconstruction of the planets. For the *American Ephemeris* Winlock constructed new tables of Mercury based on the formulae of Leverrier. And in 1872 G. W. Hill constructed new tables for Venus. Old tables, however, were still used for Mars, Jupiter and Saturn. Newcomb's goal, then, was to be able to compute ephemerides from a single uniform and consistent set of data. Just as a single Observatory such as Greenwich adopted consistent methods for observation, Newcomb wished to bring uniformity to the computed positions based on observation. This meant, for example, a uniform set of planetary masses, each determined as accurately as possible, and each used in an adopted best theory.[17]

Best known among Newcomb's assistants was George W. Hill (Figure 5) whom Newcomb called "the greatest master of mathematical astronomy during the last quarter of the nineteenth century"[18] Newcomb assigned Hill the most difficult job of all, the theory of motions of Jupiter and Saturn, made difficult because their great masses and relative proximity caused larger perturbations than in the case of the other planets. Ten years later, he produced his results in volume 4 of the *Astronomical Papers of the American Ephermeris.* Newcomb pointed to the "eminently practical character" of Hill's research, in which he concentrated not so much on elegant formulae but rather on the utmost precision in determination of astronomical quantities. The next ten years of his life were spent on correcting the orbits of Jupiter and Saturn and constructing tables of their motion, after which he returned home. "During the fifteen years of our connection," Newcomb wrote, "there was never the slightest dissension or friction between us."[19]

For this work, Newcomb founded the *Astronomical Papers Prepared for the Use of the American Ephemeris and Nautical Almanac.* In the first volume, published in 1882, Newcomb explicitly stated the purpose of this series of papers as "a systematic determination of the constants of astronomy from the best existing data, a re-investigation of the theories of the celestial motions, and the preparation of tables, formulae, and precepts for the construction of ephemerides, and for other applications of the results." In the Introduction to this volume, Newcomb made the first published announcement of his program. Even though he had it in mind when taking over the Superintendency of the Office in 1877, only now, when Congress and the Navy Department had supplied all the assistance asked for, including a force of eight to twelve computers, did Newcomb feel confident of carrying the program through. At the same time, he set forth the unpublished work now in progress, the program for its continuance, and called for cooperation of astronomers around the world.[20] The first volume, in which four of the six papers were authored by Newcomb himself, demonstrated the variety of topics that would be relevant to Newcomb's program. Newcomb discussed solar eclipses and transit of Mercury observations, compared the theories of the Moon of Hansen and Delaunay, and published his catalogue of 1098 standard reference stars. Albert A. Michelson discussed his experimental determinations of the velocity of light, while G. W. Hill calculated perturbations of Venus on Mercury. By Newcomb's death,. 7 volumes had been published, with most of the papers by Newcomb, with results fully justifying W. W. Campbell's characterization of the volumes collectively as one of the great treasures of astronomy.

The patronage of the Navy and the nation for Newcomb's work is in some ways surprising. Not only was the Almanac Office staff greatly increased in order to undertake Newcomb's program, the *Astronomical Papers* were also published by the Navy's Bureau of Navigation. From the outset Newcomb frankly admitted the limited immediate value of his investigations for practical applications. Existing tables of the planets, he wrote, were "not unsatisfactory" for current purposes; with the exception of the Moon, he saw "every reason to suppose that the tabular positions will serve the purposes for which they are immediately required in navigation and practical astronomy." Newcomb, however, was not satisfied with such a narrow victory over Nature, insisting that "when we take a wider view and consider the general wants of science both now and in the future, we find that in the increasing discordance between theory and observation there is a field which greatly needs to be investigated."[21]

Finally, in 1895 Newcomb's preliminary results were published as *The Elements of the Four Inner Planets and the Fundamental Constants of A*stronomy, completed in 1899 with his publication of the tables of Uranus and Neptune. In the estimation of E. W. Brown at Yale, "this volume gathers together Newcomb's life-work and constitutes his most enduring memorial."[22]

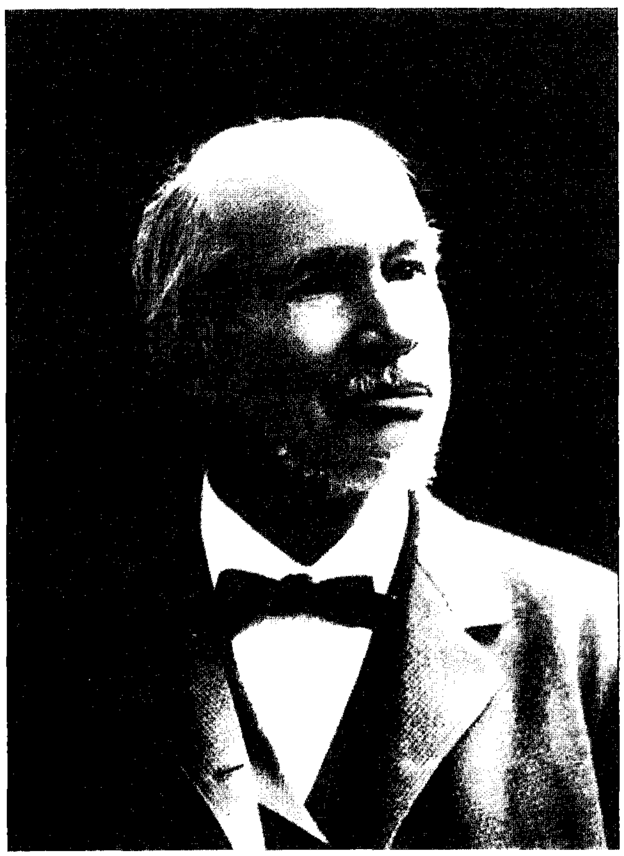


Fig. 5. George W. Hill, master mathematical astronomer, best known for his work on the orbits of Jupiter and Saturn.

In 1896 occurred what Newcomb described as "the most important event in my whole plan", implementing the new system of astronomical constants as determined by Newcomb. David Gill had first suggested in 1894 that a conference be held to stimulate cooperation among the principal almanac offices, and Arthur M. W. Downing, Director of the British Nautical Almanac Office, took the initiative to put together the Paris conference in May 1896. Represented at this meeting were the American, British, German and French Almanac Offices. They agreed that beginning in 1901 Newcomb's constants would be used in the national ephemerides. This decision was harshly attacked by prominent American astronomers, including Lewis Boss and Seth C. Chandler, the editor of the prestigious *Astronomical Journal.* The objections were both practical and technical. Some felt that Almanac Offices should not impose new constants on the astronomical community unless that community asked for them.[23]

Newcomb's great achievement, in the opinion of the eminent astronomer E. W. Brown (who followed up on Newcomb's work by producing tables of the Moon), was not in purely theoretical mathematical investigations, nor in observational astronomy, but in the combination of the two, the comparison of theory and observation. "He was a master, perhaps as great as any that the world has known," Brown wrote, "in deducing from large masses of observations the results which he needed and which would form a basis for comparison with theory." But, Brown noted, Newcomb was not at home in the purely mathematical side of mechanics, where he produced no new methods for dealing with the motions of solar system bodies.[24]

(To be continued)

Notes

13 George C. Comstock, "John Huntington Crane Coffin," *Biographical Memoirs of the National Academy of Sciences,* vol. 8, p. 6.

14 Newcomb, *Reminiscenses,* 214. On the early locations of the Nautical Almanac Office in Washington, see Weber (reference 2 above), 27. According to Weber, the Office was first located in rented quarters, before moving to the State, War and Navy Building (now the Old Executive Office Building, next to the White House) in 1883. See reference 25 below for later moves.

15 The best recent studies of Newcomb are Albert E. Moyer, A Scientist's Voice in American Culture: Simon Newcomb and the Rhetoric of Scientific Method (Berkeley, 1992), and Arthur Norberg, Simon Newcomb and Nineteenth Century Positional Astronomy (PhD Dissertation, University of Wisconsin-Madison, 1974). See also Brian Marsden, "Newcomb," Dictionary of Scientific Biography, vol. 10, 33-36.

16 Loewy, "Simon Newcomb," *Nature,* 60 (May 4, 1899), 1-3; George W. Hill, "Professor Simon Newcomb as an Astronomer," *Science,* Sept. 17, 1909, 353-357.

17 Newcomb, "The Astronomical Ephemeris and Nautical Almanac," in *Sidelights on Astronomy (op. cit.,* reference 5), 191-215.

18 Reminisences, 219.

19 G. W. Hill, "Tables of Jupiter", *Astronomical Papers of the American Ephemeris,* VII, pt. 1 (1895); Newcomb, *Reminiscenses,* 222.

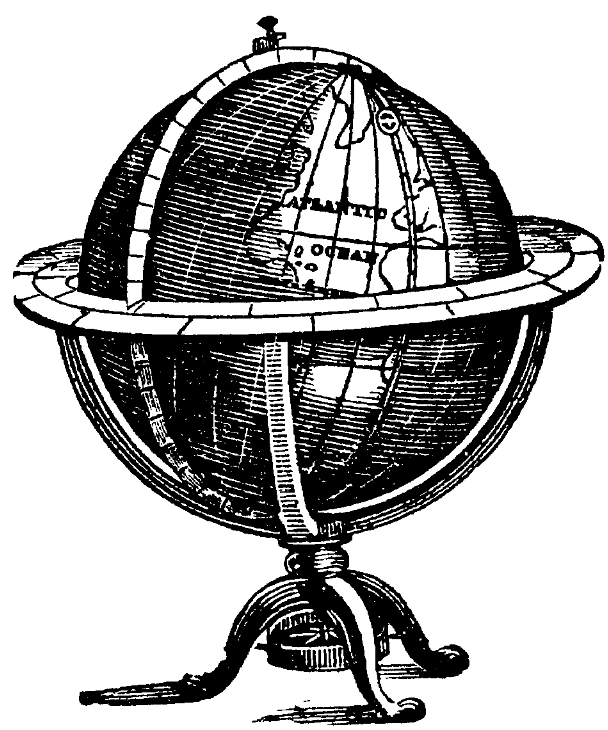
20 Newcomb, *Astronomical Papers of the American Ephemeris* (thereafter APAE), I (Washington, 1882), Prefatory Note, Introduction, x-xi.

21 Newcomb, APAE, I, Introduction.

22 E. W. Brown, "Simon Newcomb," *Bulletin of the American Mathematical Society,* 16 (1910), 341-55: 347.

23 This controversy has been described in Arthur L. Norberg, *Simon Newcomb (op. cit,* reference 15 above), 328-402, and Norberg, "Simon Newcomb's Role in the Astronomical Revolution of the Early Nineteen Hundreds," in *Sky with Ocean Joined,* Steven J. Dick and LeRoy Doggett, eds. (Washington, 1983), 75-88.

24 Brown, (op. cit., Ref. 22 above) 353.



NEWSLETTER INDEX

Index 92 (1-35) published with Issue Thirty-five (1991) is an index covering Issue One through Thirty-five.

Index to Navigation Problems (4-33), published in Issue Thirty-three (Fall 1991), covers navigation problems in Issues Four through Thirty-three.

Index to Navigation Personalities (12-53), published in Issue Fifty-three (Fall 1996), covers personalities in Issues Twelve through Fifty-three.

Index to Book Reviews (36-53), published in Issue Fifty-three (Fall 1996), covers reviews in Issues Thirty-six through Fifty-three.

Index to Navigation Basics Review (13-58), published in Issue Fifty-eight (Winter 1997-98), covers those articles written as reviews of the basics of navigation in Issues Thirteen through Fifty-eight.

Index to Navigation Foundation Peary Project (23-52), published in Issue Fifty-eight (Winter 1997-98), covers articles and comments on the analysis of the data of Robert E. Peary's expedition to the North Pole in 1909 in Issues Twenty-three through Forty-two.

Index to Marine Information Notes (3-60), published in Issue Sixty (Summer 1998), covers only those notes of more lasting interest in Issue Three through Sixty.

Index to Navigation Problems (34-60), published in Issue Sixty, covers navigation problems in Issues Thirty- four through Sixty.

Index to DO YOU KNOW. . .? (36-63), published in Issue Sixty-three (Spring 1999(covers questions in Issues Thirty-six through Sixty-three.

Index to Navigation Notes (1-56), published in Issue Fifty-six (Summer 1997), does not include the navigation problems and history articles previously published in the Navigation Notes section.

Index to Navigation Notes (57-70), published in Issue Seventy (Winter 2000-01) covers Navigation Notes in Issues Fifty-seven through Seventy.

	Box Sextant with Artificial Horizon for Use on Land, Sea, and in the Air	John M. Luykx
Sixty-one	The Peter Ifland Collection of Navigation Instruments	John M. Luykx
	A Wayward Problem	John G. Hocking
	Closed Form Solution of Lat. And Long. with Two Sights	James O. Muirhead
Sixty-two	Spherical Trigonometry in a Gale	Richard S. Preston
	Diagram for Graphical Correction to be Applied to Ex-Meridian Altitudes	
Sixty-three	Announcement of the Nautical Almanac Office Sesquicentennial Symposium 3-5 March 1999	
	The Development of Sight Reduction Tables for Air Navigation	Ernest Brown
Sixty-four	A Simplification of the Method of Lunars	Richard S. Preston
	The Complete On-Board Celestial Navigator	George G. Bennett
Sixty-five	A Field Assessment of Stark's Tables for Clearing the Lunar Distance and Finding GMT by Sextant Observation	Robert Eno
	A Simplification of the Method of Lunars (correction)	Richard S. Preston
	Millennium Madness: 2000 or Bust!	Peter Ifland
	The Development of Sight Reduction Tables for Air Navigation (a continuation)	Ernest Brown
Sixty-six	Lewis & Clark's Equal Altitudes	Bruce Stark
Sixty-seven	Millennium Madness: 2000 or Bust! (a clarification)	Peter Ifland
	The Development of Sight Reduction Tables for Air Navigation (a continuation)	Ernest Brown
	Federal Radionavigation Plan	
	Nautical Astronomy in Lewis and Clark's Day	Bruce Stark
	The Future of Almanac Data in the United States	John A. Bangert
Sixty-eight	Evolution of the Products of the Nautical Almanac Office	Alan D. Fiala
	The Personal Error	Wilson Van Dusen
	Artificial Horizons, Octants, and Back Observations as Used by Lewis and Clark	Richard S. Preston
Sixty-nine	Evolution of the Products of the Nautical Almanac Office (a continuation)	Alan D. Fiala
	The Marine Super Integrating Bubble Sextant	John M. Luykx

Seventy	Artificial Horizons, Lunars and Longitude in Australian Exploration at the Time of Lewis and Clark	Kieran Kelly
	The Lifeboat Sextant in World War II	Capt. Warren G. Leback

Index to History of Navigation (3-54), published in Issue Fifty-four (Winter 1996-97), covers history articles in Issues Three through Fifty-four. This includes articles under the heading Navigation Notes in Issues Three through Seven.

Index to History of Navigation (55-70), published in Issue Seventy (Winter 2000-01) covers history articles in Issues Fifty-five through Seventy.

ISSUE	ARTICLE	AUTHOR
Fifty-five	Determining Longitude by Lunar Distance Observation	John M. Luykx
Fifty-six	Determining Longitude by Lunar Distance Observation: A Simple Solution	John M. Luykx
Sixty-one	Excerpt from *Origins of Geomagnetic Science* (1945) European Origin Now Accepted (as to the possible Chinese origin of the magnetic compass).	
Sixty-two	The Brown-Nassau Spherical Computer	John M. Luykx
Sixty-five	The Development of Sight Reduction Tables for Air Navigation (a continuation)	Ernest Brown
Sixty-six	A Chronology of the Development and Publication of Ephemerides and Almanacs Used for Navigation	Peter Ifland
Sixty-seven	The Tamaya Artificial Horizon Marine Sextant with Six Shot Mechanical Averager	John M. Lukyx
Sixty-nine	History of the American Nautical Almanac Office	Steven J. Dick
Seventy	History of the American Nautical Almanac Office (a continuation)	Steven J. Dick

ANSWER TO DO YOU KNOW

(From page 1)

The navigator of the 1967 commemorative flight in a restored Lockheed Electra L-10, Major William L. Polhemus, in commenting on the 1937 Amelia Earhart flight in *The Quarterly Newsletter of the Institute of Navigation*, Summer 1998, describes the communications equipment available to pilot Amelia Earhart aboard the Lockheed Electra 10-E as a Western Electric supplied HF transmitter and receiver with three preset frequencies (6210-kHz for daylight communications, 3105 kHz for nighttime communications, and 500 kHz for emergency communications) as well as a tunable crystal.

The antenna for 500 kHz emergency communications had been removed in California following an accident.

Although Earhart's direction finder was only capable of receiving within the band 200-1430 kHz when she was in the near vicinity of Howland Island, she requested that USCGC *Itasca* transmit on 7500 kHz for direction finding purposes. She was unable to get an aural null from the series of Morse code letter A transmitted.

Fred Noonan certainly had the ability to get the aircraft close to Howland Island by celestial, but the proper use of the direction finder was essential to a safe landing. The very low elevation of the island coupled with the glare from the rising sun and its reflection on the water, and other factors, made a visual sighting highly improbable.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-ONE, SPRING 2001

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Sticker shock!!!! Wait until you see the new prices charged for NIMA Publications which can now only be purchased through the Government Printing Office. Sight Reduction Table 229 is now priced at $47.00 That is up from $12.50 in December. If you need a 229, try InfoCenter at navtrak@us.hsanet.net (Telephone 301-420-2468) or CelestAir at info@celestaire.com (Telephone 800-727-9785). Maybe they will have them at the old price. If they do not have them, we can get the first 3 volumes from the GPO.

Due to the NIMA Publications being offered by the Government Printing Office and not NOAA, we have had to reduce our discount on all publications now available from the GPO to 15% vice the 20% we gave members in the past. We no longer get the better discount of NOAA.

We will compile a new price list of GPO Publications as soon as they all become available. The change-over has been very slow and there are only 3 volumes of 229 available - 2291, 2292, and 2293. If you have a computer, the availability of NIMA Publications as well as other GPO products can be found at http://bookstore.gpo.gov. Or you can send me a letter, FAX, telephone call or e-mail and I will get the information for you. My foreign travel for the year is on hold until cool weather returns this fall and I will be checking daily for letters and messages.

Again I must request that members please follow these simple rules when ordering through The Foundation. Send us your order by any means: FAX, letter, telephone, or e-mail. Do not send advance payment as there are so many changes occurring daily in the price of items that it only increases paper work for us and additional check writing for you. Wait for a bill or invoice from us to pay. Items coming from the publisher will have an invoice. Do not pay this invoice. Wait until The Foundation sends you an invoice or bill to pay. If the item is sent from The Foundation and there is an invoice included in the package, that is to be paid. Sometimes because of the frequent changes in the postal rates and the confused names they give for different items, there may not be an invoice in the package. If not, a bill or invoice will be sent as soon as we know the postage or shipping costs. The changes made by the last administration are still being implemented and it is difficult to follow some of them. It requires a little time. Just remember, order anything you need and "WE" will send you a bill or invoice a little later.

Member Ed Popko has provided us with an elegant Celestial Navigation home page on the Internet. Mary Taylor has authored www.celestialnavigation.net, a most wonderful resource. He highly recommends it.

READERS FORUM

Edited by Ernest Brown

Member Peter Ifland sent by e-mail on February 21, 2001:

"I have just put up a web site with a brief text with photographs on "The History of the Sextant" at http://pwifland.tripod.com/historysextant/index.htm. Essentially the same material can still be found at the HELIOS site of The Observatory at the University of Coimbra,

DO YOU KNOW . . .?

By Ernest Brown

How the Nautical Almanac Office made a significant contribution to the defeat of the U-boat during a critical phase of the Battle of the Atlantic?

(Answer at the bottom of page 18.)

referred to in the last issue of the Newsletter, but now you have to go to the 'Arquivo' where this item was filed when the Observatory renewed their site contents at the first of the year. Now see: http://www.mat.uc.pt/~helios/Mestre/arquivo.htm.

— *Peter Ifland.*

NAVIGATION NOTES

A Lewis & Clark Lunar

By Bruce Stark

During the day, on July 17th, 1804, Lewis and Clark took observations for chronometer error, latitude, and variation of the compass. But they didn't get an observation for longitude. The moon was only five days short of being full. By the time she was high enough to be reasonably free of abnormal refraction, she was out of sextant range of the sun.

So about half an hour after dark, Lewis measured a star lunar. The moon was a little west of south. Spica was further west, about 40° away. Neither object was very high.

There are three records of this observation, and no two are exactly the same. Moulton gives Clark's copies on pages 387 and 389 of *The Journals of the Lewis and Clark Expedition, Volume* 2, and Lewis's version of page 390. I've chosen Lewis's as most likely the original.

As was pointed out in the equal altitudes article in issue #66 of the *Newsletter*, it pays to take a critical look at the numbers before you start working with them. You know a lunar distance changes about half a minute of arc for every minute of time, but how well the numbers reflect this will depend on the observer's eyesight and experience, and the progression can be erratic.

Even taking that into account, the last three contacts of this observation are so far out of line that I've discarded them. Here are the remaining five:

Time			Distance		
h	m	s			
8	53	11	41°	51'	—"
"	59	—	"	53	15
9	2	58	"	54	—
"	5	49	"	55	—
"	8	2	"	56	—

Average chronometer reading is 9:01:48
Average sextant reading is 41°53'51".

The equal altitudes observation the captains took that day (issue #66 of the *Newsletter* found the chronometer one minute nine seconds slow on local apparent time at noon. For the purposes of this paper we won't concern ourselves with whether the chronometer had gained or lost a few seconds on LAT in the nine hours since noon.

9:01:48	(average chronometer reading)
+ 1:09	(chronometer slow on LAT)
9:02:57 PM, July 17th	(LAT of lunar observation)

Since we are dealing with navigation as Nathaniel Bowditch knew it, 9:02:57 is *the* time of observation. Local apparent time—not Greenwich time—is *the* time.

That, and what follows, may be easier to understand if you've read "Nautical Astronomy in Lewis and Clark's Day" in issue #67 of the *Newsletter*. Among the things dealt with were:

1) The different ways time and date were reckoned two centuries ago.
2) Why navigators used apparent time—the hour angle of the sun—rather than mean time.
3) Why the term "Well regulated watch" simply meant a watch that had been checked by observation recently, to see how fast or slow it was on local time.
4) Why, even though the *Nautical Almanac* was calculated according to Greenwich apparent time, Greenwich time was *the* time only if you were on the Greenwich meridian.
5) Why, in the old way of thinking, a lunar (or a chronometer regulated to Greenwich) didn't give you the time—it gave you the longitude.
6) Why a rough estimate of Greenwich time was all that was needed for working an observation.

That rough estimate was arrived at by converting dead reckoning longitude into time and applying it to local time.

Rather than going to the trouble of working out Lewis and Clark's dead reckoning, let's suppose it put them at 98° West. Divide 98° by fifteen to get whole hours. Then multiply the leftover degrees by four to get minutes. Or you can use a conversion table. There's one in the present-day *Nautical Almanac*, before the "Increments and corrections" section. No need to bother with seconds.

Longitude is West, so add the converted longitude to local time to find the corresponding time at Greenwich.

9:02:57	July 17th	(time of observation)
6:32:		(For 98° west longitude)
15:35: . .	July 17th	(It's past midnight at Greenwich, but still the 17th in the astronomical way of reckoning)

If altitudes had been taken along with the distances—or before and after, and adjusted to the time of the distance—we could clear the distance, find the comparing distances in the *Almanac* that our distance fell between, and proportion for the exact Greenwich time to fit. The

The Right Ascensions and Declinations of the principal fixed Stars, adapted to the Beginning of the Year 1805.

Names of the Stars.	Right Ascension in Time.	Right Ascension Ann. Var.	Right Ascension in Degrees.	Declination.	An. Var.
	H. M. S.	S.			
Algenib	0 3 12	+ 3·06	0° 47′ 57″	14° 5′ 55″ N.	+20· 0
Schedar	0 29 37	3·31	7 34 15	55 27 43 —	+19·91
Pole Star	0 53 25	12·89	13 21 17	88 15 50 —	+19· 6
Mirach	0 58 51	3·30	14 42 36	34 35 10 —	+19· 4
Almaach	1 52 0	3·62	28 0 0	41 23 18 —	+17·80
α ARIETIS	1 56 12	3·33	29 3 0	22 32 8 —	+17· 5
Menkar	2 52 6	3·12	43 1 24	3 19 11 —	+14· 6
Algol	2 55 31	3 85	43 52 45	40 11 44 —	+14· 4
Pleiades	3 36 6	3·55	54 1 30	23 29 38 —	+12· 0
Hyades	4 8 43	3 39	62 10 45	15 8 50 —	+ 9·60
ALDEBARAN	4 24 44	3·42	66 11 0	16 6 24 —	+8· 1
Capella	5 2 18	4·41	75 34 30	45 47 16 —	+ 5· 0
Bellatrix	5 14 25	3·21	78 40 15	6 9 43 —	+ 4· 0
Betelguese	5 44 37	3 24	86 9 15	7 21 34 —	+ 1· 4
Castor	7 22 8	3 85	110 32 0	32 18 15 —	— 6· 9
Procyon	7 29 5	3·14	112 16 15	5 43 34 —	— 7· 5
POLLUX	7 33 21	3·69	113 20 15	28 29 8 —	— 7· 9
Acubens	8 47 48	3·24	131 57 0	12 36 18 —	—13·30
REGULUS	9 57 58	3·20	149 29 30	12 54 55 —	—17· 2
Lower Pointer	10 49 57	3·74	162 29 1	57 25 49 —	—19· 5
Upper Pointer	10 51 37	3·88	162 54 15	62 48 8 —	—19· 9
Aliath	12 45 30	2·69	191 22 30	57 1 13 —	—19·69
Benetnach	13 39 50	2·39	204 57 30	50 17 32 —	—18, 1
Arcturus	14 6 32	2·72	211 41 15	20 12 10 —	—19· 1
Mirach	14 46 33	2·63	221 42 15	27 54 0 —	—15·67
Alphacca	15 26 27	2·53	231 36 45	27 22 53 N.	—12· 4
Ras Algathi	17 5 45	2·73	256 26 15	14 37 22 N.	— 4· 7
Ras Alagus	17 25 53	2 77	261 28 15	12 42 52 N	— 3· 0
Rustaben	17 52 5	1·39	268 1 15	51 31 5 N.	— 0· 7
Vega	18 30 20	2·03	277 35 0	38 36 27 N.	+ 2· 6
ALTAIR	19 41 15	2 92	295 18 45	8 21 39 N.	+ 8· 5
Deneb	20 34 47	2·03	308 41 45	44 35 22 N.	+12· 5
Alderaimin	21 13 55	1,44	318 28 45	61 45 45 N.	+14·95
Scheat	22 54 19	2·87	343 34 45	27 1 33 N.	+19· 2
MARKAB	22 55 3	2·96	343 45 45	14 9 34 N.	+19· 2
Achernar	1 30 27	2·25	22 36 45	58 18 10 S.	—18· 5
Rigel	5 5 9	2 87	76 17 17	8 26 10 S	— 4· 8
Canopus	6 19 37	1·33	94 54 15	52 35 36 S.	+ 1· 7
Syrius	6 36 33	2·65	99 8 15	16 27 26 S.	+ 4· 3
Alphard	9 17 59	2·93	139 29 45	7 49 10 S.	+15· 2
VIRGIN's SPIKE	13 14 56	3·14	198 44 0	10 8 15 S.	+18· 9
Zubenesch	14 40 6	3 29	220 1 30	15 13 16 S.	+15· 3
Zubenelg	15 6 32	3·22	226 38 0	8 39 12 S.	+13· 8
ANTARES	16 17 28	3·64	244 22 0	25 59 5 S.	+ 8· 7
FOMALHAUT	22 46 50	3·33	341 42 30	30 39 2 S	—18 97

If the places of these stars are wanted for any time before the beginning of the year 1805, multiply the annual variation, both in right ascension and declination, by the number of years before 1805, and subtract the product from the right ascension standing in the table; but the product of the annual variation in declination must be added to, or subtracted from the declination, according as the sign + or — follows it; but for any year after 1805, the variation in right ascension must be added to the right ascension in this table, and the variation in declination must either be added to, or subtracted from it, according as their signs are, to fit the declination to any succeeding year. The annual variation is set down for seconds, and decimals of a second. The stars in the preceding table will be found to correspond with those whose names are marked in the planispheres; for a further description of which, see p. 227.

3 A

Table 1.

Days of the Week.	Days of the Month.	The Moon's Age.	Paſſage Merid.	Right Aſcenſion		Declination.	
				Noon.	*Midnight.*	*Noon.*	*Midnight.*
		D.	H. M.	D. M.	D. M.	D. M.	D. M.
Sun.	1	25	19. 8	17. 0	23.44	12.43 N	15.29 N
M.	2	26	20. 4	30.43	37.58	18. 4	20.25
Tu.	3	27	21. 4	45.28	53.13	22.28	24.11
W.	4	28	22. 8	61.11	69.19	25.29	26.21
Th.	5	29	23.12	77.32	85.46	26.46	26.42
F.	6	1	☌	93.56	101.56	26. 9	25.10
Sa.	7	2	0.14	109.44	117.16	23.46	22. 0
Sun	8	3	1.11	124.31	131.28	19.56	17.37
M.	9	4	2. 3	138. 9	144.35	15. 5	12.25
Tu.	10	5	2.51	150.46	156.46	9.38	6.47
W.	11	6	3.35	162.36	168.19	3.55 N	1. 3 N
Th.	12	7	4.17	173.57	179.31	1.48 S	4.35 S
F.	13	8	4.59	185. 3	190.36	7.17	9.54
Sa.	14	9	5.41	196.12	201.51	12.24	14.47
Sun.	15	10	6.24	207.36	213.27	17. 0	19. 2
M.	16	11	7. 9	219.26	225.33	20.53	22.32
Tu.	17	12	7.57	231.49	238.13	23.56	25. 5
W.	18	13	8.47	244.46	251.26	25.57	26.32
Th.	19	14	9.39	258.11	265. 0	26.48	26.44
F.	20	15	10.31	271.51	278.41	26.21	25.38
Sa.	21	16	11.23	285.30	292.15	24.35	23.14
Sun	22	17	12.14	298.54	305.27	21.34	19.38
M.	23	18	13. 3	311.54	318.15	17.27	15. 2
Tu.	24	19	13.50	324.30	330.40	12.26	9.40
W.	25	20	14.36	336.48	342.53	6.46	3.46 S
Th.	26	21	15.23	348.58	355. 6	0.42 S	2.23 N
F.	27	22	16.11	1.17	7.34	5.28 N	8.30
Sa.	28	23	17. 1	13.59	20.34	11.27	14.10
Sun.	29	24	17.55	27.20	34.19	16.55	19.20
M.	30	25	18.53	41.32	48.58	21.30	23.21
Tu.	31	26	19.54	56.36	64.25	24.50	25.56

Days of the Week.	Days of the Month.	The Moon's Semidiameter.		Hor. Parallax.		Proportional Logarithm.	
		Noon.	*Midnight.*	*Noon.*	*Midnight*		
		M. S.	M. S.	M. S.	M. S.	*Noon.*	*Midn.*
Sun.	1	16.11	16.16	59.25	59.40	4813	4795
M.	2	16.19	16.22	59.53	60. 5	4779	4765
Tu.	3	16.25	16.27	60.15	60.22	4753	4745
W.	4	16.28	16.28	60.27	60.27	4739	4739
Th.	5	16.28	16.26	60.25	60.19	4741	4748
F.	6	16.24	16.20	60.11	59.58	4758	4773
Sa.	7	16.16	16.11	59.42	59.23	4793	4816
Sun.	8	16. 5	15.59	59. 2	58.39	4842	4870
M.	9	15.52	15.46	58.15	57.50	4900	4931
Tu.	10	15.39	15.32	57.25	57. 0	4962	4994
W.	11	15.25	15.19	56.36	56.12	5025	5055
Th.	12	15.13	15. 8	55.51	55.31	5082	5108
F.	13	15. 3	14.59	55.14	54.59	5130	5150
Sa.	14	14.55	14.53	54.46	54.36	5167	5181
Sun.	15	14.51	14.49	54.28	54.23	5191	5198
M.	16	14.48	14.48	54.20	54.20	5202	5202
Tu.	17	14.49	14.50	54.21	54.25	5201	5195
W.	18	14.52	14.54	54.32	54.40	5186	5175
Th.	19	14.56	15. 0	54.50	55. 1	5162	5148
F.	20	15. 3	15. 7	55.15	55.29	5129	5111
Sa.	21	15.11	15.15	55.44	55.59	5091	5072
Sun.	22	15.20	15.24	56.15	56.31	5051	5031
M.	23	15.29	15.33	56.48	57. 4	5009	4989
Tu.	24	15.37	15.41	57.20	57.35	4968	4950
W.	25	15.46	15.49	57.50	58. 4	4931	4913
Th	26	15.53	15.56	58.17	58.29	4897	4882
F.	27	15.59	16. 2	58.41	58.51	4867	4855
Sa.	28	16. 5	16. 7	59. 1	59.10	4843	4832
Sun	29	16.10	16.11	59.19	59.25	4821	4813
M.	30	16.13	16.14	59.31	59.36	4806	4800
Tu.	31	16.15	16.16	59.39	59.41	4797	4794

Table 2.

DISTANCES of MOON's *Center* from SUN, and from STARS *WEST* of her.

Stars Names.	Days	*Noon.*	IIIh.	VIh.	IXh.	*Midnight.*	XVh	XVIIIh.	XXIh.
		D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.
α Pegasi.	1	32.19.43	33.52.16	35.26. 3	37. 0.59	38.37. 1	40.14. 4	41.52. 0	43.30.46
	2	45.10.22	46.50.35	48.31.24	50.12.48	51.54.48	53.37.15	55.20. 7	57. 3.26
	3	58.47. 9	60.31.14	62.15.37	64. 0.17	65.45.13			
α Arietis.	3	- - -	- - -	- - -	- - -	22.13.22	24. 1. 1	25.49. 1	27.37.20
	4	29.25.58	31.14.52	33. 3.56	34.53.12	36.42.38	38.32. 8	40.21.42	42.11.19
	5	44. 1. 0	45.50.42	47.40.20	49.29.55	51.19.30			
The Sun.	9	- - -	- - -	- - -	- - -	- - -	- - -	38.27.58	40. 0.48
	10	41.33.15	43. 5.19	44.37. 1	46. 8.21	47.39.18	49. 9.53	50.40. 6	52. 9.57
	11	53.39.27	55. 8.35	56.37.23	58. 5.50	59.33.57	61. 1.44	62.29.11	63.56.20
	12	65.23. 0	66.49.40	68.15.54	69.41.50	71. 7.29	72.32.52	73.57.59	75.22.52
	13	76.47.28	78.11.51	79.36. 1	80.59.59	82.23.43	83.47.16	85.10.37	86.33.49
	14	87.56.49	89.19.40	90.42.21	92. 4.55	93.27.20	94.49.38	96.11.49	97.33.55
	15	98.55.55	100.17.50	101.39.42	103. 1.29	104.23.13	105.44.53	107. 6.32	108.28. 9
	16	109.49.45	111.11.22	112.32.59	113.54.37	115.16.16	116.37.57	117.59.40	119.21.26
	17	120.43.15							
Regulus.	14	52.47.22	54.17.14	55.46.58	57.16.33	58.46. 0	60.15.20	61.44.34	63.13.42
	15	64.42.44	66.11.42	67.40.36	69. 9.26	70.38.13	72. 6.57	73.35.39	75. 4.19
	16	76.32.58							

Stars Names.	Days	*Noon*	IIIh.	VIh.	IXh.	*Midnight.*	XVh.	XVIIIh.	XXIh.
		D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.
Spica ♍	16	22.37.12	24. 5. 9	25.33.11	27. 1.17	28.29.28	29.57.44	31.20. 6	32.54.33
	17	34.23. 5	35.51.42	37.20.26	38.49.16	40.18.13	41.47.17	43.16.28	44.45.47
	18	46.15.12	47.44.46	49.14.28	50.44.29	52.14.20	53.44.30	55.14.59	56.45.21
	19	58.16. 1	59.46.52	61.17.55	62.49. 9	64.20.33	65.52.10	67.23.58	68.55.59
	20	70.28.11							
Antares.	20	24.37.10	26. 9.44	27.42.31	29.15.31	30.48.43	32.22. 8	33.55.47	35.29.39
	21	37. 3.44	38.38. 3	40.12.36	41.47.22	43.22.22	44.57.35	46.33. 2	48. 8.43
	22	49.44.37	51.20.46	52.57. 8	54.33.44	56.10.33	57.47.36	59.24.52	61. 2.22
	23	62.40. 5	64.18. 1	65.56.10	67.34.32	69.13. 7	70.51.55	72.30.57	74.10.10
	24	75.49.37	77.29.17	79. 9. 8	80.49.12	82.29.28	84. 9.55	85.50.34	87.31.24
	25	89.12.25	90.53.38	92.35. 1	94.16.35	95.58.20	97.40.15	99.22.20	101. 4.36
	26	102.47. 1							
α Aquilæ.	26	54.14.13	55.35.53	56.58.24	58.21.44	59.45.51	61.10.42	62.36.12	64. 2.20
	27	65.29. 6	66.56.23	68.24. 8	69.52.22	71.21. 5	72.50.12	74.19.40	75.49.30
	28	77.19.41	78.50. 9	80.20.52	81.51.50	83.23. 1			
α Pegasi.	28	- - -	- - -	- - -	- - -	35.37.56	37.11.59	38.46.55	40.22.40
	29	41.59. 9	43.36.21	45.14.10	46.52.33	48.31.31	50.10.52	51.50.38	53.30.47
	30	55.11.21	56.52.13	58.33.22	60.14.48	61.56.30	63.38.25	65.20.32	67. 2.51
	31	68.45.22	70.28. 1	72.10.48	73.53.43	75.36.45	77.19.52	79. 3. 5	80.46.21
	A. 1	82.29.41							

Table 3.

difference between that time and the local time of observation, converted to arc, would be the longitude found. That's all there'd be to it.

Moreover, the only elements we'd take from the *Almanac* for clearing the distance would be the Moon's horizontal parallax and semi-diameter. These change so slowly that an error of a couple of hours in our estimated Greenwich time would scarcely affect the outcome.

But, like most navigators on land, Lewis and Clark didn't bother to take altitudes with their lunars. They left them to be calculated later.

For the Moon we'd like to have Greenwich time within about four minutes. An error of five minutes could—in the worst case—cause an error of 2' or 3' in her altitude. That, in some circumstances, might affect the cleared distance. So if the Greenwich time found differs more than four or five minutes from our estimate we should, to be sure of getting the best result, repeat the procedure.

The elements that go into the calculation of an altitude are latitude, declination, and local hour angle.

In finding the local hour angle of a body—other than the Sun—the first step is to determine the "Right ascension of the meridian." RA meridian is the exact east-west position of the celestial sphere above the observer's head at the moment of observation. To find it, add the sun's right ascension to the time.

The page of the 1804 *Almanac* with the Sun's data was reproduced in issue #66 of the *Newsletter*. It lists the Sun's RA as "7:46:06.5 at Greenwich noon on the 17th and 7:50:07.9 at noon on the 18th. I'll leave the reader to interpolate for himself to find that at 15:35:00 Greenwich the Sun's RA would have been 7:48:43. Add this to local time to get RA meridian:

9:02:57	(local apparent time)
7:48:43	(RA Sun)
16:51:40	(RA meridian)

The next step is to find the body's own RA. The *Almanac* didn't give the positions of stars. Navigation manuals did that. I've included a copy of the star table from Moore's *New Practical Navigator*.

No notice was taken, in such tables, of the small, cyclical variations of a star's place during the year. Spica is listed as "Virgin's Spike." I find that on July 17th, 1804 her RA was 13:14:55, and her declination 10°8.'1 south. Using the table in an 1820 edition of Bowditch I get the same results.

The difference between Spica's RA and RA meridian is the star's local hour angle.

16:51:40	(RA meridian)
13:14:55	(RA Spica)
3:36:45	(Spica's local hour angle)

Now that we have Spica's declination and hour angle we'll turn to the Moon.

You'll find the Moon's elements in the *Almanac* pages reproduced here. Hour angles were normally expressed in time, but for some reason the Moon's RA was tabulated in arc.

Her RA was 238°13' at midnight, and 244°46' the following noon. Her declination is 25°5' south at midnight, and 25°57' the following noon.

Our estimated Greenwich time of observation is 15:35:00—three hours and thirty-five minutes past midnight. Again, I'll leave the reader to interpolate for himself rather than take up space with instructions or a table.

I find the Moon's RA was 240°10.'4 which, converted to time, is 16:00:42. Her declination was 25°20.'5 south.

16:51:40	(RA meridian)
16:00:42	(RA Moon)
00:50:58	(Moon's local hour angle)

The only other element we need to calculate the altitudes is the latitude. That, according to Clark's noon observation, was 40°27.'1 North.

Interestingly, that noon observation would have been impossible using a sextant. With the sun's declination so far north the angle between the sun and its reflection in the artificial horizon was too great. Clark used the quadrant. How he could do this is one of the things Richard Preston explains in his article on the quadrant in issue #68.

But to get back to calculating altitudes, the old way of doing it used a set of tables that included "Log rising." Since the reader is unlikely to have such tables I'll use the cosine haversine formula and the tables from a World War II era Bowditch. Norie's Nautical Tables are equally convenient, but the present-day edition expresses hour angle only in arc.

Since the cosine-haversine formula calculates zenith distance you'll have to subtract the result from 90° to get the altitude.

LHA Moon	00:50:58	log hav	8.09036
latitude	40°27.'1 N.	log cos	9.88136
declination	25°20..5 S.	log cos	9.95606
sum, after discarding tens:		log hav	7.92778
equivalent natural hav			0.00847
diff. lat. & dec.	65°47..6	nat hav	0.29498
zenith distance	66°51.'2	nat hav	0.30345
Hc Moon =	23° 8.'8		

To get from line four to line five, look in the "Log.Hav." column of the Haversine table for the nearest value to 7.92778. Next to it, in the "Nat. Hav." column, you'll find 0.00847. Add that to the natural haversine of the difference between latitude and declination and you get the natural haversine of the Moon's zenith distance. Then subtract zenith distance from 90° for her altitude.

Spica's altitude, calculated the same way, is 18°54..7.

Since these calculated altitudes are free of refraction and parallax you should "uncorrect" them before using them to clear the distance. For the star it's as simple as looking up the refraction correction and applying it with reverse sign. But it's more complicated with the Moon—unless you use the "WW" tables in my *Tables for Clearing the Lunar Distance.*

Finally, here is the data for clearing the distance:

Apparent altitude of Spica: 18°57.'5.

Apparent altitude of the Moon's center: 22°20.'7.

Sextant distance: 41°53.'8.

Sextant error (according to Lewis): 8.'7, to be subtracted.

Moon's horizontal parallax, taken from the Almanac: 54.'5.

If you're going to clear the distance without the *Tables for Clearing*, you'll also need to know that the Moon's semidiameter, adjusted for augmentation, is 14.'93.

In past editions of the *Newsletter*, John Luykx and I have each shown ways to clear a lunar, so there's no need to go over it here.

The cleared distance is 41°57.'8.

Spica is west of the Moon. In the *Almanac*, distances of bodies west of the Moon are given on pages X and XI of each month. As you can see from the photocopy of page XI, our distance had to occur on the 17th, between 15 and 18 hours.

In lieu of proportional logs, which are designed for the three hour interval, you can use tables 7 and 8 in the *Tables for Clearing the Lunar Distance.* Just multiply the resulting minutes and seconds by three. Here you'll get 7 minutes, 4 seconds from table 8, which, multiplied by three, is 21 minutes, 12 seconds. So the Greenwich apparent astronomical time, according to Lewis's lunar, was 15:21:12

15:21:12	(time at Greenwich)
9:02:57	(time at Lewis and Clark's camp)
6:18:15	(difference in time)

That difference converts to 94°34' west longitude.

But we started with 98° west longitude. Consequently, we calculated the altitudes using a Greenwich time nearly 14 minutes different from that found by observation. In 14 minutes the Moon's RA and declination change substantially. So we should recalculate the Moon's altitude and rework the lunar.

The star's RA and declination can't have changed at all, and the Sun's RA will have changed only 0.'6 in 14 minutes—too little to be of consequence when calculating an altitude for a lunar. The only elements that have to be taken from the *Almanac* again are the Moon's RA and declination.

As it turns out, recalculating the Moon's altitude is a waste of time. Her orbital motion is nearly perpendicular to her azimuth, and her altitude changes less than 1'. The longitude found remains the same: 94°34' west.

REMARKS AND SPECULATION

I'm not prepared to make a serious analysis of the Corps of Discovery's observations. Both Bob Bergantino and Dick Preston are better fitted for that—and have already done most of the work. My views are based on limited information and are subject to change. But to my mind the big question is: How could Lewis have done so poorly?

Bergantino lists the actual position of the July 17th, 1804 camp as 40°32.'4 north, 95°39' west. Lewis missed his longitude more than a degree. That's twice the maximum error one would expect could occur in a land-based observation.

Mosquitoes could have been much of the problem. No doubt every enterprising mosquito along that stretch of the Missouri was at work on Lewis while he tried to focus his mind on those Moon-star contacts.

The error in latitude probably had a small effect, and the known imperfections in the lunar theory used to compute distances for the *Almanac* may have had an effect too. Also, imperfections built in to the sextant—in the division of the limb and in centering—could have been a factor. But the big uncertainty, as other writers have pointed out, is index error. Anyone who uses a sextant is supposed to know enough to check the index often—and other adjustments occasionally. But from one year to the next, the captains used the index corrections for sextant and quadrant that had been determined in Philadelphia.

As Professor Bergantino has pointed out, Lewis's course in navigation was much too brief. Moreover, while he was trying to absorb nautical astronomy—and everything else from medicine to mineralogy—he was struggling with all the problems of launching the expedition. He can hardly be blamed for not remembering everything he was taught.

The captains knew, before they set out, the altitudes and longitudes of St Lewis, the Mandan villages, and the mouth of the Columbia. Earlier navigators had established those. But, since there is a vast amount of geography between those three anchor points, President Jefferson instructed Lewis to take and record observations. The recorded observations were to be brought back to the United States and worked by an experienced practical astronomer. Clark could then correct his dead reckoning and produce the reliable map Jefferson so much wanted.

It seems to me a well thought out work book could have made up for the inadequacies of Lewis's "crash course." Such a work book could have ignored the complexities of nautical astronomy and coached the explorers in taking and recording observations—doing what Jefferson wanted them to do.

One of Lewis's tutors, Robert Patterson, did write a special set of instructions for him, calling it the *Astronomi-*

cal Notebook. But my view of that document—expressed in mild terms—is that the captains would have been better off without it.

The Millennium

By Allan Bayless

As we all know, the spectacular around-the-world TV coverage of the end of the second millennium and the beginning of the third took place at 2400 31 Dec 1999 = 00001 Jan 2000. This seemed reasonable and is said to suggest an odometer where the old millennium, 1 + 3 nines, rolls over to become the new one, 2 + 3 zero's, or the roll-over that occurs with the change from an old to a new year. Although our newscasters mentioned there were some who said this wasn't the way it worked, they didn't explain further.

To find why it doesn't work this way, we must look back to the year 525 A.D. when a Roman abbot, Dionysius Exiguus (I think this is pronounced Ex-IG-you-us), decided to date a table of the annual dates of Easter according to the date he regarded as that of the birth of Christ rather than the corresponding Diocletian era used previously. In doing so, he innocently sowed the seed of our present difficulty by calling the first year 1 A.D. and the preceding year 1 B.C., omitting year zero. After several centuries, the Christian calendar evolved form Exiguus' tables, still using his convention. And our present civil calendar continues to do so.

Thus, where 1 Jan. A.D. is assumed to be the day of Christ's birth, his first birthday would occur on 1 Jan 2 A.D. (1 + 1). This in contrast to the situation where 1 Jan 0 is his date of birth and his first birthday is then 1 Jan A.D. (0 + 1).

A couple of important points to bear in mind:

1) 1 Jan 1 A.D. is a *special case,* the only one to which Exiguus' convention applies. All subsequent decades begin as a year with a zero its last digit. In this special case, it is necessary to add a digit to the period of time thereafter to arrive at the correct date of centennial or millennium.
2) The end of a given period of 100 or 1000 years and the beginning of the following period will take place at the same time, but the ending of the previous time period and the beginning of the next *appear* to involve different years.

Thus, according to Exiguus, the end of the first millennium occurred at the end of the last day of the 999th year after the first day. Year 1 + 999 years = 2400 31 Dec 1000 and the first day of the beginning of the 2nd millennium at the same moment is called 0000 1 Jan 1001. The end of the second millennium then occurred 1000 years after the end of the first = 2400 31 Dec 2000 = the beginning of the 3rd, 0000 1 Jan 2001, easily remembered as the title of Arthur Clarke's famous book/movie, "2001," - which got it right!

Oddly enough, the centennial preceding the end of the second thousand years was celebrated in the United States 0000 1 Jan 1901 - correctly.

It is interesting that astronomers, who otherwise would have to face this problem daily rather than every hundred years, have long since inserted year 0 in their calendar to eliminate the problem.

Although the U.S. has no specific national calendar designated in its legal code, it adopted the Gregorian calendar by Act of Parliament in the U.K. 1751

HISTORY OF NAVIGATION

History of the American Nautical Almanac Office

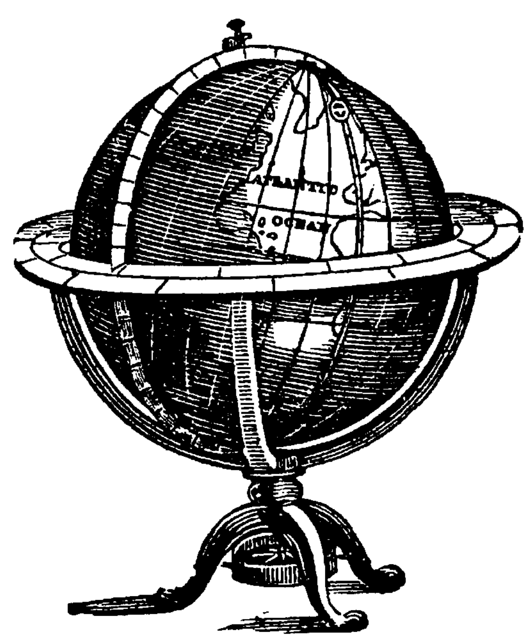
By Steven J. Dick, U.S. Naval Observatory

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory March 3-4, 1999, Courtesy of the author. (Continued from Issue Seventy)

The Nautical Almanac Office of the Naval Observatory: The Twentieth Century

Transition Years

The Nautical Almanac Office, according to conventional wisdom, became a part of the Naval Observatory when the former moved from the northwest corner of



19th and Pennsylvania Avenue to Observatory Circle in 1893. Both politics and personalities, however, made the actual case far from straightforward. The Office did indeed move to Observatory Circle on October 20 of that year, but only a year later, on September 20, 1894, did the Secretary of the Navy issue a regulation making the Nautical Almanac Office a "branch" of the Naval Observatory. And even then the Office was only absorbed into the Observatory over a period of years. According to Naval Observatory Superintendent C. H. Davis II, who should have known, "In 1894 the Nautical Almanac Office, on account of the crowded state of the Navy Department building, was accommodated at the new Observatory, which was first occupied in 1893; but the Almanac has remained a distinct organization, having its own director and independent appropriations. It has never been merged with the Observatory and should not be. This point should be distinctly noted."[25] One needs to remember here that the son of the founder of the Nautical Almanac Office, as well as the Superintendent of the USNO, is speaking. Indeed one finds in the Observatory's Annual Reports after 1894 that the title transforms from Superintendent to Director of the Nautical Almanac Office. But ambiguity remained as to whether the Office was a Department of the Observatory. We can well imagine that Simon Newcomb, who did not retire until 1897, chafed at becoming a part of the Naval Observatory. It was not only the natural inclination that the Superintendent of an independent institution did not wish to become subsumed under another institution, especially one he had anxiously departed 20 years before. There was also the personal matter that the Astronomical Director at the Naval Observatory was William Harkness, long ago Newcomb's best man at his wedding, but now a bitter enemy thanks to the transit of Venus and other controversies. Harkness (Figure 6) would have been Newcomb's boss at the new site, but one can well imagine that Harkness did not give many orders to Newcomb. Finally, in a Navy Department decision rendered January 19, 1905, the Nautical Almanac Office was held not to be a separate shore station, and this ruling seems to have settled the matter. Writing in 1928, Naval Observatory Superintendent C. S Freeman stated that "In 1904, the Nautical Almanac Office, which for 10 years had been located in the observatory grounds under general observatory supervision, was definitely incorporated as an integral part of the observatory organization and has functioned as a department of the organization ever since."[26]

Fig. 6. William Harkness, first Astronomical Director of the U.S. Naval Observatory, and Director of the Nautical Almanac Office, 1897-1899.

Not surprisingly, even after his retirement, Newcomb's legacy dominated the Nautical Almanac Office, especially until his death in 1909. After Newcomb's retirement in 1897, the position of Director was held by a succession of four Professors of Mathematics in four years (Figure 3), including Harkness. Ironically, Harkness was left with the task of incorporating Newcomb's constants, as adopted at the Paris Conference in 1896, in the Ephemeris for 1901. He was also left with the ensuing controversy; the new constants, he wrote, "met so much opposition among prominent American astronomers that it has been thought best to give in the Ephemeris for 1901 sufficient data to enable either the constants of Struve and Peters or those of the Paris Conference to be used with equal facility, and thus each astronomer is left free to choose for himself which he will employ." This was hardly in the spirit of intended standardization, and eventually Newcomb's constants won out; beginning with the volume for 1912, only Newcomb's constants were used in the body of the book.[27]

The Eichelberger and Robertson Years, 1910-1939

Beginning in 1910 two figures dominated the Nautical Almanac Office until World War II, William S. Eichelberger and A. James Robertson. Though their contributions were very different (Eichelberger's scientific and Robertson's political), their tenure saw no radical changes in the Office or its work.

The appointment of William S. Eichelberger as Director in 1910 brought stability back to the Nautical Almanac Office; during a tenure of almost 20 years, Eichelberger earned the respect not only of his colleagues but also of the wider astronomical community, extending to his activities in the nascent International Astronomical Union, where he was President of commission 4 on Ephermerides in 1925. Eichelberger (Figure 7) had obtained his PhD in astronomy from Johns Hopkins in 1891, and came to the Naval Observatory in 1896. In 1900 he passed the competitive exam to become a Professor of Mathematics (taking the place of Harkness) and advanced to the rank of Captain in 1920.

Fig. 7. William S. Eichelberger, Director of the Nautical Almanac Office, 1910-1929

Eichelberger is well-known for his contributions to fundamental meridian astronomy, and especially for his catalogue of *Positions and Proper Motions of 1504 Standard Stars* (1925), adopted as the standard by the IAU in 1925 and used by the national ephermerides until 1940

Two themes stand out in Eichelberger's tenure: international cooperation and small, but significant, changes to the *Almanac*. Already at the beginning of Eichelberger's tenure, the issue of international cooperation came to the fore. A program of exchange of data had been recommended at the International Congress in Paris in 1911, and the following year the naval appropriation bill approved by Congress authorized the Secretary of the Navy "to arrange for the exchange of data with such foreign almanac offices as he may from time to time deem desirable, with a view to reducing the amount of duplication of work in preparing the different national nautical and astronomical almanacs and increasing the total data which may be of use to navigators and astronomers available for publication in the American Ephemeris and Nautical Almanac." The United States did have some reservations, however, as evident in a clause stating that the agreement could be terminated on one year's notice. One of the reservations was the use of the Greenwich meridian, which had been used from the beginning for nautical purposes. The Navy wished to reserve the right to use the meridian of Washington for certain ephemerides. On the positive side, however, Eichelberger noted that data exchanges should allow more time to devote to original research. In fact, beginning with the volumes for 1916, the computations were shared by the nautical almanac offices of France, Great Britain, Germany and the United States.[28]

Changes made to the Almanac during Eichelberger's years were mostly technical or stylistic, but interesting landmarks nonetheless. One of the most noticeable (already a *fait accompli* when Eichelberger took office) was the discontinuation of the lunar distance tables beginning in the *Nautical Almanac* for 1912. Inquiries made in 1907 by the Chief of the Bureau of Equipment, showed that "these tables are practically no longer used by the navigators either of the naval service or of the merchant marine."[29] Thus, the chronometer method, which had become the primary method of navigation already by the late 19th century, completely superseded lunar distances. In 1916 Eichelberger initiated another change, tailoring the *Nautical Almanac* to the use of the navigator. The *American Ephemeris* from its beginning had been divided into two distinct parts. The first part was the ephemeris for the use of navigators, which was reprinted as the *Nautical Almanac*. Since 1916 the *Nautical Almanac* was prepared separately from the *Ephemeris* and therefore designed especially for navigators. The precision required for astronomers was replaced by the lesser precision needed for navigation, and the form and arrangement of the Tables were changed.[30] Perhaps the biggest change in content was in the Almanac beginning in 1925, where the civil day beginning at midnight was introduced rather than the day beginning at noon.[31]

With Eichelberger's departure in 1929 a considerable controversy erupted over his successor. Despite many objections from the American astronomical community, that successor would turn out to be A. James Robertson, the Assistant Director of the Office and the first person to assume the Directorship who was not a Professor of

Mathematics, USN. Robertson (Figure 8), the son of one of the first settlers of Washington State, had received his B.S. from the University of Michigan in 1891. He became an assistant in the Nautical Almanac Office in 1893, working under Simon Newcomb.[32] Perhaps his greatest claim to fame was his work on the fifth satellite of Jupiter. Shortly after entering the NAO, Newcomb gave him E. E. Barnard's observations of this satellite, made at Lick Observatory. Robertson derived the elements of its orbit "by the use of formulae he derived for that purpose."[33] Robertson also computed eclipses and occultations, and in 1933 was awarded an honorary doctorate by Georgetown University.

For the entire decade before World War II James Robertson served as Director of the Nautical Almanac Office. As his critics had predicted, however, he seems to have contributed little original to the Office. He was a good "computer" and did see to it that the Almanacs were produced on time and with accuracy, but he did little research. As the Superintendent, J. F . Hellweg no doubt appreciated Robertson's political contacts, which were very useful in budget fights. The scientific community, however, remained skeptical to the end; at his death in 1960 at the age of 92, the man who had boasted of his work with Newcomb, worked at the Nautical Almanac Office for 46 years, and served as its Director for a decade, earned no obituary in any scientific journal.

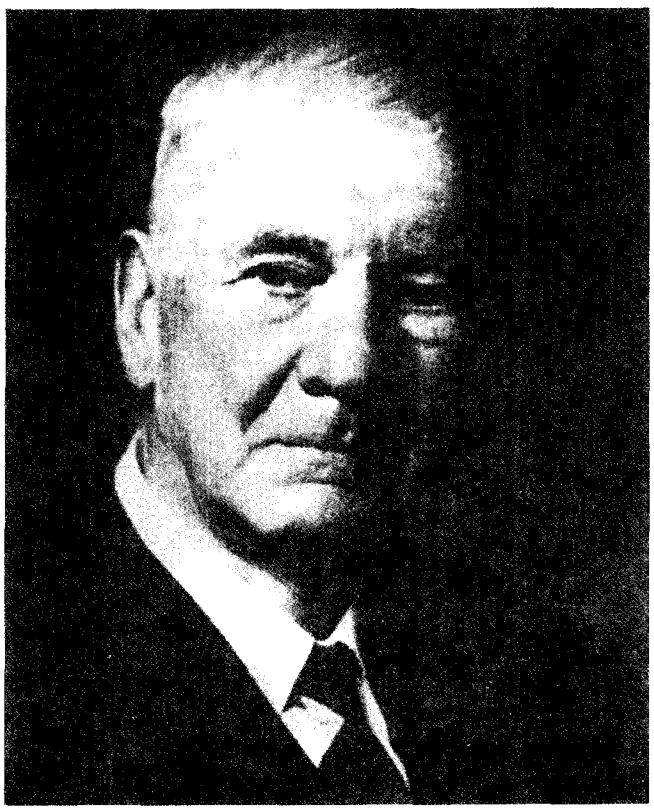


Fig. 8. A. James Robertson, Director of the Nautical Almanac Office, 1929-1939

The Eckert and Clemence Years, 1940-1958

By contrast to the relatively sedate and unprogressive years of Eichelberger and Robertson, World War II set in motion large and irrevocable changes both in production and research. Prior to the Space Age, Wallace J. Eckert and Gerald Clemence oversaw these changes, which were driven by advances in automation and the beginnings of the computer revolution. The departure of Robertson on May 31, 1939 left a gap in leadership at a crucial time as war was stirring in Europe. The Directorship was offered to Yale astronomer, Dirk Brouwer, who declined because the research possibilities at Yale were better. There was, however, a specific need at the Almanac Office that drove the selection process. The methods of the Almanac Office at this time were antiquated; a later Director of the Office recalled: "slide rules, desk calculators, logarithms, Crelle's multiplication tables, things of that sort were being used in order to produce the American Ephemeris and the Nautical Almanac" (Figure 9). The burgeoning Army Air Corps (later transformed into the U. S. Air Force), required a means of navigation as aircraft range became longer and longer. An Air Almanac was needed, indeed had already been experimented with, but with the current methods it would require a large increase in staff. The solution was to hire, on February 1, 1940, Wallace J. Eckert (1902-1971) to head the Office. Eckert (Figure 10),. who obtained his PhD in astronomy from Yale in 1931 under Brown, was one of the pioneers of computing equipment. While a Professor of Celestial Mechanics at Columbia, he had become familiar with the punched-card work of Leslie J. Comrie (1893-1950), the leader of punched-card methods in astronomy and the head of the British Nautical Almanac Office since 1930.[34]

With this background it was natural that Eckert would revolutionize the American Nautical Almanac production methods just as Comrie had a decade earlier for the British Almanac Office. This is exactly what he did with the introduction of punched-card machines, including an IBM tabulator, summary punch, and sorter for the production of the almanacs (Figure 11).[35] The *American Air Almanac* was the first "guinea pig" for the punched-card method. Despite sporadic publications for air navigation through the 1930s, based on the suggestions of P. V. Weems among others, only under Eckert in 1941 did the *American Air Almanac* become a regular publication of the American Nautical Almanac Office. Although in the meantime the German (1935), French (1936) and British (1937) Air Almanacs had begun publication, the American Air Almanac was called "the best-constructed Almanac yet devised for the use of navigators".[36]

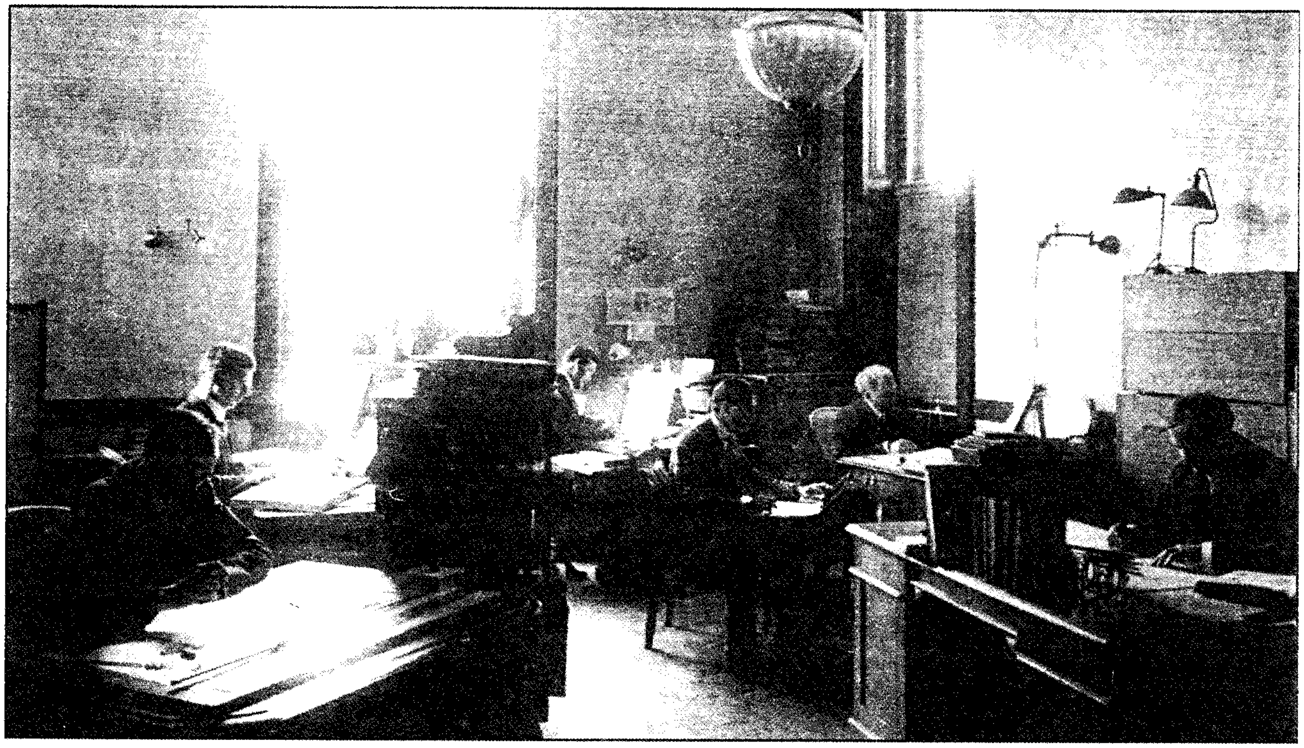


Fig. 9. Nautical Almanac Office personnel, circa 1918, in the days of hand calculators and multiplication tables. The setting is Room W of the Observatory's Main Building. Left to right: Joseph Arnaud, Arthur Snow, Frank Langelotti, Louis Lindsey, James Robertson and Clifford Lewis. Robertson was at this time the Assistant Director of the Office, and was in the room only for the photograph.

Fig. 10. Wallace J. Eckert, Superintendent during the World War II years, introduced punched-card techniques.

Fig. 11. Punched-card machine room, 1941. Helen Smith and Rubye Barnes are running the machines.

The job of automating the preparation of the *American Ephemeris and Nautical Almanac* was led by Paul Herget, an assistant professor of astronomy at the University of Cincinnati who took emergency leave from 1942-1946 in order to help out the Office. As a student at Cincinnati, Herget, like Eckert, had been much affected by Comrie's work on punched-card machines. He would be a pioneer in the application of these machines to astronomical problems. Herget also illustrates how the Office could be pulled to crucial war-time projects using the new techniques. One of the problems was related to heavy Allied submarine losses during the War. By 1943 thirty percent of Allied convoys were being lost to the "wolf pack" tactics of German submarines. Due to fuel shortages, these submarines did not return home immediately after firing their torpedoes, but lay in wait in shipping lanes observing Allied convoys and then radioing to German headquarters the positions of Allied ships. In order to counter this threat, the Allies established more than a hundred listening posts around the world, each keeping constant surveillance for incoming radio messages on a wide spectrum of frequencies. With the solutions of about a quarter million spherical triangles, these observations could locate the submarines within five miles. Because the Nautical Almanac Office had one of the few scientific computation laboratories in the Washington area, in August of 1943, Naval Communications officers visited Eckert and Herget to explain the problem and the possible solution. Herget was assigned the task, assisted only by two "WAVES" from Naval Communications, and the punched-card machinery. They carried out the work 12 hours a day over three months, working at night so that the equipment could be used during the day for the Air Almanac production. By November the book was finished and by December the allied casualty rate for ships was down to 6%. The computations for the "submarine book", Herget stated, "gave him the greatest satisfaction of his lifetime."[37]

During the War years Eckert had revolutionized Almanac Office production methods, but as the War neared its end he decided to move on to the Watson Lab. With Eckert's departure in February, 1945, Brouwer was once again offered the position. Brouwer's decline (and the decision of Assistant Director Paul Herget to return to a position at Cincinnati) paved the way for Gerald Clemence (Figure 12) to take over as Director of the Office.[38]

Fig. 12. Gerald Clemence, Director of the Nautical Almanac Office, 1945-1958. Clemence also served as the first modern Scientific Director of the U.S. Naval Observatory, 1958-1963.

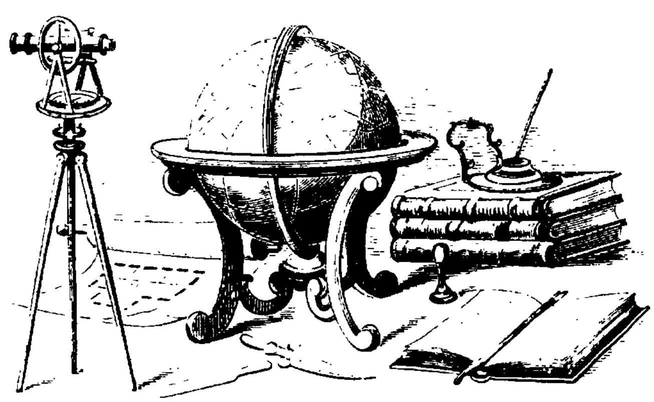
Clemence had obtained his undergraduate degree in mathematics from Brown University in 1930, and came to the Observatory in the same year. He began as a junior astronomer in the Time Service Division through 1937, then an Assistant astronomer in the 9-inch transit circle Division until 1940, working under H. R. Morgan. In 1940 he joined the Almanac Office, where he worked with Eckert and Herget in introducing the new punched-card machines.[39] Clemence's interests went far beyond the routine tasks of Almanac production, tasks that had dominated the office since Newcomb and that War had imposed on Eckert. Clemence was especially interested in the comparison of theory and observations of planetary motions, permitting improvement of the astronomical constants or the planetary theories themselves.[40]

The hallmark of the Clemence era was thus a return to research on the theories of planetary motion. It is not too much to say that Clemence picked up where Newcomb and Hill left off, employing not only a half century of new observations, but also the vastly improved methods, first punched-card and then computer. Already in 1943, Clemence had compared thousands of observations of Mercury from 1765 to 1937 with Newcomb's orbit in order to derive new elements, research published in the same *Astronomical Papers* series where Newcomb's work had appeared..[41] He then tackled the motion of Mars, Newcomb's last and most inadequate planetary project. Finding it needed a complete overhaul, Clemence started from scratch. By 1949 he had published a first-order theory, with the calculations undertaken entirely using punched cards, but he spent 20 years completing the final theory. In 1975, after extensive comparison with observations, Herget characterized the Mars theory as "the most accurate of the general theories for any of the principal planets."[42] In order to compare theory with observation Clemence had to grapple with the problems of time introduced by the variable rotation of the Earth; in this connection the concept of Ephemeris Time became an issue in which he took the lead.

Though much of Clemence's work was undertaken alone, he also had the benefit of a strong collaboration with Dirk Brouwer of Yale, Eckert at the Watson Scientific Computing Laboratory, and Herget in Cincinnati. This collaboration was greatly strengthened in 1947 when the Office of Naval Research (ONR) awarded a long-term contract to Yale, the Naval Observatory and the IBM Watson Laboratory to undertake work on a variety of solar system problems. The rationale behind the work was that more accurate theories and tables could be produced in light of the new computing machinery. The ONR contract, which set the research agenda of the Office for more than a decade, centered on a revision of the motions of the principal planets, including Mars. More specifically, the program consisted of six parts: measurement of photographic plates of Saturn's satellites in order to evaluate the mass of the system; improvement of the theory of Jupiter's Galilean satellites; work on the secular perturbations of Pluto; work on the theory of motion of Jupiter and Saturn to see if the theories of motion of the principal planets can be developed with the same degree of accuracy as the lunar theory; accurate orbits of the first four asteroids; and the theory of the motion of Mars by Hansen's method. One of the first products of this collaboration was *Coordinates of the Five Outer Planets, 1653-2060,* which quickly became the standard source for all research and published ephemerides involving the planets from Jupiter to Pluto. Between 1949 and 1970, some 22 papers were published in the *Astronomical Papers* as a result of this collaboration.[43]

An important aspect to the improvement of theories of planetary motion was the determination of a self-consistent and accurate set of astronomical constants, since the accuracy of all reduction computations for celestial positions depends on the accuracy of values of the astronomical constants used. The introduction of new constants, was, however, a delicate task, as Newcomb had discovered 50 years earlier. While some saw the current system as not completely satisfactory either from the point of view of accuracy or consistency, the practical problem was keeping the amount of recalculation in ephemerides, and in comparison of theory with observation, to a minimum. The problems and potentials of new constants were argued at a seminal meeting in Paris in the Spring of 1950. So controversial was the issue, that only well into the Space Age would new constants be introduced. Improvements to planetary orbits and astronomical constants remained important themes under the Directorships of Ray Duncombe and P. Kenneth Seidelmann. In 1964 the IAU adopted what was known as the "1968 IAU System of Astronomical Constants". Astronomical theory and practice were advancing so fast, however, that by 1970 it was recognized that the ephemerides in national almanacs required improvements, not only in constants, but also in the fundamental star catalog, the definition of time, and even required the replacement of the B1950.0 epoch for the celestial reference system. By international agreement, not until the 1984 editions were all these changes, including a new "1976 IAU System of Astronomical Constants", introduced at one time into the national almanacs. In the end, Newcomb's constants, and his theories and tables for the Sun and the inner planets, were not completely superseded until 1984.[44]

A final hallmark of the Clemence, Duncombe and Seidelmann years is international collaboration. For years Clemence worked with his British counterpart, Donald Sadler, to unify the preparation of the British and American nautical almanacs.[45] As of 1960 the contents of the *American Ephemeris* and of the British *Nautical Almanac* were unified, in accordance with resolutions of the IAU.[46] In 1961 an *Explanatory Supplement to the Astronomical Ephemeris and The American Ephemeris and Nautical Almanac* was also produced; Seidelmann edited a new and completely rewritten *Explanatory Supplement to the Astronomical Almanac*, published in 1992. Most members of the staff of the American Almanac Office in 1966 are shown in figure 13.



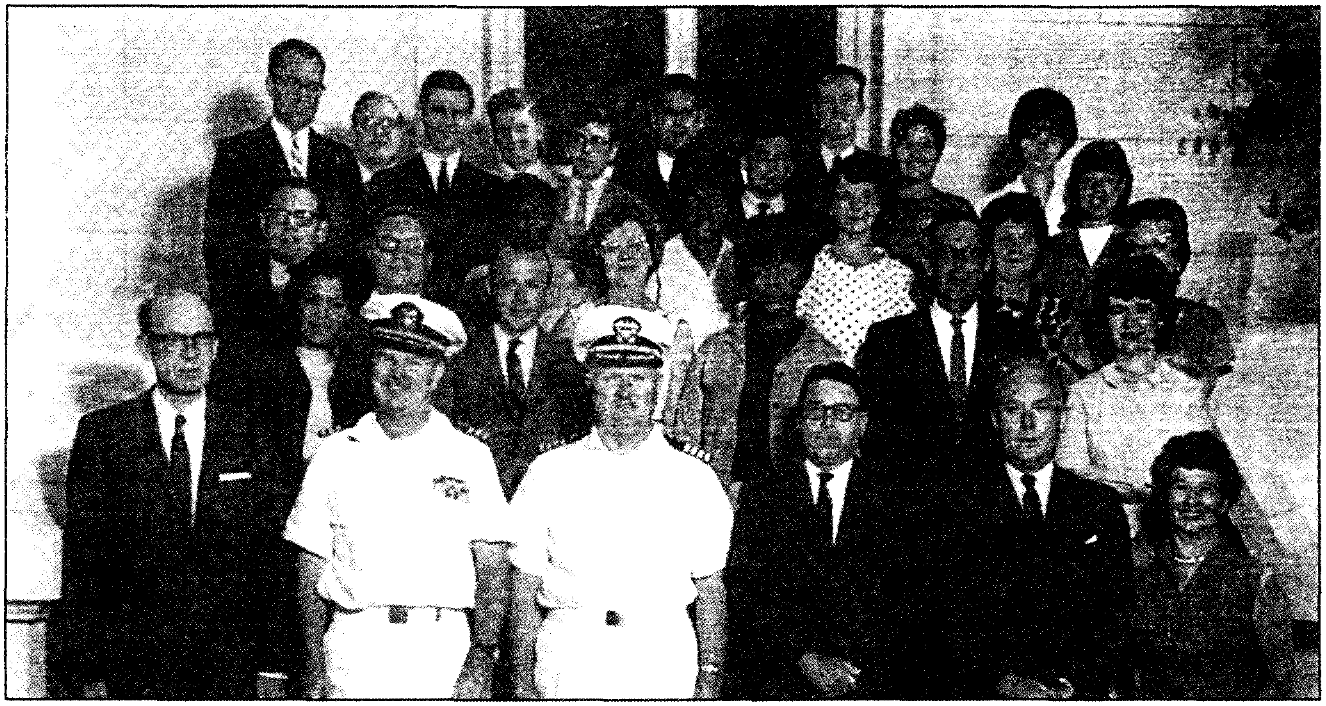


Fig. 13. Nautical Almanac Office staff, summer, 1966. Front row (left to right): Ralph Haupt, Cdr. Stanfill (Deputy Superintendent), Captain McDowell (Superintendent), Raynor Duncombe, Kaj Strand (Scientific Director), Ruth Meyers. Second row: Jean Hampton, Doug O'Handley. Barbara McMorris, Armstrong Thomas, Berenice Morrison. Third row: Alan Fiala, Sol Elvove, Gertrude Johnson, Vivian Holland, Louise Weston, Louise Long, Victoria Meiller. Back row: Ken Seidelmann, Garold Larson, Dan Pascu, Harry Heckathorn III, Lawrence Buc, William Klepczynski, Peter Schultz, George Brown, Diana Simmons, Judy Wise, Joan Bixby.

The Space Age

The beginnings of the Space Age brought the immediate realization that techniques that astronomers had long applied to celestial bodies would now be applied to artificial satellites. The first impact of the Space Age on the Naval Observatory was in the computation of orbits, long the purview of the Nautical Almanac Offices of the world, but now a matter of urgent national concern. The Vanguard project was a Naval Research Lab project, but Clemence and Duncombe served as consultants from the Naval Observatory to that project, where Herget was the principal consultant for orbital computations. By the time the Sputniks went up, Duncombe was loaned almost 100% of the time to the Vanguard project.[47] More generally, the Nautical Almanac Office as the Space Age proceeded "met increasing demands for astronomical data and ephemerides arising from space age requirements of other government agencies and industry."[48] In this, however, they were joined by new players; highly accurate ephemerides of the planets and satellites, critical for space missions, were supplied largely by the Jet Propulsion Laboratory (JPL). The Naval Observatory was slow to adopt new precise observing techniques applicable to ephemerides — radar ranging, Very Long Baseline Interferometry (VLBI), Lunar Laser Ranging, spacecraft ranging and Doppler — and the expertise was built elsewhere, including at JPL, MIT and Goddard Spaceflight Center.

Another trend of the Space Age was the increasing use of electronic computers. Because of its need for computing power, the Almanac Office and its descendants were responsible for computers. An IBM 650 was delivered to the Observatory in July, 1957 and fully operational in August, shortly before the launch of Sputnik. Clemence also played a leading role in transitioning the staff to the new methods. Given this impetus, most of the calculations of the Nautical Almanac Office had been programmed for the 650 by 1958, and other parts of the Observatory were soon to follow.[49] The last IBM 650 was manufactured in 1962, the same year that the Observatory moved on to the next model, the IBM 1410. By 1966 it had acquired an IBM 360 (model 40), and in March 1980 a 4341 replaced the 360. By 1990 the Observatory was engaged in moving all applications off of its two central computers, (an IBM 4381 and a Dec VAX 8530) onto Unix work stations within each Department. And by 1994 the computer support functions were assumed by a new Information Technology Department.[50]

Ironically, a longer-term trend of the Space Age — the use of satellites in Earth orbit as an aid to navigation on Earth — changed navigation radically, and with it the Nautical Almanac Office. With the widespread success and adoption of the Global Positioning System of satellites in the 1990s, celestial navigation became a secondary system. Increasingly navigation depended on the time service, earth rotation, and positional astronomy, all long-standing aspects of work at the Naval Observatory. In 1990 the Nautical Almanac Office underwent a major change "to respond to emerging, specialized needs of the Department of Defense (DoD), the civilian departments of the U. S. government, and the astronomical community for astronomical data." The result was the formation of the Astronomical Application Department (of which the Nautical Almanac Office was a Division), and the Orbital Mechanics Department. The Astronomical Applications Department retained the Almanac production duties and designed new software products, while the Orbital Mechanics Department continued the research function :to develop accurate planetary, lunar and satellite ephemerides and theories, to provide expertise in celestial mechanics and solar system astrometry." By 1995 much of the research function had been subsumed back under the Astronomical Applications Department.[51]

In closing, I must emphasize once again that I have only touched the tip of the iceberg in this brief overview. The history of planetary theories, of ephemerides, of astronomical constants, the contributions of numerous scientists not even mentioned here, the international cooperative efforts in the service of accurate navigation, all deserve further research. The history of the American Nautical Almanac Office needs to be seen in the context of the work of the Almanac Offices of the world, especially Her Majesty's Nautical Almanac Office in Great Britain. While many of those offices are older, perhaps none are so closely intertwined with the emergence of science in their respective countries. Few American scientific institutions can boast the 150 years of uninterrupted work that we now celebrate. The American Nautical Office is therefore an important part of the history of science in the United States.

This paper is dedicated to the memory of LeRoy Doggett (Figure 14), friend, colleague, and Head of the Nautical Almanac Office from 1990 to 1996. He exemplifies the hard work and dedication of his colleagues in the Almanac offices of the world over many years, so that navigation and science might move forward.

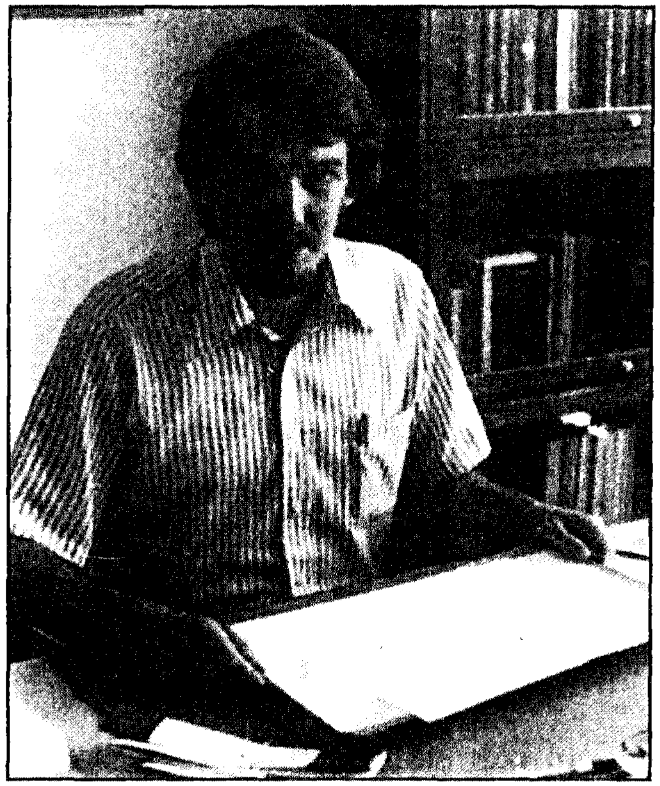
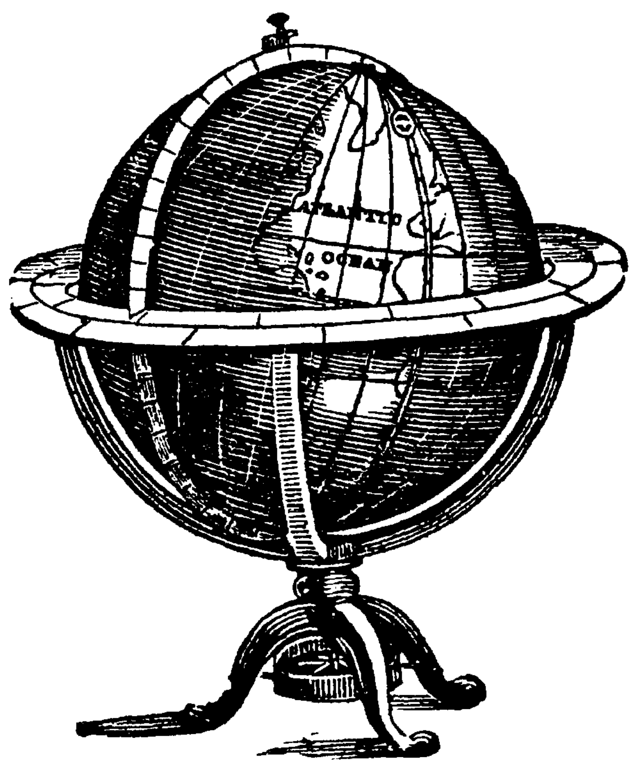


Fig. 14. LeRoy Doggett, Chief of the Nautical Almanac Office, 1990-1996



NOTES

25 [C. H. Davis, II], "Memorandum", U. S. Naval Observatory [USNO] archives, Davis to Colby Chester folder, page 2. From internal evidence the author of the document is certainly C. H. Davis, II, and the date around November 1, 1902, when Chester assumed the Superintendency. On the location of the almanac Office prior to its removal to Observatory Circle see Weber (note 2 above), 27. It had actually been removed from the State, War and Navy Building to the Navy yard in December, 1889, and to rented quarters at 1901 Pennsylvania Avenue in 1890. Weber gives the date of the Almanac Office move to Observatory Circle as October 20, 1893 (p. 27). See also C. B. Watts, "C. B. Watts Recording his Recollections of the Naval Observatory," USNO archives.

26 C. S. Freeman, Annual Report of the Naval Observatory for the Fiscal Year 1928, 22; Weber (op. cit., reference 2), 28.

27 William Harkness, in *Report of the Superintendent of the United States Naval Observatory for the Fiscal Year ending June 30, 1898, 13.* Other changes to the volumes during these years are enumerated in the *Annual Report* for 1899, 19-20. On the 1912 date, see the *Annual Report* for 1908, 14.

28 *Annual Report* for 1912, 12-14. Changes in the Almanacs are also discussed in Edgar W. Woolard, "The Centennial of the American Nautical Almanac Office," *Sky and Telescope* (December, 1951), 27-29.

29 Milton Updegraff, "Preface," in *The American Ephemeris and Nautical Almanac,* November, 1909.

30 Woolard (reference 28), 27-28. Woolard also noted that the Greenwich hour angle was added to the ephemeris of the Moon in 1932, and to the ephemerides of the Sun, planets and stars in 1934. No further changes were implemented until 1950.

31 *Annual Report* for 1923, 12. The evolution of national Almanacs is discussed in P. K. Seidelmann, P. M. Janiczek and R. F. Haupt, "The Almanacs — Yesterday Today and Tomorrow," *Navigation: Journal of the Institute of Navigation*, 24 (1976-1977), 303-312; see also Alan Fiala's "Evolution of the Products of the Nautical Almanac Office,", this volume.

32 Robertson recalled his first meeting with Newcomb, whose office was located in room 566 of the State, War and Navy Building, while his staff labored two blocks away at 19th and Pennsylvania Avenue. See James Robertson, "Highlights in the Career of Simon Newcomb," *Popular Astronomy.* 44 (November, 1936), 471-475; and Robertson "Recollections of Simon Newcomb," *Journal of the Royal Astronomical Society of Canada*, 30 (Dec, 1936), 419-421.

33 Robertson enumerated his accomplishments, including the Jupiter work, in the "Memorandum for Dr. L. M. Lucas," Dec 30, 1936, USNO archives, Robertson folder. A synopsis of the Jupiter work is *Astronomical Journal*, 35, no. 840, Aug 28, 1934.

34 S. Dick Interview with Ray Duncombe, USNO Library. On Eckert see Henry S. Tropp, "Eckert", in *Dictionary of Scientific Biography,* and M. Gutzwiller's paper in this volume.

35 Wallace Eckert, "Punched Card Methods in Scientific Computation," (Thomas J. Watson Scientific Computing Bureau, 1940).

36 *Annual Report* for 1940, 9; W. J. Eckert, "Air Almanacs," *Sky and Telescope,* November, 1944; and Seidelmann et al (reference 33 above). 307-308. *The American Air Almanac* was renamed *The Air Almanac* in 1953.

37 Donald Osterbrock and P. K. Seidelmann, "Paul Herget", *Biographical Notices of the National Academy of Sciences*, 66. On the submarine work, see Herget, "The Submarine Book" June, 1977, Herget file, USNO Archives, and the "Final Coordinates Tracking Charts HO-5405 ... Series," also in the USNO archives.

38 After Eckert's resignation in March 1945 he was "succeeded by G. M. Clemence, Paul Herget becoming assistant director." In March, 1946 Herget "terminated his leave of absence from the University of Cincinnati . . . when he resigned as Assistant Director of the Nautical Almanac Office to assume active direction of the Cincinnati Observatory." Woolard became Assistant Director. *Annual Report* for 1944-45, in *Astronomical Journal*, 51 (1946), 214, and *Annual Report* for 1945-46 in *Astronomical Journal, 52* (1947), 142.

39 On Clemence see Paul Herget, "The Keeper of Mars," Sky and Tel, (April, 1975), 215-216; Clemence, "How to Get Medals", USNO archives, Clemence folder. The latter constitutes a brief but interesting autobiography.

40 Gerald Clemence, "On the System of Astronomical Constants," *Astronomical Journal*, 53 (May, 1948), 169-179.

41 Clemence, The Motion of Mercury, 1765-1937, APAE, XI pt. 1 (1943); *Astronomical Journal*. 50 (1943), 126-127; "The Motion of Mercury," *Sky and Telescope* (Dec, 1947), 7, 31- 33.

42 Clemence, "First-Order Theory of Mars," APAE, XI, pt. 2 (1949); Theory of Mars (Completion), APAE, XVI, pt. 2 (1961).; Paul Herget, "The Keeper of Mars, *Sky and Telescope* (April, 1975), 215-216.

43 W. J. Eckert, Dirk Brouwer and G. M. Clemence, *Coordinates of the Five Outer Planets*, 1653-2060, APAE, 12 (1951); Dorrit Hoffleit, "Yale and USNO Cooperation Especially in the Brouwer and Clemence Era," *Comments on Astrophysics*, 16 (1992), 17-30; 23-24. On the close personal relationship of the three authors, see Paul Herget, "The Keeper of Mars, *Sky and Telescope*, (April, 1975), 216. The first report on the ONR work is in the *Annual Report*, in *Astronomical Journal*, 53 (1948), 151.

44 IAU *Transactions*, 1968; P. K. Seidelmann, ed., *Explanatory Supplement to the Astronomical Almanac* (Mill Valley, CA, 1992), 317 ff.

45 G. Clemence and D. Sadler, "The Conformity of the American Ephemeris and the

(British) Nautical Almanac," *Observatory*, 75 (1955),176; :"Unification of the Abridged Nautical Almanac and the American Nautical Almanac," *Journal of the Institute of Navigation*, 9, 171-176; "Unification of Astronomical and Navigational Ephemerides," *ICSU Review*, 2 (1960), 1-5.

46 Annual Report, in *Astronomical Journal*, 62 (1957), 313.

47 Ibid., 312; Duncombe interview, 18, 32-34, Constance Green and Milton Lomask, *Vanguard: A History* (Washington, 1971), especially Ch. 9, "The Tracking Systems," 145-182: 159-161.

48 Annual Report, in *Astronomical Journal*, 65 (1960), 3.

49 Annual Report, 1957, 313; *Annual Report*, 1958, 379; Astronomical Council minutes, 1956-57, USNO archives; Charles Bashe, Lyle Johnson et al., *IBM's Early Computers* (Cambridge, Mass., 1986), 165-172.

50 Annual Report, *Bulletin of the American Astronomical Society*, 27 (1995), 661.

51 Annual Report, *Bulletin of the American Astronomical Society*, 24 (1992), 589-590.

CORRECTION

Index to Navigation Notes (1-56), published in Issue Fifty-six (Summer 1997): Add to index:

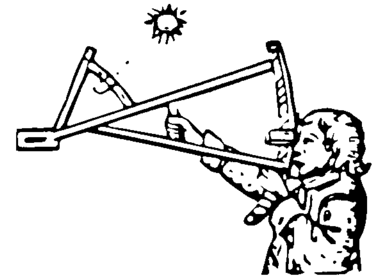
Issue	Article	Author
Forty-six (Winter 1994-95)	Night Sextant Observations	John M. Luykx

ANSWER TO DO YOU KNOW

(From page 1)

See under *The Eckert and Clemence Years, 1940-1958*, **History of the American Nautical Office,** page 13.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-TWO, SUMMER 2001

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

Captain Terry F. Carraway, USN (Ret.) extends his apology to the membership for not being able to take care of their orders, requests and questions these past several weeks.

Captain and Mrs. Carraway have been in Augusta, Georgia with their son who is in the Doctor's Hospital Burn Unit following the crash and burning of the T-34 aircraft in which he was flying.

Captain Carraway's son's attempt to save the owner-pilot added to his own injuries.

The Carraways will remain in Augusta until their son is able to return to Maryland.

READERS FORUM

Edited by Ernest Brown

Member Peter Ifland sent by e-mail on February 21, 2001:

"I have just put up a web site with a brief text with photographs on "The History of the Sextant" at http://pwifland.tripod.com/historysextant/index.htm. Essentially the same material can still be found at the HELIOS site of The Observatory at the University of Coimbra, referred to in the last issue of the Newsletter, but now you have to go to the 'Arquivo' where this item was filed when the Observatory renewed their site contents at the first of the year. Now see: http://www.mat.uc.pt/~helios/Mestre/arquivo.htm." —— *Peter Ifland.*

Editor's Note. — *The above e-mail is repeated for those who may have missed it in Issue Seventy-on.*

NAVIGATION NOTES

The Long-Term Almanac in the 1958-1984 Editions of Bowditch

By Ernest Brown

The long-term almanac in the 1958, 1977, and 1984 editions of the *American Practical Navigator* (Bowditch) was so compact that its use was too time-consuming and error prone for it to be a reliable back-up in the actual practice of navigation. The following example solutions alone should support this observation.

The long-term almanac addressed here was Appendix X in the 1958 edition and Appendix H in the 1977 and 1984 editions. The base year for the 1958 edition was 1956.0; the base year for the 1977 and 1984 editions was 1972.0. The following is from the 1977 and 1984 editions:

> "This appendix is intended for use when a more complete almanac is not available. It is based principally upon the fact that approximately correct values for the Greenwich hour angle and declination of the sun, and the Greenwich hour angle of Aries, can be obtained from an almanac that is exactly four years out of date. The differences in these values at intervals of exactly four years can be largely removed by applying an average correction to the values obtained from the tables of this appendix. The maximum error in an altitude computed by means of this appendix should not exceed 2.'0 for the sun or 1.'3 for stars.
>
> "This four-year, or quadrennial, correc-

DO YOU KNOW . . . ?

By Ernest Brown

The status of the proposal for a three to five years abridged nautical almanac?

(Answer at the back of this issue)

tion varies throughout the year for the GHA of the sun (between about plus and minus one-half of a minute) and for the declination of the sun (between about plus and minus three-fourths of a minute). For the GHA of Aries the quadrennial correction is a constant, (+)1.'84. The appropriate quadrennial correction is applied once for each full four years which has passed since the base year of the tabulation (1972 in this appendix).

"The tabulated values for GHA—175° and declination of the sun and GHA of Aries are given in four columns, labeled 0, 1, 2, and 3. The '0' column contains the data for the leap year in each four-year cycle and the 1, 2, and 3 columns contain data for, respectively, the first, second, and third years following each leap year.

"The GHA—175° and declination of the sun are given at intervals of three days throughout the four-year cycle, except for the final days of each month, when the interval varies between one and four days. Linear interpolation is made between entries to obtain data for a given day. Additional corrections of the GHA of the sun of 15° per hour, 15. per minute, and 15" per second are made to obtain the GHA at a given time. Declination of the sun is obtained to sufficient accuracy by linear interpolation alone.

"The GHA of Aries is given for each month of the four-year cycle. Additional corrections of 0°59.'14 per day, 15°02.'5 per hour, 15.per minute, and 15" per second are made to obtain the GHA at a given time.

"The SHA and declination of 38 navigational stars are given for the base year, 1972.0. Annual (not quadrennial) corrections are made to these data to obtain the values for a given year and tenth of a year.

"A multiplication table is included as an aid in applying corrections to tabulated values."

Example Of The Use Of The Base Year 1972.0 Almanac To Find Greenwich Hour Angle And Declination Of Sun

Example.— Find GHA and declination of sun at GMT $17^h\ 13^m\ 49^s$ on July 18, 1998.

Solution steps are as follows:

Sun tables. 1. Subtract 1972 from the year and divide the difference by four, obtaining *(a)* a whole number, and *(b)* a remainder. Enter column indicated by remainder *(b)* and take out values on either side of given time and date.

2. Multiply quadrennial correction for each value by whole number *(a)* obtained in step 1 and apply to tabulated values plus 175°.

3. Divide difference between corrected values by number of days (usually three) between them to determine daily change.

4. Multiply daily change by number of days and tenths since 0^h GMT of earlier tabulated date, and mark correction plus (+) or minus (-) as appropriate.

5. (GHA only). Enter multiplication table with hours, minutes, and seconds of GMT, and take out corrections *A, B,* and *C,* respectively. These are all positive.

6. Apply corrections of steps 4 and 5 to corrected *earlier* values of step 2.

Solution.—

Step 1: (1998-1972=26); 26â4 = whole number 6 and remainder 2. Using column "2" (of the sun tables), take

APPENDIX H: LONG-TERM ALMANAC

SUN										
0		Quad. GHA Corr.	1		Date	2		Quad. Dec. Corr.	3	
GHA − 175°	Dec.		GHA − 175°	Dec.		GHA − 175°	Dec.		GHA − 175°	Dec.
JULY										
° ′	° ′	′	° ′	° ′		° ′	° ′	′	° ′	° ′
4 04.5	23 07.3 N	− 0.06	4 05.2	23 08.2 N	1	4 05.4	23 09.0 N	− 0.28	4 06.3	23 09.9 N
3 56.1	22 53.5 N	− 0.07	3 56.6	22 54.7 N	4	3 57.0	22 55.8 N	− 0.31	3 57.7	22 57.0 N
3 48.4	22 36.2 N	− 0.05	3 48.8	22 37.6 N	7	3 49.2	22 39.1 N	− 0.34	3 49.8	22 40.5 N
3 41.5	22 15.3 N	− 0.01	3 41.9	22 17.1 N	10	3 42.3	22 18.8 N	− 0.37	3 42.7	22 20.5 N
3 35.5	21 51.0 N	+ 0.03	3 36.0	21 53.0 N	13	3 36.2	21 55.0 N	− 0.39	3 36.4	21 57.0 N
3 30.6	21 23.3 N	+ 0.05	3 31.1	21 25.7 N	16	3 31.1	21 27.9 N	− 0.41	3 31.3	21 30.1 N
3 26.9	20 52.4 N	+ 0.06	3 27.4	20 55.0 N	19	3 27.2	20 57.5 N	− 0.44	3 27.4	21 00.0 N
3 24.5	20 18.3 N	+ 0.04	3 24.9	20 21.2 N	22	3 24.5	20 23.8 N	− 0.47	3 24.7	20 26.6 N
3 23.4	19 41.1 N	+ 0.01	3 23.6	19 44.2 N	25	3 23.0	19 47.1 N	− 0.50	3 23.3	19 50.2 N
3 23.6	19 01.0 N	− 0.02	3 23.6	19 04.3 N	28	3 23.0	19 07.5 N	− 0.54	3 23.1	19 10.8 N

STARS

SHA (1972.0)	Annual Corr.	Star	Dec. (1972.0)	Annual Corr.
° ′	′		° ′	′
315 42.0	−0.57	Acamar	40 25.0 S	−0.24
335 49.9	−0.56	Achernar	57 22.7 S	−0.30
173 44.6	−0.84	Acrux	62 56.6 S	+0.33
291 25.3	−0.86	Aldebaran	16 27.2 N	+0.12
153 23.4	−0.59	Alkaid	49 27.2 N	−0.30
218 26.8	−0.74	Alphard	8 32.2 S	+0.26
126 37.5	−0.64	Alphecca	26 48.5 N	−0.20
358 16.0	−0.78	Alpheratz	28 56.2 N	+0.33
62 38.7	−0.73	Altair	8 47.6 N	+0.16
113 04.7	−0.92	Antares	26 22.3 S	+0.13
146 24.2	−0.68	Arcturus	19 19.6 N	−0.31
108 34.7	−1.59	Atria	68 58.7 S	+0.11
271 35.2	−0.81	Betelgeuse	7 24.2 N	+0.01
264 10.0	−0.33	Canopus	52 40.8 S	+0.03
281 20.7	−1.11	Capella	45 58.3 N	+0.06
49 52.9	−0.51	Deneb	45 10.8 N	+0.22
183 05.5	−0.76	Denebola	14 43.7 N	−0.34
349 27.2	−0.75	Diphda	18 08.4 S	−0.33
194 29.8	−0.92	Dubhe	61 54.2 N	−0.32
34 17.8	−0.71	Enif	9 44.8 N	+0.28
15 58.4	−0.83	Fomalhaut	29 46.3 S	−0.32
328 36.2	−0.85	Hamal	23 19.8 N	+0.28
137 18.4	+0.01	Kochab	74 16.2 N	−0.25
148 44.6	−0.88	Menkent	36 14.0 S	+0.29
309 25.3	−1.07	Mirfak	49 45.8 N	+0.21
76 37.1	−0.93	Nunki	26 20.0 S	−0.08
54 08.4	−1.18	Peacock	56 49.6 S	−0.19
244 05.9	−0.92	Pollux	28 05.7 N	−0.15
245 32.4	−0.78	Procyon	5 17.9 N	−0.16
96 35.5	−0.70	Rasalhague	12 34.8 N	−0.04
208 16.8	−0.80	Regulus	12 06.3 N	−0.29
281 42.1	−0.72	Rigel	8 14.0 S	−0.07
140 41.5	−1.02	Rigil Kent.	60 43.2 S	+0.25
350 16.4	−0.86	Schedar	56 23.0 N	+0.33
259 01.3	−0.66	Sirius	16 40.6 S	+0.08
159 04.3	−0.79	Spica	11 01.0 S	+0.31
223 15.5	−0.55	Suhail	43 19.1 S	+0.24
81 00.2	−0.51	Vega	38 45.4 N	+0.06

ARIES (♈)

0	1	Month	2	3
° ′	° ′		° ′	° ′
98 46.2	99 31.0	Jan.	99 16.7	99 02.4
129 19.5	130 01.4	Feb.	129 50.1	129 35.7
157 54.5	157 40.3	Mar.	157 25.9	157 11.6
188 27.8	188 13.5	Apr.	187 59.2	187 44.9
218 02.0	217 47.7	May	217 33.4	217 19.0
248 35.3	248 21.0	June	248 06.7	217 52.3
278 09.5	277 55.2	July	277 40.9	277 26.5
308 42.8	308 28.5	Aug.	308 14.2	307 59.8
339 16.1	339 01.8	Sept.	338 47.5	338 33.1
8 50.3	8 36.0	Oct.	8 21.6	8 07.3
39 23.6	39 09.2	Nov.	38 54.9	38 40.6
68 57.7	68 43.1	Dec.	68 29.1	68 14.7

MULTIPLICATION TABLE

No.	A	B	C	D	E	F	G
	°	° ′	′	′	° ′	° ′	° ′
1	15	0 15	0.2	1.8	0 59.1	15 02.5	0 15.0
2	30	0 30	0.5	3.7	1 58.3	30 04.9	0 30.1
3	45	0 45	0.8	5.5	2 57.4	45 07.4	0 45.1
4	60	1 00	1.0	7.4	3 56.6	60 09.9	1 00.2
5	75	1 15	1.2	9.2	4 55.7	75 12.3	1 15.2
6	90	1 30	1.5	11.0	5 54.8	90 14.8	1 30.2
7	105	1 45	1.8	12.9	6 54.0	105 17.2	1 45.3
8	120	2 00	2.0	14.7	7 53.1	120 19.7	2 00.3
9	135	2 15	2.2	16.6	8 52.3	135 22.2	2 15.4
10	150	2 30	2.5	18.4	9 51.4	150 24.6	2 30.4
11	165	2 45	2.8	20.2	10 50.5	165 27.1	2 45.5
12	180	3 00	3.0	22.1	11 49.7	180 29.6	3 00.5
13	195	3 15	3.2	23.9	12 48.8	195 32.0	3 15.5
14	210	3 30	3.5	25.8	13 48.0	210 34.5	3 30.6
15	225	3 45	3.8	27.6	14 47.1	225 37.0	3 45.6
16	240	4 00	4.0	29.4	15 46.2	240 39.4	4 00.7
17	255	4 15	4.2	31.3	16 45.4	255 41.9	4 15.7
18	270	4 30	4.5	33.1	17 44.5	270 44.4	4 30.7
19	285	4 45	4.8	35.0	18 43.7	285 46.8	4 45.8
20	300	5 00	5.0	36.8	19 42.8	300 49.3	5 00.8
21	315	5 15	5.2	38.6	20 41.9	315 51.7	5 15.9
22	330	5 30	5.5	40.5	21 41.1	330 54.2	5 30.9
23	345	5 45	5.8	42.3	22 40.2	345 56.7	5 45.9
24	360	6 00	6.0	44.2	23 39.4	360 59.1	6 01.0
25	—	6 15	6.2	46.0	24 38.5	—	6 16.0
26	—	6 30	6.5	47.8	25 37.6	—	6 31.1
27	—	6 45	6.8	49.7	26 36.8	—	6 46.1
28	—	7 00	7.0	51.5	27 35.9	—	7 01.1
29	—	7 15	7.2	53.4	28 35.1	—	7 16.2
30	—	7 30	7.5	55.2	29 34.2	—	7 31.2
31	—	7 45	7.8	57.0	30 33.3	—	7 46.3
32	—	8 00	8.0	58.9	—	—	8 01.3
33	—	8 15	8.2	60.7	—	—	8 16.4
34	—	8 30	8.5	62.6	—	—	8 31.4
35	—	8 45	8.8	64.4	—	—	8 46.4
36	—	9 00	9.0	66.2	—	—	9 01.5
37	—	9 15	9.2	68.1	—	—	9 16.5
38	—	9 30	9.5	69.9	—	—	9 31.6
39	—	9 45	9.8	71.8	—	—	9 46.6
40	—	10 00	10.0	73.6	—	—	10 01.6
41	—	10 15	10.2	75.4	—	—	10 16.7
42	—	10 30	10.5	77.3	—	—	10 31.7
43	—	10 45	10.8	79.1	—	—	10 46.8
44	—	11 00	11.0	81.0	—	—	11 01.8
45	—	11 15	11.2	82.8	—	—	11 16.8
46	—	11 30	11.5	84.6	—	—	11 31.9
47	—	11 45	11.8	86.5	—	—	11 46.9
48	—	12 00	12.0	88.3	—	—	12 02.0
49	—	12 15	12.2	90.2	—	—	12 17.0
50	—	12 30	12.5	92.0	—	—	12 32.1
51	—	12 45	12.8	93.8	—	—	12 47.1
52	—	13 00	13.0	95.7	—	—	13 02.1
53	—	13 15	13.2	97.5	—	—	13 17.2
54	—	13 30	13.5	99.4	—	—	13 32.2
55	—	13 45	13.8	—	—	—	13 47.3
56	—	14 00	14.0	—	—	—	14 02.3
57	—	14 15	14.2	—	—	—	14 17.3
58	—	14 30	14.5	—	—	—	14 32.4
59	—	14 45	14.8	—	—	—	14 47.4
60	—	15 00	15.0	—	—	—	15 02.5

DECIMAL PARTS OF DAY AND YEAR

Decimal	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Hour of Day	0000 to 0112	0112 to 0336	0336 to 0600	0600 to 0824	0824 to 1048	1048 to 1312	1312 to 1536	1536 to 1800	1800 to 2024	2024 to 2248	2248 to 2400
Day of Year	Jan. 1 to Jan. 18	Jan. 19 to Feb. 23	Feb. 24 to Apr. 1	Apr 2 to May 7	May 8 to June 13	June 14 to July 19	July 20 to Aug. 25	Aug. 26 to Sept. 30	Oct. 1 to Nov. 6	Nov. 7 to Dec. 12	Dec. 13 to Dec. 31

out values on both sides of given time and date:

	GHA-175°		Quad. GHA corr.
July 16	3°31.'1	+	0.'05
July 19	3°27.'2	+	0.'06

	Declination	Quad. dec. corr
July 16	21°27.'9 N	-0.'41
July 19	20°57.'5 N	-0.'44

Step 2. —

GHA

July 16	178° 31.'1	+ (6x0.'05)
	+ 0.'3	
	178° 31.'4	*corrected to 0^h July 16, 1998*
July 19	178° 27.'2	+ (6x0.'06)
	+ 0.'4	
	178° 27.'6	*corrected to 0^h July 19, 1998*

Declination

July 16	21° 27.'9 N	- (6x0.'41)
	- 2.'5	
	21° 25.'4 N	*corrected to 0^h July 16, 1998*
July 19	20° 57.'5 N	- (6(0.'44)
	- 2.'6	
	20° 54.'9 N	*corrected to 0^h July 19, 1998*

Step 3. —

GHA

July 16		178° 31.'4
July 19		178° 27.'6
3-day change	(-)	3.'8
daily change	(-)	1.'3

Declination

July 16		21° 25.'4 N
July 19		20° 54.'9 N
3-day change	(-)	30.'5
daily change	(-)	10.'2

Step 4 —

GHA

daily change	(-) 1.'3	x
days & tenths	2.7	
corr.	(-) 3.'5	

Declination

daily change	(-) 10.'2	x
days & tenths	2.7	
corr.	(-) 27.'5	

Steps 5 & 6 — (GHA only)

GHA

corr.		(-) 3.'5	
A	255°	00.0	
B	3	15.0	
C		12.2	
0^h July 16	178°	31.4	(from step 2)
GHA	76°	55.'1	(step 6)

By 1998 *Nautical Almanac*

18^d 17^h	73°	26.'8
13^m 49^s	3	27.3
GHA	76°	54.'1

Step 6 — (Declination only)

	Declination
corr.	(-) 27.'5
0^h July 16	21° 25.'4
declination	20° 57.'9 N

By 1998 *Nautical Almanac*

	Declination	
18^d 17^h	20° 58.'3 N	d (-) 0.'5
d corr.	(-) 0.1	
declination	20° 58.'2 N	

Example Of The Use Of The Base Year 1972.0 Almanac To Find Greenwich Hour Angle And Declination Of Star

For a given Greenwich mean time and date, the almanac is used to find GHA of Aries and the sidereal hour angle (SHA) and declination of the star. The GHA of the star is equal to the GHA of Aries plus the SHA of the star.

Example. — Find the GHA and declination of Spica at GMT 11^h 06^m 33^s on September 9, 2000.

Solution steps for GHA of Aries are as follows:

Aries table. 1. Subtract 1972 from the year and divide the difference by four, obtaining *(a)* a whole number, and *(b)* a remainder. Enter column indicated by remainder *(b)* and take out value for given month.

2. Enter multiplication table with whole number *(a)* of step 1, day of month, hours of GMT, minutes of GMT, and seconds of GMT, and take out corrections *D, E, F, G,* and *C*, respectively.

3. Add values of steps 1 and 2.

Solution for GHA of Aries —

Step 1: (2000-1972=28); 28â4 = whole number 7 and remainder 0. Using column "O" of Aries table for given month, September, extract 339° 16.'1.

Step 2: Enter multiplication table with whole number 7 of step 1, day of month (9), hours of GMT (11), minutes of GMT (6) and seconds of GMT (33), and take out corrections D, E, F, G, and C, respectively.

		GHA of Aries	
Remainder 0 & Sept.		339°16.'1]	Aries table
whole number 7	D	12.'9)	
day of month (9)	E	8° 52.'3)	
hrs of GMT (11)	F	165° 27.'1)	Multiplication
min. of GMT (6)	G	1° 30.'2)	Table
sec. of GMT (33)	C	8.'2)	
GHA of Aries		155° 26.'8	*(Step 3)*

By 2000 *Nautical Almanac*

9^d	11^h	153° 47.'9
6^m	33^s	1 38.5
GHA of Aries		155° 26.'4

Solution steps for SHA and declination of Spica are as follows:

Stars table. 1. Enter table with star name and take out tabulated values.

2. Subtract 1972.0 from given year and tenth; multiply annual correction by difference. Apply as correction (+ or - , as appropriate) to value of step 1.

Step 1:

SPICA SHA (1972.0)	Annual Corr	SPICA Dec. (1972.0)	Annual . Corr.
159°04.'3	(-) 0.'79	11°01.'0 S	(+) 0.'31

Step 2:

From Decimal Parts of Day and Year Table, Sept. 9 yields 0.7 of year.

2000.7-1972.0 = 28.7 = difference

SPICA SHA Corr	SPICA Dec. Corr.
28.7 ((-) 0.'79	28.7 ((+) 0.'31
Corr. (-) 22.'7	Corr. (+) 8.'9

SHA (1972.0) 159° 04.3 Dec (1972.0) 11° 01.'0 S

SHA (2000.7) 158°41.'6 Dec (2000.7) 11° 09.'9 S

By 2000 *Nautical Almanac:*
SHA Spica 158° 42.'1
Dec. Spica 11° 09.'7 S

Solution for GHA of Spica: —
GHA Spica = GHA Aries + SHA Spica
= 155° 26.'8 + 158° 41.'6
GHA Spica = 314° 08.'4

By 2000 *Nautical Almanac:*
GHA Spica = GHA Aries + SHA Aries
= 155° 26.'4 + 158° 42.'1
GHA Spica = 314° 08.'5

A properly designed workform could be used to reduce the tedium of the forgoing data extractions and computations. But certainly with respect to the sun application, one would still not have a practical backup almanac. Geoffrey Kolbe's *Long Term Almanac 2000-2050,* reviewed in this issue, is a practical backup almanac for use at sea.

HISTORY OF NAVIGATION

History of H.M. Nautical Almanac Office

By George A. Wilkins, Superintendent of H.M. Nautical Almanac Office, 1970-1989

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Summary

The British Nautical Almanac Office was established in 1832 as a replacement for the system of home-based computers and comparers that had been used for the production of the *Nautical Almanac* from 1767 onwards. For the next 100 years the Superintendents of the Office, W. S. Stratford, J. R. Hind, A. M. W. Downing and P. H. Cowell, were content to make only occasional improvements to the Almanac. Then L. J. Comrie and his successor, D. H. Sadler, greatly extended the work of the Office by producing additional publications for astronomy, navigation and computing. The Office also acted as an international centre for occultations of stars by the Moon.

The Office joined other departments of the Royal Greenwich Observatory (RGO) at Herstmonceux Castle, Sussex, in 1949. Very strong links with the Nautical Almanac Office of the U. S. Naval Observatory were developed and arrangements were introduced to share the computation and printing of the almanacs and other publications. From 1975 onwards, however, the staff and activities of the U.K. Office were reduced as the role of the RGO was changed.

Prologue

The International bestseller *Longitude* by Dava Sobel[1] claims to be "the true story of a lone genius who solved the greatest scientific problem of his time", but it fails to give a fair account of the way in which the problem of the determination of longitude at sea was also solved by astronomers.

John Harrison, the hero of Dava Sobel's story, solved the problem by making a mechanical chronometer that would keep time at sea to better than two seconds per month, but such chronometers were extremely expensive and did not come into widespread use for another century.

The development of the alternative astronomical method of 'lunar distances' required the efforts of many persons over many years. The founding of the Royal Observatory at Greenwich in 1675 and the subsequent observations by Flamsteed, Halley and Bradley, provided the observational basis for the production by the fifth Astronomer Royal, Nevil Maskelyne, of the first edition of *The Nautical Almanac and Astronomical Ephemeris* for the year 1767[2].

The Almanac contained predicted values of 'lunar distances', that is of the angles between bright stars and the Moon, for comparison with the angles measured by the navigator using a good Hadley's quadrant, or preferably a sextant. It also contained the data that the navigator needed for determining local solar time from observations of the angular elevation (or altitude) of the Sun above the horizon. The navigator also needed a set of *Requisite Tables*, which gave *Instructions for Finding the Longitude at Sea, by the Help of the Ephemeris*, and 'a watch that can be depended upon for keeping the time within a minute for six hours'.

Extracts from the first Almanac and an account of the use of the method of lunar distances are given in a special article[3] in the *Nautical Almanac* for 1967. Further information is given in a booklet[4] and a paper[5] which were prepared at the time of the bicentenary of the issue of the first *Nautical Almanac*.

Maskelyne continued to Be responsible for the production of the *Nautical Almanac* until his death in 1811, when he was succeeded as Astronomer Royal by John Pond. Unfortunately, Pond failed to exercise proper control over the work of preparing the Almanac, and so Thomas Young[6] was made *Superintendent of the Nautical Almanac* in 1818 at the same time as he was made Secretary of the Board of Longitude. It seems surprising that the Almanacs continue to indicate that they were to be printed according to the directions of John Pond.

Young restored the reliability of the Almanac for navigation, but he had made no attempt to make the Almanac more suitable for use by astronomers[7]. When he died in 1829 the task of supervision reverted to Pond until 1831 when Lt. W. S. Stratford[8] was appointed Superintendent. Stratford was then the secretary of the Astronomical Society of London (later the Royal Astronomical Society), which had put forward a series of recommendations for changes to the Almanac[9].

At that time the computations for the Almanac were carried out by persons who worked at home. Each table was calculated independently by two persons and their results were compared by a third person. This system often involved long delays in resolving the discrepancies that occurred. Stratford decided to change this system and set up the *Nautical Almanac Office* in 1832[10].

The first 'century' of the Nautical Almanac Office, 1832-1930

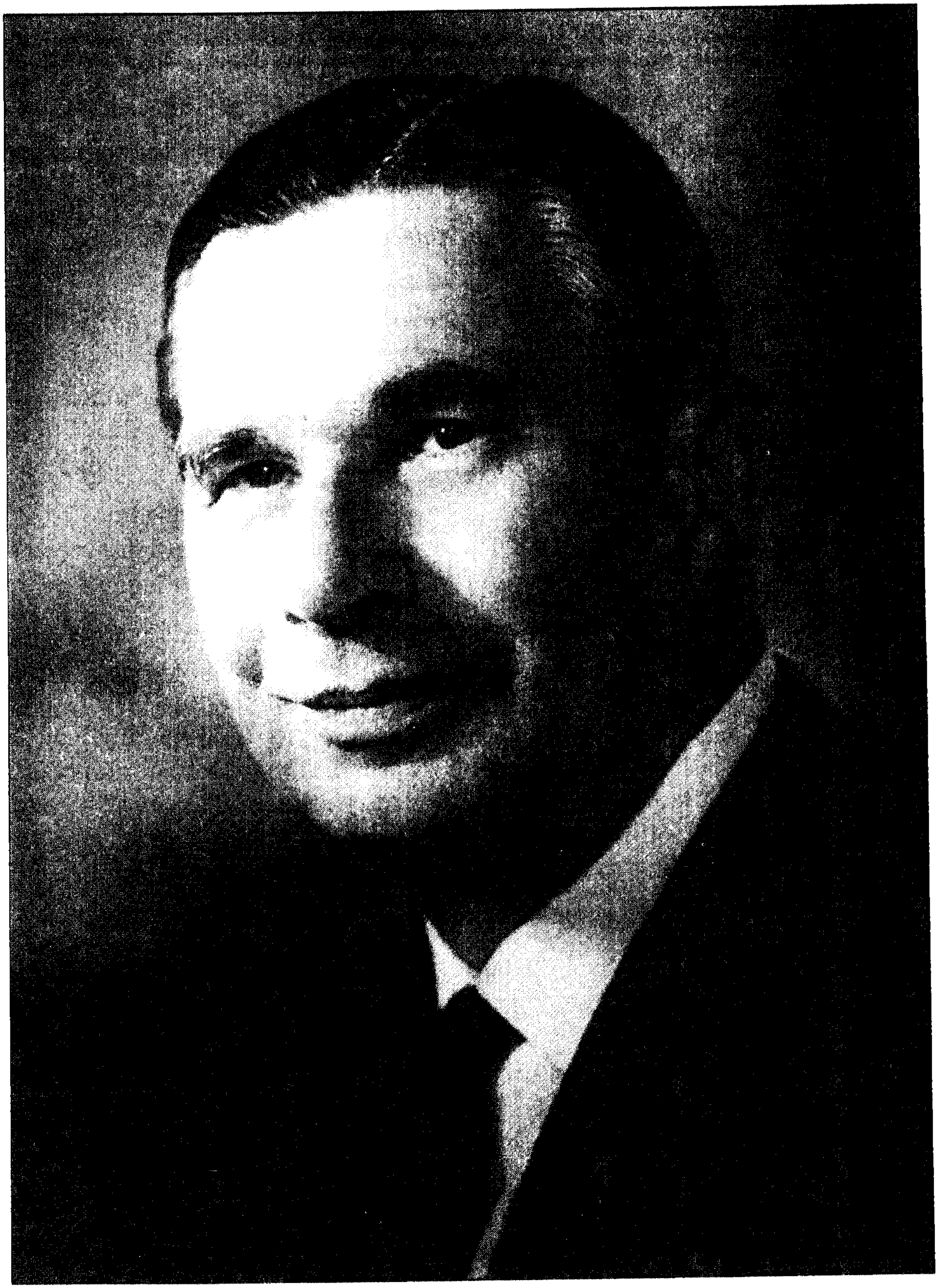
Stratford immediately went to work to implement the recommendations of the Astronomical Society and he introduced many changes into the Almanac for 1834, in which the recommendations were reprinted. One change was the use of Greenwich mean time, rather than apparent time at Greenwich as the argument of the ephemerides. This change recognised the widespread use of mean time by astronomers and the growing use of chronometers for navigation. Nevertheless, many ships continued to rely on the much cheaper method of lunar distances.

For nearly the next 100 years the work of the Office and the Almanac itself gradually evolved without any major changes. Ephemerides of minor planets and comets were soon introduced and later in the century tabulations of the apparent places of stars expanded as they were needed for the accurate determination of time for civil purposes.

Stratford was succeeded in 1853 by John R. Hind[11] who had discovered 10 minor planets. He continued to be the director of a private observatory and was active in the affairs of the Royal Astronomical Society. Hind was Superintendent for 38 years and was followed in 1891 by Arthur M. W. Downing[12], an Irishman who had previously worked at the Royal Observatory.

Under Downing the first part of the Almanac, which contained the data for navigational purposes, was published separately from 1896 onwards. A few years later Downing introduced into the Almanac for 1901 onwards ephemerides based on Simon Newcomb's tables and constants, but without first consulting the Royal Astronomical Society. He was criticised, but his decision was upheld.

The prefix H.M. to the name of he Office first appeared without comment in 1904 in the preface to the Almanac for 1907. We have been unable to find the authority for this change, but neither have we found any objection to it.



Donald H. Sadler, Superintendent, H.M. Nautical Almanac Office, 1937-1970

Philip H. Cowell[13], who succeeded Downing in 1910, had also previously served in the Royal Observatory and had carried out research on the motion of the Moon. He is, however, now best known for the method of numerical integration that is derived from the method used by Cowell and Crommelin[14] for their accurate computation of the orbit of Comet Halley before its return in 1910. He was frustrated by the refusal by the Admiralty of his request for additional staff for research in celestial mechanics and by his failure to obtain a professorship at Cambridge.

From then on Cowell was content to oversee the day-to-day work of the Office, and he made no further attempt to continue, for example, his studies of the motion of the Moon. I do not know to what extent he was responsible for the introduction in 1914 of *The Nautical Almanac, Abridged for the use of seamen.*

The work of the Office attracted the attention of a New Zealander, Leslie John Comrie[15], who had been wounded in the Great War and who had then become an Isaac Newton student at Cambridge, where he obtained his doctorate for a thesis on the occultations of stars by planets. While still at Cambridge, Comrie became the Director of the Computing Section of the British Astronomical Association, which, incidentally, Downing had helped to found for amateur astronomers in 1890. Comrie produced the first edition of *The Handbook of the BAA* for the year 1922, and came to the USA to teach at Swarthmore College and Evanston. In 1925 he returned to England and joined the staff of the NAO; he soon became Deputy Superintendent.

Comrie then completely revolutionised the work of the Office[16a], by first introducing commercial calculating machines to replace the use of logarithms, and then by obtaining the use of punched-card equipment for evaluating the ephemeris of the Moon from E. W. Brown's new theory[17]. At the same time Comrie was redesigning the Almanac so that the edition for 1931, which was issued before Comrie became Superintendent in 1930, contained major changes in content and typography and a much greater amount of explanatory material.

Cowell never used a calculating machine, but he was able to carry out mentally accurate multiplications of 3-figure numbers faster than his assistants could check him using tables. On his 60th birthday he sat at his desk until 12 noon and then walked out without saying a word.

The period of transition 1930 to 1949

Cowell had tended to go back to the old system of paying staff on short-term contracts, but Comrie was anxious to build up the permanent staff of the Office and one of his appointments was of Donald H. Sadler[18], then a 22-year youth from Cambridge with one-year's post-graduate experience of numerical work.

At that time predictions of occultations of stars by the Moon were made by members of the BAA, and one of them, J. D. McNeile had made a machine in wood that acted as an analogue computer. Comrie saw the value of this and arranged for the foreman of the workshop of the Royal Observatory, A. C. S. Westcott, to construct a similar machine in metal. He did the job in his own time for £100. The new occultation machine was used in the NAO for over thirty years.

Details of the machine and of the methods used for the calculations are given in a booklet on the prediction and reduction of occultations[19]. The preface acknowledges the kindness of Dr. James Robertson, the director of the (American) Nautical Almanac Office in communicating the method used in the selection of occulted stars.

Comrie was the first to propose the use of the standard equinox of 1950.0 for the computation of orbits and he designed the first edition of *Planetary Co-ordinates*, which was published in 1933 for the years 1800-1940. Details of methods of interpolation and other numerical processes were published in the booklet *Interpolation and allied tables*, which was printed from stereographic plates of the *Nautical Almanac* for 1937.

Comrie was probably most widely known as a maker of mathematical tables, which were renowned for their accuracy and typographical design. Unfortunately, he failed to make a clear separation between the official work of the NAO and the unofficial work for which he paid staff privately. As a consequence he was summarily dismissed in 1936 after the visit of an Admiralty team which inspected the work of the Office after a request from Comrie for more staff.

Comrie went on to set up the Scientific Computing Service[16b], but he died in 1950 before the era of electronic computers had begun. I regret that I did not meet Comrie, but several members of the NAO staff have written down their recollections of him.

Donald Sadler was made Superintendent, but, possibly because he was still very young, it was decided that he should report to the Astronomer Royal, then H. Spencer Jones (later Sir Harold), who finally produced convincing evidence that the errors in the predicted longitudes of the Moon and planets were due to irregularities in the rotation of the Earth. This had been suspected by Simon Newcomb and others, but there appears to have been a general reluctance to accept this hypothesis, possibly because it was not then possible to explain the mechanism satisfactorily.

Sadler carried through several projects started by Comrie, including the production of the first UK almanac for air navigation (for the end of 1937), the publication in 1939 of the second volume of *Planetary Co-ordinates* (for 1940-1960) and the publication for 1941 onwards of the international almanac *Apparent Places of Fundamental Stars*, for which the calculations were made in several countries. The Office also published *Seven-figure trigonometrical tables for every second of time* in 1939 and *Five-figure tables of natural trigonometric functions* (for every 10 seconds of arc) in 1947.

Surprisingly, the exchange of astronomical calculations continued throughout the second World War, with neutral countries acting as intermediaries. Indeed, the NAO became an international centre for the prediction and reduction of lunar occultations in 1943, with H. W. P. Richards as the head of the section concerned.

The NAO was expanded during the war to produce, for example, 'Bomb Ballistic Tables' and to carry out computations for many other wartime projects. Eventually it became the operational centre for the Admiralty Computing Service[20a]. After the war some of the additional ACS staff moved to the National Physical Laboratory to form the nucleus of its new Mathematics Division[20b].

During this period of intense activity, Sadler found the time and the energy to continue to act as the Secretary of the Royal Astronomical Society. He has given an account of this period in the chapter for the decade 1940-1950 in the history of the Society[21].

After the war, in 1947, Sadler made the first of several visits to Washington, and it is clear that he established a very good working relationship with Gerald Clemence, who was then the Director of the NAO at USNO. These visits, and those of Clemence to England, were usually made in association with attendance at meetings of Working Party 53 of the Air Standardisation Coordinating Committee of the air forces of the USA and British Commonwealth. This visit proved to be the key that opened a long and successful period of cooperation between the two Offices. Most of the rest of my paper is dominated by this cooperation.

The period of unification, 1949-1969

After the move in 1949 of the NAO to Herstmonceux Castle in Sussex to join the recently renamed Royal Greenwich Observatory (RGO), Donald Sadler and Gerald Clemence carried through the unification of the almanacs of the UK and the USA. They had to persuade the navies and the air forces to change their practices in order to arrive at a common content and format, and this was not easy.

The first almanac to be unified was the *Air Almanac*, for the year 1953. From then on, the UK and US editions had a common content, but were printed separately and had different methods of binding. The copy for the daily pages was produced in the USA, while that for the auxiliary and explanatory pages was produced in England; proofreading was shared. Reproducible material was not only exchanged between the two Offices, but was made available very cheaply to other countries for use in their almanacs, either directly or after the language of the headings had been changed.

Sadler was largely responsible for the design of *The Star Almanac for Land Surveyors*, which was first issued for the year 1951 and which is still in use in nearly its original form almost 50 years later! He tried unsuccessfully to persuade Clemence to make this a joint publication.

I joined the NAO in 1951 and, like Sadler, I was then just 22, but I had not attended any astronomical courses at university — I had degrees in physics and mathematics, together with an interest in computing that I had gained while carrying out my PhD research on the daily variations of the Earth's magnetic field. My first jobs were given to me by Sadler so that I would learn about spherical and dynamical astronomy as well as about the computing techniques that were then in use in the Office. At that time, almost everyone had a manual Brunsviga calculating machine on their desks, there were a few electro-mechanical Marchant and Friden machines, two National accounting machines, one for decimal and one for sexagesimal arithmetic, and a set of Hollerith punched-card machines in a separate building.

The punched-card machines were on rental from the British Tabulating Machine Company (BTMC), which at that time had a marketing agreement with IBM and through which the Office acquired an IBM 602A calculating punch. This agreement was broken when IBM decided to compete with BTMC in the UK and the Office then had great difficulty in getting parts and support for the 602A, which was 'programmed' by wiring on a large plugboard, and in getting delivery of an IBM card-controlled typewriter.

One of my first jobs was to plan and oversee the calculation on the punched-card machines of daily values of the nutation in longitude and obliquity from new series that had been developed at USNO by Edgar Woolard. We used the method of 'cyclic packs' that had been developed by Comrie and the results were used in the computation of the *Improved Lunar Ephemeris*, which was published as a Joint Supplement to *The American Ephemeris* and *The (British) Nautical Almanac* in 1954.

1954 was also the year in which Sadler and Miss Flora McBain, who had joined the Office in 1937, were married in secret; the wedding was attended by Sir Harold and Lady Spencer Jones and two former members of the Office. It may be noted that Sadler was a keen and proficient sportsman. The isolated position of Herstmonceux Castle resulted in the RGO having an active Social and Sports Club, in which members of the NAO played a prominent role in the early years.

Sir Harold Spencer Jones retired at the end of 1955 and Richard van de Riet Woolley, then the Director of the Mount Strombo Observatory in Australia, was appointed as the 11th Astronomer Royal. His comment on landing — that space travel was 'utter bilge' — hit the headlines and delighted the cartoonists.

At about this time I was given the job of preparing a completely revised and expanded edition of the booklet *Interpolation and Allied Tables*. We started to do this in co-operation with staff of the Mathematics Division of the National Physical Laboratory, but we found that our target readers were different and so we went our separate ways. The NAO booklet was published in 1956, by which time I had started to prepare the companion booklet *Subtabulation*.

The first section of *Subtabulation* was intended for use with electronic computers, but the other two were primarily intended to provide a record of the methods that had previously been used in the Office. Sadler wrote the second section on the 'end-figure method', which used preprinted tables for manual calculations. He gave me the task of drafting the third section on the method of 'bridging differences', which was still being used on the National and Hollerith machines. A wide variety of formulae and precepts were available, but I could find no documentation on how they had been derived. I felt very pleased when I succeeded in developing a systematic way of producing such formulae.

I used to see the correspondence between Sadler and Clemence about the unification of the almanacs for marine navigation. My recollection is that it was Clemence who proposed using a layout with data for three days at each opening, but Sadler did much to fill in the detail of the layout that was eventually adopted. In this case, we produced the daily pages using an IBM card-controlled typewriter and pre-printed ruled forms, which required the development of a special, but simple, technique to ensure that the columns of figures kept a constant distance from the rules.

The unified publication was called, simply, *The Nautical Almanac* and so for a long time there was much confusion with our main almanac, even after it had dropped the first half of its name to become *The Astronomical Ephemeris*. The unification of the navigational almanacs was accompanied by a unification of the auxiliary navigation tables (mainly for RA/Dec to Alt/Az conversions), but here the UK was content to adopt the US publications with comparatively minor changes.

As early as 1952, Sadler had put forward a proposal for an *International Fundamental Astronomical Ephemeris* that would obviate the need for each major country to prepare and print high-precision ephemerides of the Sun, Moon and planets. This idea did not find general favour, although Germany gave up its *Berliner Jahrbuch* and took over from us the work of publishing *Apparent Places of Fundamental Stars.*

The concept of ephemeris time was introduced in 1952 and then during the 1950s the formal definition was changed twice from the original 'operational definition' initially favoured by Clemence to the formal definition that was eventually used. I attended some of the discussions about timescales when Clemence visited Herstmonceux; Professor Samuel Herrick participated in some of them as he spent a sabbatical year with us.

The introduction of ephemeris time demanded changes in the astronomical almanacs and so it provided an ideal opportunity to take unification one stage further. There was already a lot in common between the British and American astronomical almanacs, but there had to be a lot of give and take to get the final agreement on content and on the sharing of the work of computation and printing. In this case we produced the reproducible material for the first half, while that for the second half was produced in the USA. The change point was easily seen as different typographical fonts were used in the two halves. There was also an agreement to disagree on spelling!

Unfortunately, Clemence could not get authority to change the title of the *American Ephemeris* to a common title as it would have required the approval of the US Congress. Our almanac was renamed the *Astronomical Ephemeris.* From 1960 onwards, the two almanacs were identical in content, apart from the title page and other preliminaries, such as the list of the staff, but the colour of the UK edition was changed from blue to green.

Sadler and Clemence wished to strengthen the cooperation between the two offices by exchanging staff. As a consequence I spent a year in the U.S.A. after preparing the copy for *Subtabulation.* I worked at the U.S. Naval Observatory from February to September 1957 and then went to Yale University Observatory for a further five months. I gained experience in programming an IBM 650 electronic computer while trying to determine improved orbital elements for the satellites of Mars and I learnt about various aspects of celestial mechanics. More importantly, I developed a good working relationship with the staff of the NAO in the Naval Observatory. Further details of my experiences during this year are given in Annex 1 to this paper.

While I was in the USA, the (British) NAO moved into the new West Building on the hill to the south-west of the Castle. The staff immediately had the new and unexpected task of providing the first UK prediction service for artificial satellites, but I was disappointed to find on my return that Woolley would not support the work and that at the beginning of 1958 the task had been transferred to the Royal Aircraft Establishment at Farnborough (and later to the Radio and Space Research Station at Slough.)

Another disappointment was that the Admiralty had not approved our proposal that the NAO should have a English Electric DEUCE computer; instead it decided that we should have a BTMC (later ICT) 1201 computer. I realized that his would be technically inferior to the IBM 650, but I did not realize that I would have to write almost all of the basic software before we could use it for our work. My experience at USNO proved to be invaluable.

On my return I was given the task of editing the contributions from the two offices to the long-overdue *Explanatory Supplement to the Ephemeris.* One aim was to give a uniform typographical style throughout, but it was not possible to eliminate the differences in literary style nor in the approach to the methods of computation. Sadler and Woolard differed in both, and I sometimes had to insert extra material to give an alternative explanation or method. This is probably most noticeable in section 3 on systems of time measurement. The Supplement contains a brief account of the history of the Almanac and a list of the appendices and supplements to it

The *Explanatory Supplement* was published only in the UK. Unfortunately, it turned out that Her Majesty's Stationery Office (HMSO) was unable to set up an effective sales system for it in the USA and so we had a lot of complaints about this aspect of the arrangements. Subsequently, we issued a series of *NAO Technical Notes* that gave information about various aspects of the work of the NAO; some of them were published later. A partial list of them is given in the 1992 edition of the *Explanatory Supplement.*

Sadler's flair for organisation had been recognised by the International Astronomical Union and he served as its General Secretary during the period 1958-1964. He did a lot of the work for this at the weekends — he would always go to his office after we had finished playing men's doubles tennis on Sunday mornings, usually with the Astronomer Royal, Woolley, and Albert E. Carter, who was the head of the machine section of the Office.

I suspect that Sadler's involvement with the IAU and other organisations was probably the reason why he did not learn to program, although I am sure that he would have made an excellent programmer. He probably delegated more responsibilities to me than he would otherwise have done.

My own involvement with the IAU began in 1963 when I was appointed secretary of the IAU Working Group on the System of Astronomical Constants. After this I had the task of writing a program to compute the fundamental lunar ephemeris, taking into account the new system of constants and the further corrections developed by W. J. Eckert, who had been Director of US NAO. I was able to start from a Fortran program that had been written by Neil Block at the Jet Propulsion Laboratory, but I had to develop the new program on an IBM 7090 in London as our own ICT 1201 was quite inadequate.

We were pressing for a better computer, but again I was thwarted as the Admiralty turned down our proposal for an IBM 360 system and insisted that we had an ICT (later ICL) 1909 system. This turned out to be much better than I had expected, but it did not allow us to exchange programs easily with USNO as I had hoped. We were however, able to use it to compute the new lunar ephemeris. I also developed a system for automatic phototypesetting of tabular matter; this was used primarily for the *Astronomical Ephemeris* and the *Star Almanac.*

During the 1960s the cooperation between our two offices continued as various improvements were made to the publications. I believe that Sadler played a principal role in the design of the series of *Sight Reduction Tables for Marine Navigation*, which were published in 1971 onwards. His final task for the IAU was to organise the General Assembly in Brighton in 1970, and so at the beginning of that year I became Acting Superintendent until he formally retired in February of the next year. (To be continued)

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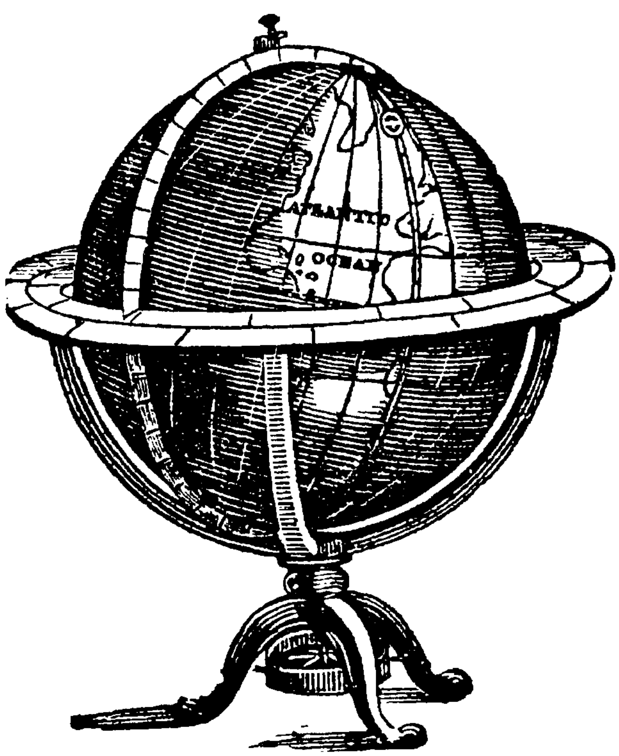


BOOK REVIEW

By Ernest Brown

LONG TERM ALMANAC 2000-2050

For the sun and selected stars
With concise sight reduction tables
by Geoffrey Kolbe

Cloth, 90 pp.
Pisces Press 2000
Pisces Press, Newcastle, Roxburghshire, TD9 OSN, Scotland
IBSN 0- 9537537-1-9

The author states in the introduction that ease of use has been a primary consideration in the design of this almanac. I suggest that comparison of this almanac with one of the same basic type but designed primarily for compactness would be useful in determining the author's success.

The long-term almanac for base year 1972.0, appendix H, in the 1977 and 1984 editions of the *American Practical Navigator* (Bowditch), like Geoffrey Kolbe's almanac, is based principally upon the fact that approximately correct values for the Greenwich hour angle (GHA) and declination of the sun, and the Greenwich hour angle of Aries, can be obtained from an almanac that is exactly four years out of date. The differences in these values at intervals of exactly four years can be largely removed by applying average corrections. This four-year, or quadrennial correction, varies throughout the year for the GHA and declination of the sun. For the GHA of Aries the quadrennial correction is a constant (+) 1.'84.

Appendix H presents on only two pages of the three-page almanac the base data for the sun for each of the four years of the cycle at intervals of three days, except for the final days of each month when the interval varies between one and four days:

GHA-175°, quadrennial GHA correction, declination, and quadrennial declination correction.

A small part of the third page is used to present the base data for GHA of Aries at monthly intervals throughout the four-year cycle.

The corresponding data in Geoffrey Kolbe's almanac is presented on 48 of the 6" x 9 1/8" pages. There are daily entries for:

GHA of the sun for 00 hours
hourly acceleration of sun's GHA, i.e. the average amount by which the GHA advances on a standard increment of 15° per hour for each day
quadrennial correction for the sun's GHA
declination of the sun for 00 hours
hourly rate of the sun's declination, i.e. the average amount by which the declination changes for each hour of the day

quadrennial correction for the sun's declination
GHA of Aries for 00 hours

The foregoing data is clearly presented for easy reading and extraction opposite each day of the month in a separate 12-page Daily Table for each year of the four-year cycle.

For determining the factor by which the quadrennial correction is multiplied to obtain the approximately correct value and for finding which Daily Table (**0, 1, 2, or 3**) of the four-year cycle is to be used, the procedure is as follows:

> Subtract the base year 2000.0 from the given year and divide the result by 4 to obtain a whole number *a* and a remainder *b*, a number which when added to the whole number equals the difference between the given year and 2000. The whole number is the factor by which the quadrennial correction is multiplied; the remainder is either **0, 1, 2,** or **3.**

In the case of the sun, the daily tabulation avoids the need for the laborious interpolation required by Appendix H even when the given day corresponds to one of the tabulated days. Using appendix H, first one must apply the quadrennial correction to GHA-175° and the declination for each of the two days bracketing the desired GMT time and Greenwich date; the 3-day change and the daily change are calculated; and then the interpolation is completed for the days and tenth of day involved in the interpolations of GHA and declination of the sun. The only interpolation required with Geoffrey Kolbe's almanac is so simple it can be done mentally.

The simplicity of the use of the almanac is demonstrated by example solutions:

Example. — Find the GHA of the sun for 11^h 27^m 39^s on July 18, 2014.

Solution. —

Step 1. — Subtract 2000 from 2014 to obtain 14. Divide 14 by 4 to obtain whole number 3 and remainder 2. Entering the "2" Daily Table for July 18, the 00 hours value for GHA of the sun is 178° 27.'4.

Step 2. — The hourly acceleration tabulated for the 18^{th} is (-) 0.'05. This multiplied by 11.5 (11 hours + 0.5 for 27^m gives a total acceleration of about (-) 0.'58.

Step 3. — The quadrennial correction for the day is (-) 0.'16, which multiplied by whole number 3 gives (-) 0.'48.

	178° 27.'4
	(-) 00.'58
	(-) 00.'48
Giving	178° 26.'3

Step 4. — From the Tables of GHA Increments

11^h	165°
27^m	6° 45.
39^s	9.'8
Total increment	171° 54,.8
	+ 178° 26.'3
GHA of Sun	350° 21.'1

Example. — Find the declination of the sun for 11^h 27^m 39^s on July 18, 2016.

Solution —

Step 1. — Proceed as for step 1 of the GHA solution above to find the correct Daily Table. However, in this case the whole number *a* is 4 and the remainder is "0"

Step 2. — In the "0" Daily table for July 18, the 00 hours declination of the sun is 21° 00.'2 N. The hourly rate is given as (-) 0.'45. Multiply this by 11.'5 giving (-) 05.'2.

Step 3. — The quadrennial correction for the day is given as (-) 0.'38. Multiply this by the whole number *a*, which is 4, to give a correction of (-) 1.'52.

Step 4. — The declination is:

21° 00.'2 N	from step 1
(-) 05.'2	from step 2
(-) 1.'5	From step 3
20° 53.'5 N	

Example. — Find the GHA of Aries for 19^h 13^m 06^s on May 12, 2036.

Solution. —

Step 1. — Proceed as for step 1 of the GHA of the sun solution above to find the correct Daily Table. The whole number *a* is 9 and the remainder is "0". In the "0" Daily Table on May 12 the 00 hours GHA of Aries is 230° 04.'4.

Step 2. — Extract from the Aries table of the Tables of GHA Increments:

Quad.corr. (a=9)	16.'6
Increment for 19^h	+285° 46.'8
Increment for 13^m	3° 15.'5
Increment for 06^s	1.'5
Total Increment	289° 20.'4
Adding Total Increment to	230° 04.'4
	289° 20.'4
GHA of Aries	159° 24.'8

For simplicity of design and ease of use, the quadrennial correction is included in the Table of GHA Increments.

The Year 2000 Star Position Table gives the sidereal hour angle (SHA) and declination of 39 selected stars, including Polaris, for the 15th of each month. Mental interpolation can be used to adjust the values to the desired date.

The annual corrections to the year 2000 values of SHA and declination of each star are given on each of the six pages of the table. This data is clearly presented for ease of use.

Other material in this small volume should enhance its value as a major component of an emergency navigation kit. There are two star charts, one for the northern sky and another for the southern sky. There is a sextant altitude correction table. The refraction corrections therein for the sun are for observations of its lower limb and include adjustment to give the altitude to the center of the sun. Because of an assumed semidiameter of the sun of 16.'1, a monthly correction table is provided for making the small corrections for months other than March and October. Also there is a compact sight reduction table.

The sight reduction table is made up of 18 pages of *natural* log sines and log cosines in the range 0°-90° at 1. intervals. These logarithms are used to solve the two spherical right triangles (and their auxiliary parts) formed by dropping a perpendicular from the celestial body to the observer's meridian, as in the Ageton method (H.O.211).

The natural logarithms are multiplied by 100,000 with signs changed to positive for ease of computation. The logarithms are to six figures rather than the five usually used in such short methods for greater accuracy and ease of interpolation where required.

Unlike Ageton and other short methods there are no rules, as for data extraction, printed on the pages of the table. However, in the explanation, rules are given for assigning values to the equations used in the computations. For the equation

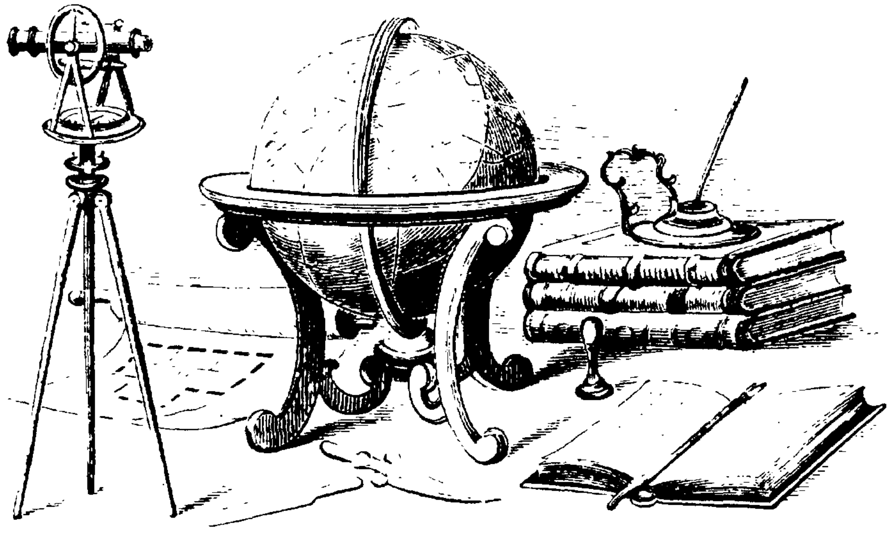
LOGCOS A + LOGSIN C = LOGSIN D
A = declination
C = LHA if LHA is less than 90°
C = 180° - LHA if LHA>90<180
C = LHA - 180° if LHA >180°<270°
C = 360°- LHA if LHA >270°

D is an auxiliary part, the perpendicular dropped from the body to the meridian.

The user should be able to prepare a workform on which the several rules are included without difficulty.

To determine in which azimuth quadrant the celestial body lies it is usually only necessary to look at the LHA, latitude, and the declination to see where the geographical position of the body is relative to the estimated position. But when the body lies in the East or West, there can be some confusion as to quadrant. The problem is resolved by a simple test.

This very attractive, small, easily stowed package of long-term almanac and sight reduction table should serve to insure that the celestial navigation backup capability will not be lost due to failing to stow the current or previous year's annual almanac because of over reliance on the almost universally used Global Positioning System and other satellite systems.



ANSWER TO DO YOU KNOW? . . .

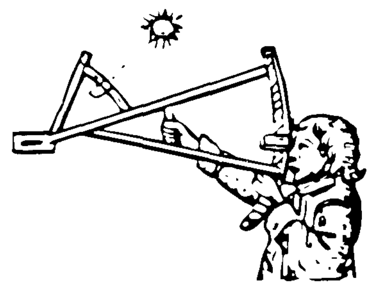
(from page 1)

In his paper "The Future of Almanac Data in the United States" in the *Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory, March 3-4, 1999,* John A. Bangert, Head, Astronomical Applications Department, U.S. Naval Observatory, mentioned a proposal to produce an *Abridged Nautical Almanac* for U.S. Navy use only. The development of the *Abridged Nautical Almanac* is currently suspended.

The above paper was reprinted in Issue Sixty-seven.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION — ISSUE SEVENTY-THREE, FALL 2001



This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry F. Carraway

The life of the Carraway family is beginning to return to normal. It has been a hectic year. With my son's plane crash and being away from the office for two and one half months left many chores uncompleted.

My family thanks all of the members who sent words of condolence and concern for my son. His survival is a miracle. The plane was completely destroyed and our friend, who was the owner of the plane and flying at the time, died in the crash. No one can believe that my son survived with no broken bones and only burns, which were 3rd degree. His recovery in the burn unit in Augusta, Georgia would not have been as long had he not developed a very serious infection from one of the 15 tubes that were attached and feeding different drugs into him.

He will take a least one more year before he fully recovers. He has lost 30% of his lung capacity, bubbles behind the lens of his left eye, all caused by the heat of the ensuing fire. His left arm is recovering from not being used for the two months he was sedated and fed paralytic drugs to keep him from moving.

He does go to work at least two times a week. He has a good attitude and is in very good spirits.

Many more celestial navigation publications are becoming available from the Government Printing Office. The price is much higher than when these publications were handled by NOAA/NOS. However, they are at least available and can still be ordered through The Navigation Foundation. The discount on publications from the Government Printing Office is 15%. The discount for books from other publishers is still 20%. Chart orders are still 20% discount on all orders of less than $50.00 and a 25% discount on all orders over $50.00.

Membership continues to slowly decline due to the increasing age of our members and the lack of interest due to the ease of GPS. We can continue to sustain the current level of activity for members but unless we gain new members in the future the long term life of The Navigation Foundation is in doubt. We will continue so do not be concerned about the quality of The Navigator's Newsletter or orders for charts, books and publications.

We are still receiving bank drafts for membership renewal without any indication for whom the draft was intended. The latest was from the BCH Company, 835 Main Street, P.O. Box 702, Bridgeport, CT 06601-2353. It had an invoice date of 30 May 2001 and a check date of 1 August 2001. I have tried to reconcile the ZIP Code, renewal dates and dates of the invoice and check date with a name but have been unsuccessful. If the member will send me a note, either by mail or e-mail to: navigate@ix.netcom.com, the check number, I will credit the renewal to that member.

The Rear Admiral Thomas D. Davies Award for Excellence in Navigation at Tabor Academy was presented to John C. Phelan.

DO YOU KNOW . . .?

By Ernest Brown

What method then Lieutenant Commander Richard E. Byrd, USN, used to reduce his sun observations during the May 9, 1926, polar flight of the Fokker Tri-motor *Josephine Ford* piloted by Floyd Bennett?

(Answer at back of this issue)

HISTORY OF NAVIGATION

History of H.M. Nautical Almanac Office

By George A. Wilkins, Superintendent of H.M. Nautical Almanac Office, 1970-1989

Reprinted from Proceedings, Nautical Almanac Office, Sesquicentennial Symposium, U.S. Naval Observatory, March 3-4, 1999. Courtesy of the author. (Continued from Issue Seventy-two)

The period of reduction, 1970-1989

During his period of office Woolley attempted to change the RGO from a public-service establishment to an astronomical research institute. Such changes became easier when the primary responsibility for the funding of the Observatory was transferred from the Ministry of Defence to the newly-formed Science Research Council in 1965.

The navigational work of the Office was supported by special funding from the Ministry of Defence. We could justify the occultation programme as a research activity, especially as it was extended to cover the occultations of radio and later X-ray sources. The discovery of the first quasar was an unexpected offshoot of the NAO's occultation programme. The NAO provided predictions for the occultations of radio sources, which were used to help to map their structures. Then Cyril Hazard observed one that behaved like a point source; W. Nicholson in the NAO was responsible for the reduction of the observed data to determine the coordinates of the source, and this led to the optical identification of 3C 273 as a quasar[22].

The NAO did not have enough resources to carry out a major program of research or development in celestial mechanics — the US Navy was more sympathetic to this than the Ministry of Defence and, later, the SRC. Woolley, moreover, saw no value in the production of the *Astronomical Ephemeris* and in similar fundamental work. Consequently, early in 1970 I found myself faced with a decision by an SRC committee that we should cease to publish the AE. Fortunately, the committee was meeting at Herstmonceux and the chairman allowed me to speak to the committee. When I explained how our work was used by the International community, and in particular, how our material formed the first half of the *American Ephemeris*, the committee rescinded its earlier decision.

Sadler not only passed on to me the job of Superintendent of the NAO, but he nominated me for two IAU jobs, so that I became the chairman of he IAU Working Group on Numerical Data and the IAU's representative on the Federation of Astronomical and Geophysical Services (FAGS). The former job also entailed me acting as the IAU representative on CODATA (The ICSU special committee for data for science and technology). I later became the secretary of FAGS. I found these activities extremely interesting, but they must have reduced the amount of effort that I put into the NAO work.

The international service for the prediction and reduction of occultations of stars by the Moon, which was led by Mrs. Flora Sadler, was at this time primarily aimed at providing a uniform time-scale against which the variations in the rate of the rotation of the Earth could be determined. This aspect of the lunar occultation programme was, however, superseded by the availability of atomic time, but the expertise in the office was used by Leslie V. Morrison and his team to collect and re-reduce earlier observations, and so to improve considerably our knowledge of the variations in the 'length-of-day' since the 17th century. Later, Morrison also provided the technical back-up for Richard Stephenson's work on the use of the records of ancient eclipses for the same purpose[23].

The NAO also provided support for Gordon E. Taylor to allow him to follow up his personal interest in the occultations of stars by minor planets. Eventually this gave interesting results that could not then be obtained by other methods. We also like to believe that it was his prediction of the occultation of a star by Uranus as part of our regular programme that led to the discovery of the rings of Uranus.

As a further contribution to research, Dr. Andrew T. Sinclair, and, later, Dr. Donald B. Taylor, both of whom had been students of Dr. P. J. Message at the University of Liverpool, did, however, produce a series of papers on the motions of minor planets and satellites whilst also contributing to other aspects of the work of the office. (I knew Message well as he and I had been at Yale at the same time.) Sinclair took over the work on the satellites of Mars that I had started at USNO in 1957 and he produced an improved set of orbital elements.

Sir Richard Woolley retired at the end of 1971 and was succeeded as Director, but not as Astronomer Royal, by Dr. E. Margaret Burbidge. She resigned after a short while and her place was taken in 1974 by Dr. Alan Hunter, who led the celebrations of the Tercentenary of the Royal Observatory in 1975[24]. Under his leadership the various departments of the Observatory were grouped into Divisions and I was made Head of the Almanacs and Time Division, so that I became responsible for administrative oversight of the Time Department, which was headed by Humphry M Smith. Later, the Libraries and Archives Department was added to the Division.

At this time, the Computer (formerly Machine) Section of the NAO was made into a separate department within the A&T Division; Carter continued as its head. My increasing involvement in administrative and external activities meant that I stopped being an active user of the computer system and I was no longer able to keep up with the details of the technical developments in computing.

One of Woolley's criticisms of the *Astronomical Ephemeris* had been that it did not cater properly for the needs of astrophysical observers, and so I took the opportunity provided by the IAU General Assembly in Sydney in 1973 to try to find out what changes ought to be made. There was also a need to update the fundamental ephemerides to take into account the need for the use of timescales that were consistent with the theories of relativity

We were also under renewed pressure to reduce the costs of producing and distributing the *Astronomical Ephermeris*. At that time we used to distribute about 100 copies of the *Advanced Proofs* of the AE several years in advance of final publication so that other countries could use our data in computations for their local almanacs. We also used to send copies in exchange for the publications of other observatories and institutes, but it was clear that in most cases these were not of equal value.

The eventual resolution of these matters required a lot of discussion between our two offices. During this period Dr. P. Kenneth Seidelmann succeeded Duncombe as Director of the US NAO and I am glad to say that the good relations were maintained. In our Office, Mrs. Flora Sadler had retired in 1973 and Dr. Bernard D. Yallop had taken charge of the publications work of the NAO.

The most fundamental change was that the separate printing of the AE in the UK was stopped after the edition for 1980, although the UK continued to compute its share of the ephemerides and to provide reproducible material for the jointly-prepared almanac. I was very pleased when the Scientific Director of USNO, then Dr. K. A. Strand, was persuaded to seek the approval of Congress for the change of name of the *American Ephemeris* to the *Astronomical Almanac.*

There were many changes in the arrangement of the material, and variations in typeface occurred throughout the volume. The changes in the basis of the ephemerides took longer to implement and must have imposed a considerable extra load on the staff in USNO as we were unable to contribute our full share. The improved ephemerides were first included in the Almanac for 1984.

The advance distribution of advance proofs was stopped, but we expanded the contents of the next volume of *Planetary Co-ordinates* to include, for example, tabulations for the Moon. We first produced *Planetary and Lunar Coordinates* for 1980-1984 and the volume for 1984-2000 came later.

In the early 1970s the NAO had been party to a bid for a lunar laser ranging system to be built in the UK for deployment in South Africa, but that was not approved by the Research Council, possibly because we could not get appropriate support from any South African group. We did, however, get approval for Sinclair to spend a year in Australia to work on the LLR project at Orroral, near Canberra. This proved to be one of the keys to the later success of the satellite laser ranging (SLR) project, which replaced the photographic zenith telescope as the RGO's contribution to the determination of universal time and polar motion.

By this time the occultation program was obsolete and so several NAO staff moved to the Time Department to develop and operate the new satellite laser ranging system. Morrison was moved to the Astrometry division and so he was not available to edit the new edition of the *Explanatory Supplement* as I had hoped. We did, however, contribute to the new edition which was edited by Seidelmann and published in the USA in 1992.

Between 1978 and 1988 I was heavily involved in the international MERIT project, which led to the setting up of the successful International Earth Rotation Service, and also in organising the activities of IAU Commission 5 (Documentation and Astronomical Data) of which I was President from 1985 to 1991. Consequently, more and more responsibility fell on Yallop. He took a greater interest in navigation than I had done and started the series of volumes of *Compact Data for Navigation and Astronomy* using the technique that we had introduced earlier for the daily ephemeris of the Moon in the *Astronomical Ephemeris.*

From Herstmonceux to Cambridge, 1989-1998

During the 1970s the RGO was subjected to a major review of its role, but it was eventually given responsibility for the management of the construction and operation of the Northern Hemisphere Observatory, as it was then called. The new observatory was established on the island of La Palma in the Canary Islands as part of an international observatory. The public service role of the RGO was also recognized, but as a third priority. The staffs of the NAO and of the Time Department were, however, cut after Professor Alec Boksenberg became Director in 1981 and several experienced members were encouraged to take 'voluntary premature retirement'.

Further reviews took place during the 1980s and it was eventually decided that the RGO should be moved to a new site at Cambridge, close to the Institute of Astronomy. I reached retiring age in 1989 before the move took place and I formally gave up my management responsibilities at the end of March. The Time Department was closed, although I was able to argue successfully that the SLR operations should continue at Herstmonceux.

Bernard Yallop was already responsible for the production of the almanacs and so naturally took over the formal title of Superintendent and the responsibility for obtaining the staff and funding for the operations at a time when the Research Council was reducing the role of the Observatory to that of supporting the UK telescope facilities on La Palma..

The staff of the NAO was reduced to 4 or 5 persons when the move to Cambridge took place in 1990, but it continued to fulfill its share of the cooperative work with

USNO and to provide a public data service. Don Taylor also managed to find time to keep up some research in celestial mechanics.

I am not aware of the circumstances, but Yallop was given the task of meeting all the costs of the Office from the revenue from the sales of its publications and services. Prior to this the Ministry of Defence had paid the Research Council for the costs of the work done by the Office for the navigational publications, but had retained all the profits from the sales. Fortunately, in spite of the growing use of GPS, the sales of *The Nautical Almanac* were still high and the profits were sufficient to keep the Office alive.

Bernard Yallop reached retirement age in 1996 and Andrew Sinclair, who had worked in the NAO from 1968 to 1990 was given the job of overseeing the work of the Office on a part-time basis, while continuing to be Head of the SLR Department of the RGO. He had an even rougher time as there was first of all a proposal to turn the RGO into a non-profit company and then the decision of the Particle Physics and Astronomy Research Council to close the RGO at the end of October 1998.

At one time it appeared that the NAO might be taken over by a major publisher, but eventually it was decided that the Office should go to the Rutherford Appleton Laboratory. Only three of the staff have moved; one of them, Catherine Y. Hohenkerk, gave an account of the post-1990 activities of the NAO in an article in the final issue of the RGO house magazine[25]. It is ironic that another of them, Steve Bell, had recently written a guide to the total eclipse of the sun in 1999 that is a bestseller[26]. It is such a pity that the RGO is now itself in permanent eclipse, but we hope that the partial eclipse of the NAO will soon be over and that UK will once again play a full and fitting role in the international services for astronomy and navigation.

Additional sources

Information about the origin and early development of the *Nautical Almanac* may be found in many books on the history of astronomy or navigation, but there are few accounts of the history of the Nautical Almanac Office apart from the paper that I prepared on the occasion of the tercentenary of the RGO[27]. After his retirement, Sadler started to draft a general history of the Office, but he abandoned the project when he was unable to find any significant amount of original documents prior to 1930. (It appears that the archives were destroyed by Downing and Cowell prior to their retirements.)

Sadler went on to draft from memory *A personal history of H. M. Nautical Almanac Office 30 October 1930 - 18 February 1972*, but the manuscript was in an unchecked and unedited state when he died. After my retirement, I typed and edited the material and issued a small number of copies of a 'preliminary version' of the document in May 1993, in time for a reunion of NAO that was held at Greenwich. I was, however, unable to resolve some of the inconsistencies in the draft or to fill in some of the missing detail. Although this document makes fascinating reading for persons who have been connected with the Office, the general impression seemed to be that it would not be suitable for general publication[28].

Since then I have continued to collect information about the history of the Office and have started to write up my recollections of my period of service from 1951-1989 as part of a more general account of the history of the RGO during the period that it was at Herstmonceux Castle from 1948 to 1990[29]. I have also written articles about Downing, Cowell and Sadler for publication in the *New Dictionary of National Biography* that is being prepared by Oxford University Press. I understand that the earlier DNB articles on Young and Stratford have been revised and that new articles on Hind and Comrie have been written.

A chronological table of events relating to the *Nautical Almanac* and the NAO from 1767 onwards is given in Annex 2; it includes some items that have been omitted from the above account.

Finally, it seems to be appropriate to draw attention to a volume that is complementary to Dava Sobel's *Longitude*, namely that on Greenwich time by the late Derek Howse[30], since it includes much material that is relevant to the activities of the (British) Nautical Almanac Office.

Acknowledgements

I am indebted to the late Donald Sadler in many ways, but especially for choosing me to work in H. M. Nautical Almanac Office and then for giving me appropriate training and opportunities to participate in a wide variety of activities and to succeed him as Superintendent of the Nautical Almanac. In the particular context of this paper, I must acknowledge my possession of much material about the history of the NAO that he collected during his retirement[29]. I have found much interest and enjoyment in reading his recollections and those of other members of the staff whom he encouraged to write to him about their experiences.

This is not the place to list all those persons who have given me assistance in my searches for information about the NAO and its staff, but I would like to thank Adam Perkins, the RGO archivist, for his help during and between my visits to the Cambridge University Library, where there is a very large volume of material relating to the NAO from 1930 onwards.

Finally, I would like to express my thanks for the invitation to speak at the U. S. Naval Observatory Symposium to celebrate the 150th anniversary of the establishment of the U.S. Nautical Almanac Office.

NOTES AND REFERENCES

22. C. Hazard, et al, "Investigation of the radio source 3C 273 by the method of lunar occultations," *Nature* 197 (1963), 1037-1039.

23. Richard Stephenson, *Historical eclipses and Earth's rotation* (Cambridge University Press, 1997).

24. An important by-product of the Tercentenary was a paperback giving a historical review of the RGO by William Hunter McCrea, *Royal Greenwich Observatory* (H.M. Stationery Office, 1975).

25. C. Y. Hohenkerk, "The NAO — Past and Present", *Spectrum* (RGO, October, 1998), 52- 54.

26. Steve Ball, *A Guide to the 1999 Total Eclipse of the Sun* (H.M, Stationery Office, 1996). Later editions were published by H.M. Nautical Almanac Office with the title *The RGO Guide to the 1999 Total Eclipse of the Sun*.

27. G. A. Wilkins, "The expanding role of H.M. Nautical Almanac Office, 1818-1975", *Vistas in Astronomy* 20 (1976), 239-243.

28. The manuscript and a copy of the typescript of my preliminary version of Sadler's personal history of the NAO have been deposited in the archives of the RGO in the Cambridge University Library.

29. It is unlikely that my history of the RGO will be published, but the typescript and background documents that I have collected will also be deposited, together with those relating to the earlier history of the NAO, in the RGO archives.

30. Derek Howse, *Greenwich time and the longitude* (1st ed. Oxford Univ. Press, 1980; 2nd ed. Philip Wilson, London, 1997).

ANNEX 1

Duty at the U.S. Naval Observatory in 1967.

By George A. Wilkins

Donald Sadler, the Superintendent of H.M. Nautical Almanac Office in the Royal Greenwich Observatory, and Gerald Clemence, the Director of the Nautical Almanac Office in the U. S. Naval Observatory, had the idea of an exchange of staff to strengthen still further the cooperation between the two offices. At the end of 1956 I was told that, as the first step, I would spend about six months at the US Naval Observatory (USNO) and then a further six months at the Yale University Observatory, where I would have the opportunity to attend lectures on celestial mechanics.

The administrative arrangements for my visit were very unusual. While I was at USNO I became a temporary member of the staff and I was paid accordingly. I continued, however, to be on the staff of the RGO and I received my normal pay and a 'Foreign Service Allowance'. As a consequence I had to pass my USNO pay cheques to the British Embassy.

The anomaly in my position became very clear on the first day when I was sworn in by the Superintendent of the Observatory. It was agreed, however, that I could omit one sentence from the normal text.

At the time I was married and we had a son who was not quite two years old. Unfortunately, since my tour of duty was to be only one year and not the usual three years, the Admiralty were not prepared to pay the fares for my wife and child and my FSA was only that for a single man. Moreover, since my wife was not travelling officially, she could not have a diplomatic visa, and since she wished to come for a year, she could not have a visitor's visa. As a consequence, she had to obtain an immigrant's visa!

We crossed the Atlantic in S.S. Queen Elizabeth in February 1957. But owing to a dock strike in New York we landed in Halifax and then had a 40-hour journey by train to New York, where we stayed overnight before continuing to Washington.

After all this hassle we were delighted to stay in the Clemence's home in the grounds of the Observatory for about a week while we looked for a tolerable apartment that we could afford. Clemence also started to teach me to drive in his Volkswagen Beetle, but in order that I could get more practice I bought a second-hand car (a large Plymouth saloon) which I than parked and drove on the Observatory roads until I was confident enough to take and pass the driving test. My wife and I were also helped by other members of the USNO staff, but especially by Dr. Raynor J. Duncombe and his wife, Mrs. Julena S. Duncombe, with whom we developed a lasting friendship, and who soon became Uncle Ray and Auntie Julie to our son, Michael.

I had expected that I would share in the work of preparing material for the almanacs, but instead I was given the task of computing improved orbits for the satellites of Mars, which were discovered in 1877 by Asaph Hall at the U.S. Naval Observatory, then in Foggy Bottom. In particular, I was to try to obtain a more accurate value for the secular acceleration of the inner satellite Phobos, as a Russian astronomer, Shklovskii, had concluded[1] that the value obtained by Sharpless at USNO in 1945 implied that the satellite was hollow and therefore artificial!

This task would not only give me experience in solving a practical problem in dynamical astronomy, but it would also give me my first opportunity to write programs for an electronic computer — the Observatory was to take delivery of an IBM 650 computer shortly after my arrival in Washington. In fact, I started to test my programs on similar computers in the Pentagon and the Naval Research Laboratory.

While I was at USNO I was allocated a roll-top desk (previously used by H. R. Morgan) in the Library, and so I did not interact with the NAO staff as much as I had expected. I hope, however, that I made useful contributions to the development of useful communal software for the IBM 650 computer. In spite of my isolation, I did get to know quite a number of members of the staff of the Observatory, and over 50 of them signed the copy of

The American Ephemeris that was presented to me when I left to go to New Haven, Connecticut, in September 1957.

While at the Observatory I was able to attend a weekend 'neighbours meeting' at the Yale University Observatory in New Haven, Connecticut, and meetings of the American Astronomical Society in Cambridge, Massachusetts, and in Champagne-Urbana, Illinois. In the autumn at Yale I attended lectures on, for example, lunar theory by Professor Dirk Brouwer and I continued my work on the satellites of Mars as I was able to use another IBM 650 there. Many years later I was pleased to find[2] that "At the time the Mariner 9 spacecraft went into orbit around Mars and began its observations of Phobos and Deimos, Wilkins' theory provided the best predictions of the satellites' positions".

The Russians launched their Sputnik satellites in the autumn soon after we had moved to Connecticut, and the U.S. Army launched the first Explorer satellite while we were back in Washington in February 1958 for a 'neighbours meeting' at the Observatory. Duncombe was associated with the computation of the orbit of the satellite, and so Message and I were able to visit the computer center on Pennsylvania Avenue and see the large IBM 704 computer that was being used. We were also able to look around the adjacent exhibition about the Vanguard satellite project.

We returned home towards the end of the month; before doing so, I sold our Plymouth to Dr. J. Kovalevsky, from the Bureau des Longitudes, Paris, who had recently started a visit to the Yale University Observatory. I was later pleased to find that it gave him good service. Our transatlantic journey was again in S.S. Queen Elizabeth, on which we embarked in New York.

Unfortunately, no member of the USNO staff spent a similar period working in the NAO at Herstmonceux Castle. I am very grateful for the valuable experience that I gained at USNO and Yale, as well as for the friendships that I made at the time. These have been renewed subsequently by short visits and at meetings of the International Astronomical Union, where we have also established good relationships with the staff of the other organisations that contribute to the totality of international ephemerides.

Our son, Michael, returned, as a student, to the Naval Observatory in 1974 to work in the NAO for about seven months. He enjoyed the hospitality of Dr. & Mrs. Duncombe and gained much benefit from the experience. Unfortunately, he died in 1977 in a mountaineering accident in the Swiss Alps shortly after graduating in mathematics from the University of Cambridge.

1. The arguments are given in: I. S. Shklovskii and Carl Sagan, *Intelligent life in the Universe* (Dell Publishing Co., New York, 1968), 363-376.

2. The comment is by J. B. Pollack in *Planetary Satellites* (J. A. Burns, Ed., University of Arizona Press, 1977), p. 399.

ANNEX 2

Chronology of the Nautical Almanac and of H.M. Nautical Almanac Office, 1767-1998.

1767	First year of *The Nautical Almanac and Astronomical Ephemeris*, with tabulations of lunar distances, produced by Nevil Maskelyne, 5th Astronomer Royal.
1811	John Pond succeeded Maskelyne as Astronomer Royal.
1818	Thomas Young was appointed Superintendent of the Nautical Almanac; he was also the secretary of the Board of Longitude.
1829	Young died and Pond resumed responsibility for the *Nautical Almanac*.
1831	Lt. W. S. Stratford, then secretary of the Royal Astronomical Society, was appointed Superintendent of the Nautical Almanac.
1832	Stratford established the Nautical Almanac Office with permanent staff to replace the system of home-based computers and comparers.
1834	Major changes were introduced into the *Nautical Almanac* to make it more suitable for astronomical use.
1853	John R. Hind became Superintendent.
1891	A. M. W. Downing became Superintendent.
1896	First year that Part 1 of the *Nautical Almanac* (containing date for navigational purposes) was published separately for the convenience of sailors.
1901	Ephemerides based on Simon Newcomb's tables and constants were introduced.
1904	The name of the Office was first given the prefix H.M. in the *Nautical Almanac* for 1907.
1910	P. H. Cowell became Superintendent.
1911	Agreement was reached at a conference in Paris on the sharing of calculations between the principal ephemeris offices.
1914	First year of *The Nautical Almanac, Abridged for the Use of Seamen*.
1925	Leslie J. Comrie became Deputy Superintendent and introduced the use of calculating machines and also of commercial accounting and punched-card machines.
1930	Comrie became Superintendent and Donald H. Sadler joined the staff.
1931	Major changes and much explanatory matter were introduced into the *Nautical Almanac*.
1933	Publication of first volume of *Planetary Co-ordinates referred to the equinox of 1950.0*.
1936	Publication of *Interpolation and Allied Tables*, based mainly on extracts from the *Nautical Almanac* for 1937.
1936	Comrie was replaced by Sadler, who from 1937 reported to the Astronomer Royal, instead of directly to the Hydrographer of the Navy.
1937	First volume of *The Air Almanac* for Oct.-Dec.
1938	A booklet on *The prediction and reduction of occultations of stars by the Moon* was issued as a supplement to the *Nautical Almanac* for 1938.
1939	The Office was evacuated form Greenwich to Bath.

1940 The type for the *Nautical Almanac* was lost in a fire, started during an air-raid, at Hammond's printing works.

1941 First year of *Apparent Places of Fundamental Stars*, which was prepared by the Office for the International Astronomical Union.

1941 Start of publication of the series *Astronomical Navigation Tables.*

1943 The Office became an international centre for the prediction and reduction of occultations of stars by the Moon.

1943-1945 The Office acted as the operational centre for the Admiralty Computing Service.

1949 The Office moved form Bath to Herstmonceux Castle as part of the Royal Greenwich Observatory, and occupied temporary wartime 'huts'.

1951 First year of *The Star Almanac for Land Surveyors.*

1951 Installation of BTMC punched-card machines.

1952 The almanac for marine navigation was redesigned and renamed *The Abridged Nautical Almanac.*

1953 First year of the unified *Air Almanac* for use by the air forces of the commonwealth and of the United States of America.

1953 Installation of an IBM card-controlled typewriter for the production of reproducible printer's copy.

1954 Publication of the *Improved Lunar Ephermeris* by the USGPO as a Joint Supplement to the British and American astronomical almanacs.

1954 Sadler and Miss Flora M. McBain, who had joined the Office in 1937, were married.

1956 Publication of a completely new edition of *Interpolation and Allied Tables*, which was reprinted many times

1957 George A. Wilkins was seconded to work in the Nautical Almanac Office of the US Naval Observatory for 6 months and then to the Yale University Observatory for 6 months.

1957 The Office provided a satellite prediction service for the UK from October to December after moving into the new 'West Building'.

1958 First year of the unified *Nautical Almanac* for use by the Royal Navy and the United States Navy.

1958 Publication of the booklet *Subtabulation.*

1958-1964 Sadler was General Secretary of the International Astronomical Union.

1959 Last volume of *Apparent Places of Fundamental Stars* prepared by the Office; then by the Astronomisches Rechen-Insitut, Heidelberg.

1959 Installation of an ICT 1201 electronic computer.

1960 First year of the unification of the British and American astronomical almanacs, but with separate titles as *The Astronomical Ephemeris* and *The American Ephemeris and Nautical Almanac*

1961 Publication (by HMSO) of the jointly-prepared *Explanatory Supplement to the unified astronomical almanacs*

1961 Publication of *Royal Observatory Annals* No. 1, "Nutation 1900-1959"; based on E. W. Woolard's series.

1965 Funding of the RGO (and NAO) was transferred from the Ministry of Defence to the newly formed Science Research Council.

1966 Installation of an ICT 1909 computer.

1966 Walter A. Scott, Head of the Navigation Section, retired after more than 40 years service in the Office.

1968 A booklet *Man is not lost* was published to mark the bicentenary of the *Nautical Almanac.*

1968 First use of automatic composition for phototypesetting of the ephemerides in the first half of the *Astronomical Ephemeris* for 1972.

1970 Wilkins became Superintendent (but in an 'acting' capacity until Sadler formally retired from the post in 1971).

1971 Publication of the first volume *Sight Reduction Tables for Marine Navigation*, which was prepared jointly with US.

1972 Sadler retired after more than 41 years in the Office.

1974 Formation of Almanacs and Time Division of the RGO, with the separation of the Computer Department from the NAO.

1979 Publication of *Planetary and Lunar coordinates* for 1980 onwards.

1980 Last year of the lunar occultation programme.

1980 Last year of the distribution of proof copies of Part 1 of the *Astronomical Ephemeris.*

1981 First year of *The Astronomical Almanac*, which was prepared and published jointly but printed in the USA.

1984 *The Astronomical Almanac 1984* contained a Supplement on "The introduction of the improved IAU system of astronomical constants, time scales and reference frame into the Astronomical Almanac". The planetary and lunar ephemerides were based on numerical integrations constructed at the Jet Propulsion Laboratory.

1985 Publication of the first volume of *Compact data for navigation.*

1989 Bernard D. Yallop became Superintendent.

1990 The office moved with the RGO to Cambridge.

1991 The mode of funding of the Office was changed so that it became dependent on the revenue from the sales of its publications.

1992 The *Explanatory Supplement to the Astronomical Almanac*, edited by P. K. Seidelmann, was published in the USA by University Science Books, California.

1994 Responsibility for the funding of the RGO (and NAO) was transferred to the Particle Physics and Astronomy Research Council.

1996 Publication of *A guide to the 1999 total solar eclipse of the Sun;* later editions as *The RGO guide.*

1996 Andrew T. Sinclair became Head of the Office while continuing to be Head of the Satellite Laser Ranging Department of the RGO.

1997 Last year of the British edition of the *Air Almanac.*

1998 The RGO at Cambridge was closed and the remaining three members of the staff of the Office (not including Sinclair) moved to the Rutherford Appleton Laboratory, near Abingdon in Oxfordshire.

ANSWER TO DO YOU KNOW? . . .

(from page 1)

Richard E. Byrd used the pole as the assumed position method discovered by Arthur Hinks of the Royal Geographic Society and taught to him by George W. Littlehales of the U.S. Navy Hydrographic Office.

The reduction is made by almanac alone. At the pole the celestial horizon and celestial equator coincide, as do the zenith and elevated pole. The vertical circles and circles of declination become identical. Computed altitude and declination then become the same, and azimuth is replaced by GHA as an indication of the direction. The declination is used as Hc, and compared with Ho found in the usual way, to obtain *a*. For a "toward" case this is plotted along the meridian over which the body is located and for an "away" case it is plotted in the opposite direction. Such a line of position or its AP, can be advanced or retired in the usual manner using grid direction. For universal use the method should not be used if the observer is more than a few degrees from the pole, unless an adjustment is made to the line of position.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-FOUR, WINTER 2001-02

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Over the past few months The Foundation has been receiving very few letters from our members. The Readers Forum has been a stimulating part of the Newsletter. If you find the Newsletter too bland to elicit a response, then let us know. If there are areas of celestial navigation that are of a particular interest to you, let us know. You, our members, are the only reason The Navigation Foundation exists. If you are not pleased with us, then we must change to fulfill your expectations. But we have to know your expectations, so write us.

In Newsletter Number 71 I informed you, with the "Re-Invention of Government" NOA/NOOA/NIMA publications were being printed by the Government Printing Office and the price had increased in some cases to 500% over the old price charged for navigation publications. For instance, the NIMA PUB 229/249 sight Reduction Tables were $13.50 in September 2000. Today the same publication from the Government Printing Office is $47.00 and PUB 249 is $44.00. To date we do not know how many of the NIMA/NOS Publications will be printed at what cost. VP-OS Universal Plotting Sheets are no longer being printed by the government. The current Government Printing Office price for the Nautical Almanac is $40.00.

Now that the bad news has been covered, there is good news to report to you. Members only can purchase the Commercial Version of PUB 229 or 249 throughThe Navigation Foundation at $19.95 and get a 20% discount on your purchase. VP-OS Universal Plotting Sheets are available through The Foundation at $4.95 per pad of 50, with a 20% discount. Again, that is for members only. For your non-member friends they can purchase 229 or 249 from CelestAir, Inc. for the full price ($19.95). The Commercial version of the Nautical Almanac is available from The Foundation at $22.95 with a 20% discount, or you can order direct from Paradise Cay Publications for the full price of $22.95.

Help your foundation by getting new members, ordering charts, books and publications, both government and commercial, through us. Each order helps a little and each "little" will keep us viable. As you know, the Foundation has no paid employees and the directors handle all of the administration, orders and replies because they wish to keep the art of celestial navigation alive. The directors receive no remuneration for their efforts. We are truly a non-profit organization which is dedicated to serving its members.

The March 10, 2000 issue of *Trident*, a magazine published by the Brigade of Midshipmen, U.S. Naval Academy, reported that Midshipman, fourth class, Alexander Erving, recipient of both the Rear Adm. Thomas D. Davies Award for Excellence in Navigation, and the Tabor Academy of Marion, Mass., Award for Excellence in Celestial Navigation, had been designated as a Senior Skipper. The Senior Skipper qualification entitled Midshipman Erving to command an Academy sailing vessel larger than 40 feet in offshore waters day and night, using celestial navigation.

Midshipman Erving was the first in his class and no doubt the first "plebe" to receive the qualification.

DO YOU KNOW . . . ?

By Ernest Brown

How often Cold War U.S. Air Force navigation students were required to observe and plot a 3-star fix, calibrate their air speed, compute wind speed and direction using a special circular slide rule, determine ground speed and track, determine ETAs to upcoming action points, and determine course corrections, with fix errors greater than 5 NM being deemed unacceptable?

(Answer page 11 of this issue.)

At the Tabor Academy, Erving sailed aboard the school's 114-foot sail training vessel. He served as a deck hand and then Watch Officer's Mate, running an Orientation at Sea summer program for new students. As a high school senior he served as Watch Captain and was responsible for half of the crew sailing between Massachusetts and the British Virgin Islands, using only celestial navigation techniques.

NAVIGATION NOTES

The Astro Compass

(The following information on the astro compass is from the 1955 edition of H.O. Pub. No. 216, Air Navigation)

Description. — The **astro compass** is not a compass in the sense that it provides a continuous and automatic indication of a reference direction, for it indicates such a direction only momentarily and then only if it is oriented to the celestial sphere, by means of celestial coordinates, and to the horizontal. It is used by an air navigator (1) to obtain the true heading of the aircraft, (2) to find he true or relative bearing of an object, and (3) to identify celestial bodies.

Referring to figure 1, the **standard** or base is installed in the aircraft in such manner that when the astro compass is in place, the lubber's line points forward, parallel to the longitudinal axis. The instrument is leveled by means of the two leveling screws until the bubbles in the two levels are centered. This places the azimuth scale in the horizontal plane. When it is set to the true heading of the aircraft, all graduations on the scale are aligned with the true directions (fig. 2). If the latitude of the place of observation is now set on the latitude scale, the plane of the local hour angle scale is parallel to the plane of the celestial equator (fig. 3). An **alidade** or **sighting assembly** (fig. 4) is mounted in such a manner that when the LHA scale is set to 0°, the alidade is aligned with the celestial meridian. If the alidade is now rotated about its horizontal axis, the line of sight moves along an hour circle and the angle formed with the plane of the celestial equator (declination) is measured on the declination scale. As the LHA scale is rotated, the line of sight follows a parallel of declination. Thus, as in figure 5, if the LHA index is aligned with the observer's celestial meridian, the line of sight indicates the point on the celestial sphere having the LHA and declination set on the respective scales.

The coordinates of the celestial equator system are hour angle and declination; those of the horizon system are altitude and azimuth. The two systems are connected by the coordinate, latitude. We thus have five coordinates, any three of which determine the other two. Since the astro compass is designed to find azimuth, no provision is made for an altitude scale. When the instrument is properly installed, leveled, and aligned with a celestial body, known coordinates set on any three of the scales determine the setting of the fourth scale.

The sighting assembly (fig.1) can be used to observe a celestial body, or to take a bearing on any object. It contains a small lens to bring two convergent luminous lines on the far vane into focus. The lens is used only for this purpose and not for observing celestial bodies. Below the lens is a translucent screen having two vertical lines which extend across the base of the alidade to the middle **shadow-bar** of the far vane. In stellar observations, the star is seen *above the lens* at the junction of the luminous lines (extended). See figure 6. For solar observations, the shadow of the shadow bar falls between the lines on the translucent screen.

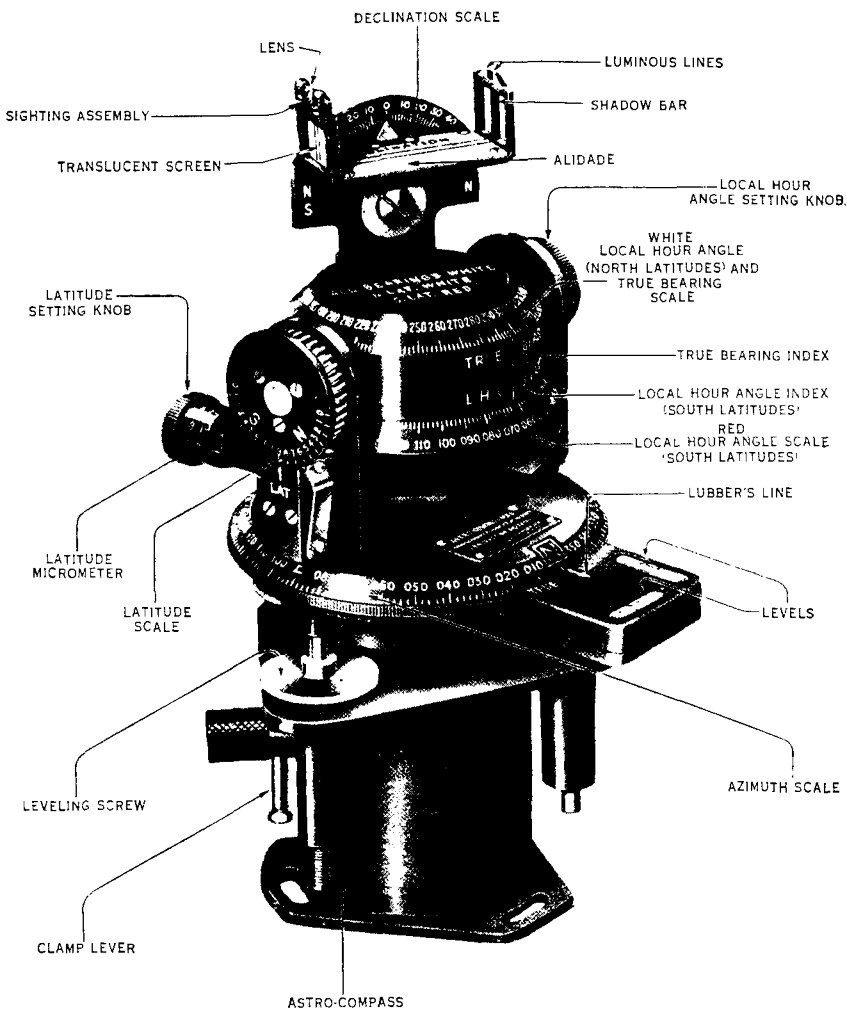


Figure 1 — An astro compass

The bearing index is on the LHA drum above the index for LHA, south latitude. To take a bearing, set the latitude scale to 90°, as in figure 1. When the alidade is aligned with the desired object, the bearing index indicates the relative bearing if the azimuth scale is set with the large "boxed N" (fig. 1) at the lubber's line, and the true bearing if the azimuth scale is set with the true heading of the aircraft at the lubber's line.

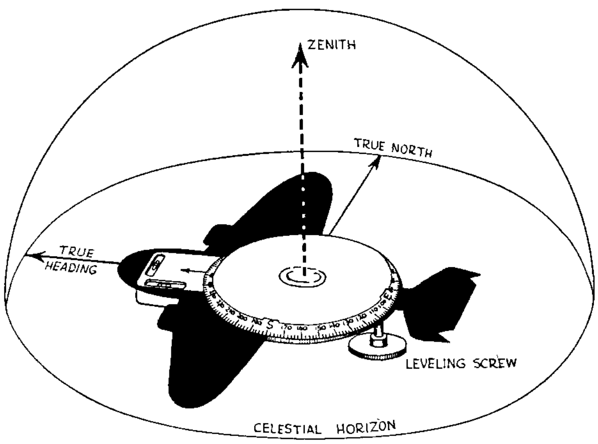


Figure 2 — when the instrument is level, the plane of the azimuth scale is parallel to the horizon. When the scale is set to the true heading, all graduations show true directions (horizon system).

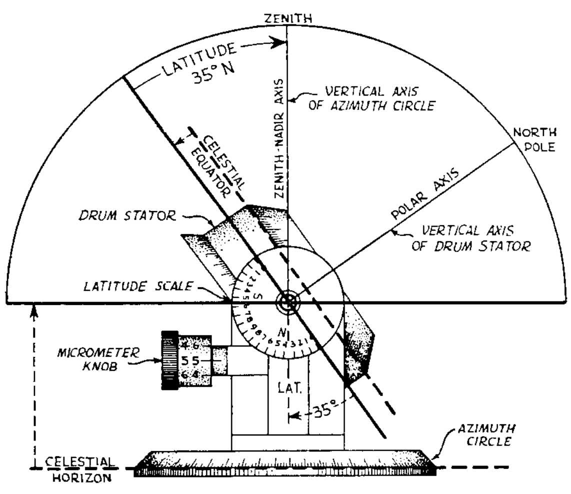


Figure 3 — Setting the latitude scale aligns the LHA scale with the celestial equator (celestial equator system)

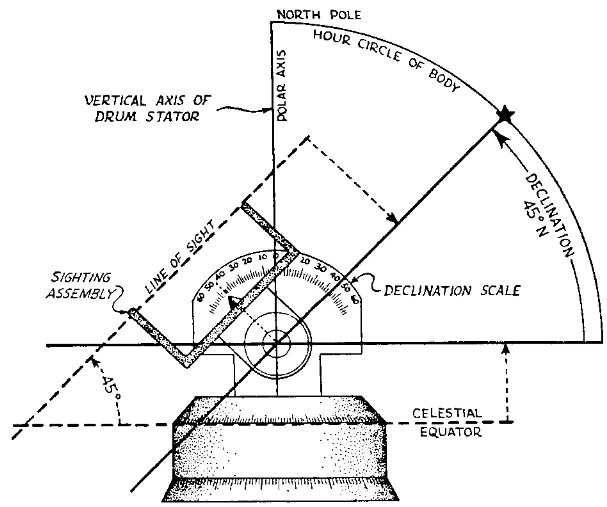


Figure 4 — Declination is set on the declination scale.

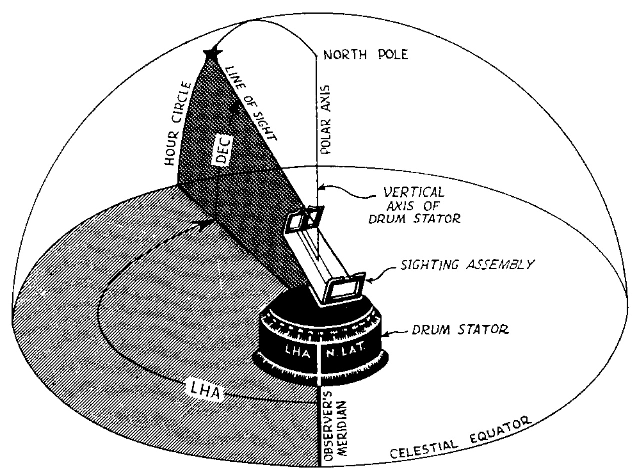


Figure 5 — Adjustment of LHA and d *scales locates a celestial body.*

To find true heading. — In each of the following cases the instrument is placed in the standard which is aligned with the longitudinal axis of the aircraft, and is then accurately leveled using the bubbles. Latitude is set to the nearest 0°.5 using the latitude micrometer. Local hour angle and declination are set to the nearest 1°.

(1) Set the latitude scale to the latitude of the estimated position, using white figures for north latitude and red figures for south latitude.

(2) Compute the LHA of the body for the longitude of the estimated position and the time of the observation. LHA=GHA-west longitude (or+east longitude).

(3) Set LHA on the hour angle scale. The index for south latitude is adjacent to "boxed N" (000°) on the azimuth scale and the lower (red) LHA scale is used. For north latitude the index is on the opposite side and the upper (white) scale indicates LHA.

(4) Set the body's declination on the declination scale. The white figures are for north declination and the red are for south declination.

(5) Rotate the instrument until the alidade is aligned with the body. In the case of the sun and frequently of a bright moon, the shadow of the bar is seen to fall between the parallel lines on the shadow screen. In the case of a star, a plane, or faint moon alignment is achieved by placing the eye close to the lens so that the luminous guidelines can be seen through it and the body above it (fig. 6). The point of intersection of the two guidelines (extended) coincides with the body when the instrument is accurately oriented.

(6) Read true heading on the azimuth scale at the lubber's line.

True bearing method — In latitudes between approximately 30° S and 30°N the shadow bar of the alidade becomes so nearly horizontal that accurate azimuth readings are difficult to make. In this case the following method is recommended, particulary for stars:

(1) Set the latitude scale to 90°.

(2) Compute the azimuth of the selected body for the time and place of observation. H.O. 249 is convenient for this purpose.

(3) Set the azimuth of the body on the LHA scale opposite the true bearing index.

(4) Rotate the instrument until the body appears in the sight, tilting the alidade upward toward te body as necessary.

(5) Read true heading on the azimuth scale.

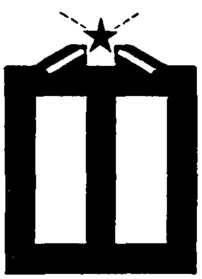


Fig. 6 — At night, a body is located at the junction of the two luminous lines.

The azimuth of Polaris is obtained from a special table in *The Nautical Almanac* for any northern latitude from 0° to 70°. At high latitudes the azimuth of Polaris may depart 3° or more from true north, but in this region its altitude is so high as to make azimuth observations unreliable.

Relative bearing method. — (1) Set "boxed N" on the azimuth scale to the lubber's line.

(2) Set the latitude scale to 90°.

(3) Rotate the LHA drum and tilt the alidade as necessary upward toward the body.

(4) Read *relative* bearing at true bearing index.

(5) Compute the azimuth of the body observed.

(6) True heading is obtained by subtracting the relative bearing from the azimuth of the body.

To steer a true heading. — This method may be used in regions where magnetic compasses are unreliable.

(1) Set the desired true heading against the lubber's line.

(2) Set the latitude of the estimated position on the latitude scale.

(3) Compute the LHA of the body for the longitude of the estimated position and the time of the observation.

(4) Set the declination scale to the declination of the body.

(5) Coach the pilot until the body is sighted at the alidade. The pilot notes the reading of his direction gyro or other steering compass and steers this course until the next astro check.

Alternative method — (1) Find the present true heading of the aircraft.

(2) Compute the difference between TH thus found and the desired TH.

(3) Alter heading left or right by the amount of this difference.

To obtain a bearing of a distant object. — (1) Set the latitude scale to 90°.

(2) Set the azimuth scale to the true heading if a true bearing is desired, and to "boxed N" if a relative bearing is desired.

(3) Rotate the hour angle drum and tilt the alidade as necessary toward the distant object.

(4) Read the bearing (relative or true) at the lubber's line.

To identify a star or planet. — (1) Set the azimuth scale to true heading.

(2) Set the latitude scale to the latitude of the estimated position.

(3) Rotate the hour angle drum and tilt the alidade as necessary toward the body. These adjustments should be made carefully until the body is at the intersection of the luminous guide lines, extended. *Note the time.*

(4) Read LHA and declination on their respective scales.

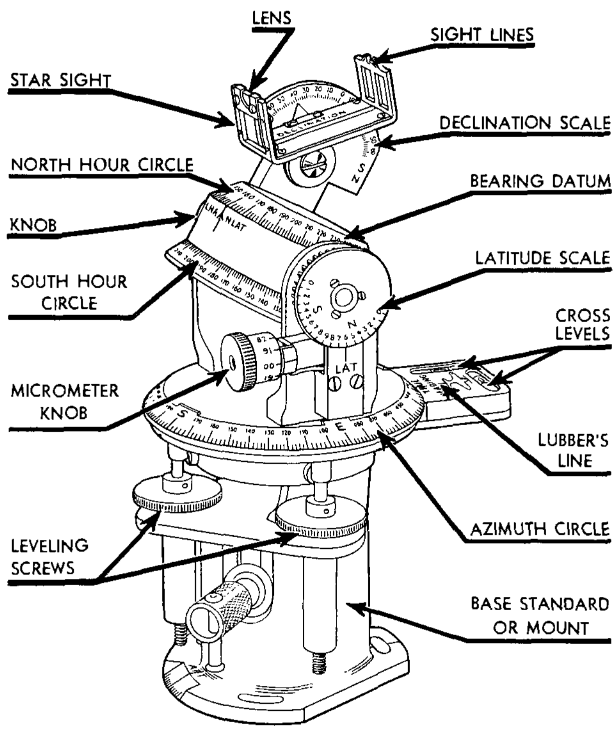


Figure 7— Line drawing on astro compass.

(5) Compute GHA Aries for the time of sight.

(6) Compute GHA Star by applying the longitude of the EP to the LHA Star as read on the scale, adding if in west longitude and subtracting if in east longitude.

(7) Compute the sidereal hour angle of the body by subtracting GHA Aries from GHA Star.

(8) From the table on the inside front cover of *The Air Almanac* find the star which most nearly corresponds to the computed SHA (step 7) and the measured declination (step 4).

(9) If SHA and declination do not correspond with any of the tabulated values, the body may be a planet. Enter the daily page of *The Air Almanac* for the current date and search in the planet columns for a correspondence of GHA Star (step 6) and declination (step 4).

(10) If still no correspondence is found and no mistake in measurement or computation has been made, the body may be one of the stars or planets not tabulated in *The Air Almanac*. The search can be continued, if expedient, in *The Nautical Almanac*. The necessity for such persistence is rare in air navigation, since other stars are usually available for observation.

NEWSLETTER INDEX

Index 92 (1-35) published with Issue Thirty-five (1991) is an index covering Issue One through Thirty-five.

Index to Navigation Problems (4-33), published in Issue Thirty-three (Fall 1991), covers navigation problems in Issues Four through Thirty-three.

Index to Navigation Personalities (12-53), published in Issue Fifty-three (Fall 1996) covers personalities in Issues Twelve through Fifty-three.

Index to Book Reviews (36-53), published in Issue Fifty-three (Fall 1996), covers reviews in Issues Thirty-six through Fifty-three.

Index to Navigation Basics Review (13-58), published in Issue Fifty-eight (Winter 1997-98), covers those articles written as reviews of the basics of navigation in Issues Thirteen through Fifty-eight.

Index to Navigation Foundation Peary Project (23-42), published in Issue Fifty-eight (Winter 1997-98), covers articles and comments on the analysis of the data of Robert E. Peary's expedition to the North Pole in 1909 in Issues Twenty-three through Forty-two.

Index to Marine Information Notes (3-60), published in Issue Sixty (Summer 1998), covers only those notes of more lasting interest in Issues Three through Sixty.

Index to Navigation Problems (34-60), published in Issue Sixty (Summer 1998), covers navigation problems in Issues Thirty-four through Sixty.

Index to DO YOU KNOW . . . ? (36-63), published in issue Sixty-three (Spring 1999), covers questions in Issues Thirty-six through Sixty-three.

Index to Navigation Notes (1-74), published in Issue Seventy-four (Winter 2001-02), does not include the navigation problems and history articles previously published in the Navigation Notes section.

ISSUE	ARTICLE	AUTHOR
Fall 1994	Latitude by Polaris	Leonard Rifkin
Seven Winter 1984-85	Salvaging Sights in Ageton's "Forbidden Zone"	
Eight Spring 1985	Rating The Quartz Timepiece	Paul E. Shaad
	Selecting Stars for Pre computation	T. D. Davies
Nine Summer 1985	Correction for Nutation Precession and Aberration	T. D. Davies
Ten Fall 1985	Rating Chronometers	John M. Luykx
Eleven Winter 1985-86	The Dot Reckoner	Leonard Gray
Twelve Spring 1986	Navigation Notes (Improvement in Precession & Nutation Correction Tables in *Sight Reduction* Tables for 42 Stars	T. D. Davies
Thirteen Summer 1986	The Constant Error Circle: An Alternative Method	T. D. Davies
	Navigation Instructors	
Fourteen Fall 1986	The Local Apparent Moon Sight	Macey Casebeer
	Assumed Longitude by Direct Calculation	Allan Bayless
Fifteen Winter 1986-87	Position from Observation of a Single Body	James N. Wilson
	The New "Floppy Almanac"	Allan Bayless
Sixteen Spring 1987	Star Finders	Anthony L. Kelley
	Some Interesting Tales from Sweden	T. D. Davies
Seventeen Summer 1987	The Haversine	Donald J. Pegg
Eighteen Fall 1987	The Indirect-Horizon Scope	T. D. Davies
Nineteen Winter 1987-88	Chronometer Accuracy	John M. Luykx
Twenty Spring 1988	Notes on Shiphandling	H. F. Van Der Grinten
Twenty-one Summer 1988	The art of the Sextant, Dipping the Star	T. D. Davies
Twenty-two Fall 1988	Constant Error Circles Revisited	T. D. Davies
The Vertical Sextant	Byron Franklin	
Twenty-four Spring 1989	Notes on the Sextant	Paul M. Anderton
	Distance by the Graphic Method	Anthony L. Kelley
Twenty-five Summer 1989	Bowditch: The Art of Navigation in His Day	Erving Arundale
	Celestial sights Near the Pole	T. D. Davies

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	Notes on the Accuracy of the Nocturnal Based on Observations Taken in April 1989	John M. Luykx
Twenty-six Fall 1989	The Land Navigators	T. D. Davies
Twenty-seven Winter 1989-90	A Graphic Solution to the Noonday Fix Problem	N. E. Andross
Twenty-eight Spring 1990	Navigation Programming	Harry H. Dresser, Jr.
Twenty-nine Summer 1990	Measuring the Dip of the Horizon	T. D. Davies
Thirty Fall 1990	Probability and the Celestial Fix	T. D. Davies
Thirty-one Winter 1990-91	Remarks on Aspects of Polar Navigation	T. D. Davies
	New Interest in Lunar Distances	T. D. Davies
Forty-six Winter 1994-95	Night Sextant Observations	John M. Luykx
Forty-nine Fall 1995	Comments on the 1995 Edition of Bowditch	Ernest Brown
Fifty-four Winter 1996-97	Pocket Sextant for Use on Land	John M. Luykx
Fifty-five Spring 1997	Accuracy of Navigation Timepieces	John M. Luykx
Fifty-six Summer 1997	Equation of Time by Nautical Almanac	Ernest Brown
Fifty-seven Fall 1997	Accurate Time	Wilson Van Ducen
	Some Comments on Establishing Longitude by Means of a Noon Sight	Eric B. Forsyth
	Regulation of Master Navigation Watch	John M. Luykx
	Calculate Your Own Nautical Almanac Data for Sun Sights	Bill Murdoch
Fifty-eight Winter 1997-98	Advice for Observing the Lunar Distance	Bruce D. Stark
	Clearing a Lunar Distance with the New Tables	Bruce Stark
	Calculate Your Own Nautical Almanac Data (correction)	Bill Murdoch
Fifty-nine Spring 1998	More on the Lunar Distance	Bruce Stark
	Celestial Sight Reduction Using Direction Cosines	John Muirhead
	Clearing a Lunar Distance with the New Tables (correction)	Bruce Stark
	Calculate Your Own Nautical Almanac Data for Sun Sights (correction)	Bill Murdoch
Sixty Summer 1998	Ideas and Equations Behind My Tables for Clearing the Lunar Distance	Bruce Stark

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	Box Sextant with Artificial Horizon for Use on Land, Sea, and in the Air	John M. Luykx
Sixty-one Fall 1998	The Peter Ifland Collection of Navigation Instruments	John M. Luykx
	A Wayward Problem	John G. Hocking
	Closed Form Solution of Lat. and Long. with Two Sights	James O. Muirhead
Sixty-two Winter 1998-99	Spherical Trigonometry in a Gale	Richard S. Preston
	Diagram for Graphical Correction to be Applied to Ex-Meridian Altitudes	
Sixty-three Spring 1999	Announcement of the Nautical Almanac Office Sesquicentennial Symposium 3-5 March 1999	
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Sixty-four Summer 1999	A simplification of the Method of Lunars	Richard S. Preston
	The Complete On-Board Celestial Navigator	George C. Bennett
Sixty-five Fall 1999	A Field Assessment of Stark's Tables for Clearing the Lunar Distance and Finding GMT by Sextant Observation	Robert Eno
	A Simplification of the Method of Lunars (correction)	Richard S. Preston
	Millennium Madness: 2000 or Bust!	Peter Ifland
	The Development of Sight Reduction Tables for Air Navigation (a continuation)	Ernest Brown
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Sixty-seven Spring 2000	Millennium Madness: 2000 or Bust! (a clarification)	Peter Ifland
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	Federal Radionavigation Plan	
	Nautical Astronomy in Lewis and Clark's Day	Bruce Stark
	The Future of Almanac Data in the United States	John A. Bangert
Sixty-eight Summer 2000	Evolution of the Products of the Nautical Almanac Office	Alan D. Fiala
	The Personal Error	Wilson Van Dusen
	Artificial Horizons, Octants, and Back Observations as Used by Lewis and Clark	Richard S. Preston
Sixty-nine Fall 2000	Evolution of the Products of the Nautical Almanac Office (a continuation)	Alan D. Fiala
	The Marine Super Integrating Bubble Sextant	John M. Luykx
Seventy Winter 2000-01	Artificial Horizons, Lunars and Longitude in Australian Exploration at the Time of Lewis and Clark	Kieran Kelly
	The Lifeboat Sextant in World War II	Capt. Warren G. Leback

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Seventy-one Spring 2001	A Lewis and Clark Lunar	Bruce Stark
Seventy-two Summer 2001	The Long-Term Almanac in the 1958-1984 Editions of Bowditch	Ernest Brown
Seventy-four Winter 2001-02	The Astro Compass	

Index to History of Navigation (3-74), published in Issue Seventy-four (2001-02), covers history articles in Issues Three through Seventy-four. This includes articles under the heading Navigation Notes in Issues Three through Seven.

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Three Winter 1983-84	History of Navigation (Hipparchus)	T. D. Davies
Four Spring 1984	History of navigation (Division of Circle)	T. D. Davies
Five Summer 1984	History of Navigation (Backstaff)	T. D. Davies
Six Fall 1984	History of Navigation (Backstaff)	T. D. Davies
Seven Winter 1984-85	History of Navigation (Astrolabe)	T. D. Davies
Nine Summer 1985	Magnetic Compass	T. D. Davies
Ten Fall 1985	Nocturnal Time	T. D. Davies
Eleven Winter 1985-86	Harrison's Clock	T. D. Davies
Twelve Spring 1986	Columbus' Ability to Determine Latitude by Polaris	T. D. Davies
Thirteen Summer 1986	Mathematical Tables	T. D. Davies
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Fifteen Winter 1986-87	More on Finding the Longitude at Sea Using the Chronometer	John M. Luykx
Sixteen Spring 1987	Getting Chronometer Error and Daily Rate	John M. Luykx
Seventeen Summer 1987	The Tordesillas Line	T. D. Davies
Eighteen Fall 1987	Early Altitude Measuring Instruments: The Seaman's Quadrant	John M. Luykx
Nineteen Winter 1987-88	Early Altitude Measuring Instruments: The Mariner's Astrolabe	John M. Luykx
Twenty Spring 1988	Early Altitude Measuring Instruments: The Cross-Staff	John M. Luykx

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Twenty-one Summer 1988	Early Altitude Measuring Instruments: The Back-Staff	John M. Luykx
Twenty-two Fall 1988	Early Altitude Measuring Instruments: The Sea-Ring	John M. Luykx
Twenty-three Winter 1988-89	Early Time Measuring Instrument: The Ring Dial	John M. Luykx
Twenty-four Spring 1989	Early Time Measuring Instruments: Nocturnal	John M. Luykx
Twenty-five Summer 1989	Early Dip-Measuring Instruments: The Navigator's Prism	John M. Luykx
	Bowditch: The Art of Navigation in His Day	Erving Arundale
Twenty-six Fall 1989	Artificial Horizon Sextant I	John M. Luykx
Twenty-seven Winter 1989-90	Artificial Horizon Sextant II (continuation)	John M. Luykx
Twenty-eight Spring 1990	Artificial Horizon Sextant III (conclusions)	John M. Luykx
Twenty-nine Summer 1990	The Weems Star Altitude Curves	John M. Luykx
Thirty Fall 1990	The Bygrave Position Slide Rule	John M. Luykx
Thirty-one Winter 1990-91	Le Grant Routtier of Pierre Garcie (1520)	John M. Luykx
Thirty-three Fall 1991	Celestial Navigation by Chronometer Time Sight	John M. Luykx
Thirty-four Winter 1991-92	The Quincentenary of the First Columbus Voyage to the Americas	John M. Luykx
Thirty-five Spring 1992	The Quincentenary of the First Columbus Voyage to the Americas (a continuation)	John M. Luykx
Thirty-six Summer 1992	The Quincentenary of the First Columbus Voyage to the Americas (a continuation)	John M. Luykx
Thirty-seven Fall 1992	The Quincentenary of the First Columbus Voyage to the Americas (conclusion)	John M. Luykx
Thirty-nine Spring 1993	Christopher Columbus: A Man of History	John M. Luykx
Forty Summer 1993	John Harrison: Horologist	John M. Luykx
Forty-one & Forty-two Fall/Winter 1993-94	The Fleuriais Gyroscopic Sextant	John M. Luykx
Forty-three Spring 1994	Determining the Longitude of a Place by Chronometer	John M. Luykx
Forty-four Summer 1994	Origins of Geomagnetic Science	David G. Knapp
Forty-five Fall 1994	Origins of Geomagnetic Science (a continuation)	David G. Knapp

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Forty-seven Spring 1995	Origins of Geomagnetic Science (conclusion)	David G. Knapp
Forty-eight Summer 1995	Navigation as it Pertains to Shore Bombardment During Naval Amphibious Operations	John M. Luykx
Fifty-two Summer 1996	The Plath (SOLD) German Navy Gyro Sextant Type KS-3D of 1945	John M. Luykx
Fifty-four Winter 1996-97	Determining Longitude by Lunar Distance Observation (Part 1)	John M. Luykx
Fifty-five Spring 1997	Determining Longitude by Lunar Distance Observation	John M. Luykx
Fifty-six Summer 1997	Determining Longitude by Lunar Distance Observation: A Simple Solution	John M. Luykx
Sixty-one Fall 1998	Excerpt from *Origin of Geomagnetic Science* (1945) European Origin Now Accepted (as to the possible Chinese origin of the magnetic compass)	
Sixty-two Winter 1998-99	The Brown-Nassau Spherical Computer	John M. Luykx
Sixty-five Fall 1999	The Development of Sight Reduction Tables for Air Navigation (a continuation)	Ernest Brown
Sixty-six Winter 1999-00	A Chronology of the Development and Publication of Ephemerides and Almanacs Used for Navigation	Peter Ifland
Sixty-seven Spring 2000	The Tamaya Artificial Horizon Marine Sextant with Six Shot Mechanical Averager	John M. Luykx
Sixty-nine Fall 2000	History of the American Nautical Almanac Office	Steven J. Dick
Seventy Winter 2000-01	History of the American Nautical Almanac Office (a continuation)	Steven J. Dick
Seventy-one Spring 2001	History of the American Nautical Almanac Office (a continuation)	Steven J. Dick
Seventy-two Summer 2001	History of H.M. Nautical Almanac Office	George A. Wilkins
Seventy-three Fall 2001	History of H.M. Nautical Almanac Office (a continuation)	George A. Wilkins

ANSWER TO DO YOU KNOW . . .?

(from page 1)

No more than every 20 minutes. This frequency was essential because the Strategic Air Command, in particular, could not rely upon land-based aids such as Loran because of vulnerability of such aids to enemy attack.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-FIVE, SPRING 2002

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

We are gratified with the response from our members for more letters to the editor. Some will have to wait to be included in the Summer Issue. We thank you for the response.

As we stated in Newsletter, Issue #74, Winter 2001-2002, there is a source of commercial versions of Publication PUB 229 and 249 for a list price of $19.95 with a members discount of 20%. The Government issues are also available at a substantially higher price but with only a 15% discount. The problem is the Government Printing (GPO) was directed to take over all of the navigation publications formerly supplied by NOAA/NOS. The GPO price is higher than NOAA/NOS and gives The Navigation Foundation a much less discount than NOAA/NOS to pass on to our members. The Government issue price for PUB 229 is $47.00 and PUB 249 is $44.00. All orders are plus postage.

Government charts are $17.00 list price with a members discount of 20% for all orders under $50.00 and a 25% discount for all orders over $50.00. Back issues of the Newsletter are available. With the price for 1 - 3 of $5.00 each, 4 - 10, $4.00 each, and 10+, $3.00 each. All are postage paid.

As with the advent of GPS, interest in celestial navigation has waned. With the Internet, the interest in writing letters has followed. However, E-mail messages are just as welcome as letters to the editor as if they were sent via the United States Postal Service. So please feel free to give us your questions, comments, views, gripes, complaints or compliments on the Internet. Our

E-mail address is navigate@ix.netcom.com. Each one is answered within a day unless I am on travel. My wife and I travel extensively in the late Fall, Winter and early Spring. We are seldom away for more than 2 weeks unless it is to China, which is 3 weeks. Upon our return I spend all the time required to fill your orders, answer E-mail and regular mail.

READERS FORUM

Edited by Ernest Brown

Mrs. Angela C. Preston wrote:

"With sorrow I report the death of my husband, Richard S. Preston. He enjoyed your publication and contributed to it. He also taught me to appreciate its contents. In his memory, please continue his subscription" . . .

— *Angela C. Preston*

Squadron Leader Bryan J. Hunt, Royal Air Force, wrote on Feb. 3, 2002:

"I am on service with the Royal Air Force in the Gulf region, working with the US forces in support of Op Enduring Freedom and Op Southern Watch, and have been out here since Oct 01. I managed to obtain a sextant and have taken the time to learn the rudiments of celestial navigation. Being located in a desert with cloudless skies and a good horizon, I have been able to sharpen up my star shots and after a bit of practice, I have been able to determine my position with a fair degree of accuracy. It has been enjoyable for me and has generated a fair amount of interest amongst my colleagues.

DO YOU KNOW . . .?

By Ernest Brown

What obstacle to the use of the sextant the navigator of the *Norge* faced just prior to reaching the North Pole?

(Answer at back of this issue)

"Not much of a story — but it has helped to while away the days out here."

— *Regards, Bryan J. Hunt*

Squadron Leader Bryan J. Hunt wrote again on Feb. 10, 2002:

"Thank you for your encouraging e-mail. I am also a keen offshore yachtsman and have watched others use sextants, and I plan to improve my skills prior to taking my Ocean Yachtmaster exams for the Royal Yacht Association. Following designs in Brig Bagnold's book on pre-war vehicle journeys in Libya, I have constructed a sun compass which takes away the compass deviation problems in vehicles. Luckily I get the chance from time to time to drive off-base and the compass is quite good fun to use for DR navigation — provided that the odometer is correctly set! Certainly more intrinsically interesting than a GPS (which, I confess, I do use).

"Will soon be leaving this location to take up a staff position in Naples — more sailing, but less chance to bashing around the desert and getting into trouble. Per Ardua ad Astra. By struggle to the Stars (the motto of the Royal Air Force)"

— *Bryan J. Hunt*

Member Carey Stead wrote from Dorval, QC on February 9, 2002:

"Thank you for arranging the delivery of a nautical almanac to me.

"Could you also provide me with vol I for the current epoch of the Air Sight Reduction Tables — pub 249. It would be appreciated.

"I am an instructor to a group of five students currently studying celestial navigation. At the current price for Bowditch, I doubt that any of them will buy a copy. Instead, they will rely on the 'on-line' texts of the publication. I have, so far, located three sources for the theory part of the publication, being that part that was in volume I of earlier editions. One of these sources or URL's also provides the tables which are to be found in Vol II of earlier editions. None-the-less, I would like to be in a position to inform these students of the price, including a shipping charge (or estimated shipping charge) of the Foundation for the current (1995) edition. Could you provide this information? It also would be appreciated."

— *Carey Stead*

2000 - 01 *FIONA* VOYAGE

Issue 68 (Summer 2000)	*Fiona's* tentative timetable, 2000-01, and announcement that newsletters for this cruise can be downloaded from the website www.yachtfiona.com
Issue 70 (Winter 2000-01)	Newsletter #1 from Alesund, Norway, in August 2000 following visits to Iceland and Jan Mayen Island north of the Arctic Circle.
Issue 75 (Spring 2002)	Newsletters #2 - #4

Member Eric B. Forsyth wrote this Newsletter #2 from Lisbon Portugal in October, 2000:

NEWSLETTER #2

"Dear Friends, We are tied up in the magnificent marina that forms part of the impressive Expo 98 site in Lisbon. It is quite definitely the end of a phase in the cruise. We have spent nearly three months since leaving Norway mostly day sailing: tied up or anchored each night in Scotland, Ireland and Portugal. This is reflected in the mileage logged: only 2,207 nm since leaving Norway. But the next leg will bring the average up; Madeira, then St. Martin in the Caribbean by Christmas. Before that I will fly to New York for a couple of weeks.

"When we left Norway we saw the Northern Lights for the first time in the cruise; further north it was too light but the apple green curtain appeared in the northern sky after sunset as we ploughed our way to the Shetland Islands. We also sailed through the North Sea oil field; one evening we had twenty rigs in sight at the same time. As we approached the islands the wind piped up on the nose and we gave up the idea of making Lerwick by nightfall, instead we tacked into a wide bay on the southeast side of Fetlar Island. With gale force 7 forecast, we gratefully dropped the hook before dark and contemplated the barren landscape: almost treeless with a few isolated farms. The next day was an easy sail to the capital, Lerwick. This old town of sturdy, stone buildings was a great introduction to what would be a dominant motif of this part of the cruise: European history. Lerwick is so picturesque, with twisting quaint streets that scarcely run twenty yards before disappearing round a corner, that it could form a set for 'Brigadoon'. Doug was delighted to be re-acquainted with the typical highland pub. An overnight sail brought us to Kirkwall, the principal town of the Orkneys. We tied up next to several rather dirty and smelly fishing boats. We toured the island by bus and stopped off in Stromness, just in time to visit the beer festival held at a Victorian edifice called the Stromness Hotel. We also visited the Stromness museum, which had a section devoted to the Hudson's Bay Company. Many of their factors (supervisors of the trading post) came from the Orkneys. It was in Stromness that half-Indian children were sent to school, the offspring of the Orkney men and their (temporary) Indian wives. I suspect it was very cold at those HBC trading posts in winter. There was also an exhibit about one of my favorite Arctic explorers, John Rae. In Kirkwall itself there are the wonderful ruins of Patrick Stewart's Palace, a magnificent 16th-century building next to the cathedral. South of Kirkwall lies Scapa Flow, the deep-water harbor used by the British Royal Navy north sea fleet for many years. In 1918 the German fleet surrendered here at the conclusion of WWI, nearly seventy ships. A year later the commanding admiral, Von Reuter, convinced the Versailles peace talks were going badly for Germany, ordered all the ships scuttled. On receiving the secret pre-arranged signal, the skeleton crews on every ship simultaneously sank them. At the time, a party of school children was touring the impressive sight in a launch. Goodness knows what they thought as each mighty battleship began to sink and turn turtle. 'It wasn't my fault miss, honestly, I didn't touch anything!' Salvaging the wrecks provided work in the Orkneys for years. There is some suspicion that the Brits colored the reports of the treaty negotiations received by the German admiral, as they did not really want a competitive battle fleet left in Europe in the post-war years.

"We powered overnight to Inverness across a calm sea full of coastal traffic. At Inverness John signed off and we were joined by Colin, a serious Englishman who was studying for his Royal Yachting Association (RYA) skipper's ticket. I had known him many years ago when he spent a sabbatical leave at my laboratory on Long Island. In addition, my old friend Derek and his wife, Hilary, joined us briefly for the passage through the Caledonian Canal to the Atlantic Ocean.

"The passage is real fun. There are lunchtime and evening tie-ups, often near castle ruins or charming Scottish pubs. The highlight is a traversal of Loch Ness, of Monster fame. The highland scenery is magnificent the whole way. There are a couple of dozen locks and *Fiona* was raised to over a hundred feet above sea level. When Derek and Hilary left us at Fort William we sailed to Tobermory on the island of Mull. We took a bus ride to Craignur, where a gimmicky narrow gauge steam railway transports tourists to a restored family castle and garden called Torosay. By sheer chance the late owner, David James, was in the Royal Navy in 1944 when he helped build the base at Port Lockroy in Antarctica, the southerly destination of *Fiona's* 1998-99 cruise. Before that he had served on MTB's in the channel, got captured, busted out of the POW camp and was subsequently posted to the Antarctic to keep him out of more trouble. From Tobermory our destination was Coll, a remote island on the western fringes of Scotland with a population of 140 hardy souls. The forecast was not good — gales, gales, and our anchorage was open to the south. The next day we left with the hope of sailing to Ireland, but wind and seas were against us. The forecast was force 8, perhaps 9, so with rare prudence we altered course for a cove on the SW corner of Mull. We sailed past Staffa on the way with Fingal's Cave on the south side. On entering the cove the engine refused to start and we anchored under sail. The problem lay with the starter motor. After a couple of greasy hours in the engine room, I changed the starter for the spare which *Fiona* had carried on all her previous voyages without ever being needed. The SW gales persisted but never mind, we were only four miles from Iona, so a bus ride and a trip on the ferry landed us there for a tour of the famous abbey. By the 6th century A.D. monks were discovering the western islands and establishing themselves there, goodness knows why. The living must have been terribly hard. Later the Vikings made life even tougher. The abbey has been restored and is used today as a religious retreat. The museum contains some great 12th and 13th century effigies of dead knights displaying the Norse influence. The nunnery, established in the 12th century, lies in ruins. A westerly wind gave us hard sail past Bloody Foreland, the NW corner of Ireland, and in view of the time lost at Mull we sailed right past the mouth of Donegal Bay without stopping and anchored at Clifden, in County Galway, two days out from Mull.

"Clifden is an interesting town. It is about as far west as you can get in the British Islands. For years, Marconi maintained a radio transmitting station nearby in the early part of the 20th century. When Alcock and Brown made the first non-stop flight across the Atlantic in 1922, they crash-landed at Clifden. The mayor at the time, bedeviled by the poverty of the area, envisaged a great airport because of the proximity to the American continent. We took a bus ride to Galway, the nearest city. As the bus trundled along the coast road, I was struck by the harshness of the countryside — vast gray-green rocky outcropping interspersed with bogs. Here and there stood the gable ends of small, ruined cottages, probably abandoned in the Great Famine of the 1850's. More on that subject later. From Clifden we beat past Slyne Head with a moderate wind and headed for the Aran Islands. We moored in Kilronan harbor, on the largest of the islands, Inishmore. Until very recently life was hard on those islands, located on the fringes of the Atlantic Ocean west of Galway. A famous documentary, 'Man of Aran', made by Robert Flaherty in the 1930's, is shown several times daily at the visitor center. In order to grow anything the islanders had to scrounge soil from cracks in the rocks and mix it with seaweed. Now they just go to the supermarket. There is a fantastic iron-age fort on the west side of Aran overlooking a 300 ft vertical cliff. In some ways it reminded me of the defensive Maori settlements I saw in New Zealand in 1996. Apparently in all primitive societies there were always people who found it easier to kill and steal rather than toil to produce food. Have we changed much? When we returned to the boat, we found the wind was forecast to be NW for the night so we slipped the mooring for an overnight sail to Dingle. Any help in sailing around the prominent capes, which jut out to the SW, was welcome. This part of Ireland is full of pre-Viking monasteries. On a tour our guide claimed 440 A.D. for the founding of the earliest, which I felt was a little fishy, as that would pre-date the arrival of Christianity in the British Isles. Still, the ruins are obviously very ancient. One small building, possibly 8th century, known as the Gallarus Oratory, is still in perfect condition and quite watertight. It si constructed of dry stone, no mortar is used, even for the roof. The ruins of many churches in the area contain graves from the 12th century and again reflect the enormous Viking influence after about 1000 A.D. It seemed to rain continuously during our stay in Dingle. From Dingle we sailed, again with a NW wind, to Sneem Harbor which is a very pleasant, wooded, anchorage. It is a two-mile walk to the village itself, a picture perfect Irish village with a rustic bridge over a gurgling river. As we were leaving to walk back to the boat, a van in the small market area was displaying antiques for sale. There were several small oil paintings in heavy, old-fashioned gilt frames. The owner said he had gotten them from a nunnery which was being closed. One of small fishing boats clawing off a stormy coast caught my eye and I hesitantly asked the price. When he quoted forty pounds (about $50) I could not resist buying it. At that price Colin also bought one. It left us with the problem of getting them back on board via the dinghy and then protecting them until we could get them home. When Colin examined his painting more closely at home he found our 'paintings' were actually varnished prints — but they look nice! We sailed form Sneem to Dursey Sound, a turbulent, tide-wracked strait, and then to an anchorage at Castletown, where we refueled at the fishing boat dock in the morning. We were now on the south coat of Ireland and were through with beating past rocky capes sticking out in the Atlantic. On the way to Kinsale we sailed past the imposing edifice of Fastnet Rock lighthouse. From Kinsale we had a relatively short sail in heavy weather to Crosshaven; we tied up at the Royal Cork Yacht Club (RCYC), our final port in Ireland, where we planned to rest up for a week before leaving for Portugal.

"In fact there was not a lot of resting achieved: apart from a few repairs to the boat, it had to be restocked for the next leg. In addition, my Aunt May flew in from London with her sons and we had a couple of days in their rented car seeing the sights and chasing down a little family history in Cork. The attentive readers of these newsletters (there must be one or two) will recall I visited my great-grandmother's grave on Barbados in 1999 on the return trip from Antarctica. When she died in 1880 her husband returned to Cork and married her sister. Their house is listed in a 1900 census. So, in the pouring rain, May, my cousins and myself tramped through some fairly mean streets looking for my great-grandfather's old addresses. We did find one, (and perhaps two, streets have changed so much in a hundred years). It had been greatly gentrified and looks like it's worth a million dollars. We also visited Cogh (pronounced 'Cove') which is perhaps better known as Queenstown, when it was the last European port for many transatlantic liners. In the old railway station, now no longer used for trains, there is an Irish Heritage center. Naturally there is much of the great emigration from Ireland in the 19th century; many left from Queenstown and probably arrived there at that very station. I was surprised at the different emphasis on the tragedy of the Great Famine and subsequent emigration by the Irish, as opposed to the Irish-American view. In the latter, the villains are the English who allegedly refused to provide aid and encouraged emigration to clear the land. The Irish view is more balanced, I thought: that the land was too poor to support so many peasants, and well meaning people in Ireland and England tried to help. When the potato blight was added, the problem was overwhelming. The same benefactors provided money for emigration because it was genuinely felt that the only chance for the poor peasants (who generally agreed) to lead better life was in the New World.

"When we arrived at the RCYC I renewed my friendship with Barbara and Frank Fitzgibbon, who live nearby. We first met during the circumnavigation, 1995-97. Barbara and Frank have a lovely house overlooking the approach to Crosshaven. They invited me and the crew to dinner and later sponsored a cruising evening at the yacht club when we showed the video of the Antarctic cruise (1998-99).

"When we left Ireland we had a stiff NW gale behind us that gave us more than 180 nm made good in the first twenty-four hours, but then the wind switched to SW and we sailed close-hauled, sometimes in gale strength. Near 44°N we sailed into a high that produced lighter wind which finally headed us before dying out. We motored the last eighty miles to Viana do Castelo in Portugal. The swell from the remains of Hurricane Isaac a few hundred miles to the NW caused impressive waves at the mole guarding the entrance to the harbor. It had taken us five days from Ireland.

"As soon as we got to Portugal there was a noticeable improvement in the weather, and Doug was moved to put on shorts for the first time this cruise. However, he enjoyed only a day in Viana before leaving for the U.S. His place was taken by Bill Steenberg, who was actually waiting on the dock at the marina as we pulled in. Bill sailed on *Fiona* last year on the Cape Town to New York leg and has signed up for the transatlantic run to St. Martin.

"Viana do Castelo is a charming town with pleasant plazas, restaurants and pastelarias (my favorite: a variety of cakes and tarts with coffee). There is an imposing church on a hill overlooking the town which is reached by means of the elevador, or funicular. We took a bus to Porto when we tied up in Leixoes, which gave us a chance to see the countryside. The Portuguese are a lovely people, but they do love their dogs, so when walking in town it pays to do so penitently, with head bowed. Many of the harbors on the coast are about thirty-five miles apart. Sailing form one to the other is quite feasible during a daylight run. This set the pattern of our Portuguese cruise — a day sail followed by one or two days in port to allow exploration of early attractions.

"Porto is not recommended for yachts due to heavy seas that frequently break on the bar of the River Douro. It is a fascinating town, almost vertical in places, with red-roofed houses crammed into the slopes. On the south bank are the famous port wine cellars, from which all port is shipped after aging. A tour of the Sandeman cellars revealed why I am quite partial to port: it is 20% brandy, added to 'fortify' it. From Leixoes we sailed to Aveiro, just an overnight anchorage on the river, then we headed for Figueira da Foz, a nice seaside resort. We took a bus to Leiria to inspect the old castle, and the next day a train ride to Coimbra. There is an amazing miniature village, which predates Disney World by about fifty years. But the main point of interest is the site of the country estate where Inez de Castro was murdered in the 14th century. Now it is a very up-market hotel, but they have preserved a small building called the 'Font d'Amores'. The story of Inez is fascinating, so here it is: Prince Pedro, the son of King Afonso IV of Portugal, was forced into an arranged marriage with a noble lady. Although they had three children, the marriage was loveless, typical of the political maneuvering of the period. Pedro fell in love with a lady-in-waiting called Inez and moved her onto an estate at Coimbra. Inez was Spanish and the King was very concerned that Portugal would become embroiled in the feuding between Aragon and Castile. When Pedro's wife died during the birth of her third child, the King decided Inez was too much of a threat and sent three knights to kill her. They tracked her down to Coimbra and stabbed the defenseless lady to death — so much for chivalry. It was at the Font d'Amores, close to the scene of her death, that Pedro and Inez first made love, according to the legend and the tourist bureau. A year later, Alfonso died and Pedro assumed the throne. He had been distraught over the death of his beloved Inez and now he had revenge of sorts. He caught two of the three knights, who died rather cruelly. He then had Inez disinterred from the Monastery of St. Clara and the body moved to Alcobaca. Before reburial, Inez was cleaned up and sat on a throne wearing the crown of Portugal. Pedro made his nobles kneel before her and swear allegiance while kissing her boney hand. Pretty macabre. When we were tied up at Nazare we took a bus to Alcobaca, where Pedro and Inez still lie near each other under elaborate effigies in the vast Monastery.

"From Nazare we sailed to Cascais near Estoril and then arranged to spend a month at the Expo 98 marina in Lisbon. The Expo is still going strong, with crowds on the weekends. The aquarium is fantastic. It is one of the largest in the world. The buildings are most imaginative and interesting. Bill has left for a couple of weeks with friends in Zimbabwe and soon I will fly to New York. Colin has gone home, having accumulated enough sea miles to get his RYA skipper's license and having learned how to plot running fixes from sun sights. Total mileage for the trip so far is 7,701 nm.

— Until next time", Eric

Member Eric B. Forsyth wrote Newsletter #3 from Marsh Harbour, Bahamas in March 2001:

NEWSLETTER #3

"After a hectic two weeks in New York, I returned to Lisbon in mid-November. Bill had already returned to *Fiona* after a brief trip to Zimbabwe. A third crew member, Damian, had arranged to join the boat after crewing on a trip to the Canaries. In fact, he got on board just a few hours before I did. The next day we did the final shopping for fresh provisions in preparation for our transatlantic departure on the morrow. In the afternoon Damian checked his e-mail. I don't know what it said, but he returned to the boat with a taxi, loaded his gear, and hightailed it to the airport. Bill and I looked at each other after his departure in some consternation. During my trip to New York I had had a hernia patched up and I had promised the doctor to take it easy. Bill was a very active 76 years old, but between us I was not too sanguine

about a two-man 3,000 mile transatlantic crossing. Nevertheless, the next day we sailed down the Tagus River past the Lisbon waterfront in mist and rain and set sail in light winds for Madeira. When we arrived, the small inner harbor at Funchal was crowded but we managed to raft up to another boat tied to the wall. We enjoyed our brief stay and took the new teleferique to the top of the hill. A traditional way down, now enjoyed by tourists, is to shoot down the hill on a wicker toboggan, guided by two locals in straw hats. We took the cable car. We checked our e-mail, bought some Madeira wine, refueled and left. Two days out a vast low pressure system over the English Channel gave us some heavy weather with gusts to 30 knots. We reefed in driving rain; later, on my watch, the cumbersome whisker pole came loose from its lashings and nearly went over the side. I managed to catch it and tie it down again. Somehow I wasn't having the kind of restful recuperation envisaged by my surgeon. Fortunately, the weather moderated and we had fairly light winds as we plowed south and west to a point not too far from the Cape Verde Islands. Then the idea was to turn west and pick up the Trade Winds. We finally did get the Trades at 23 degrees north and we headed for St. Martin. Each evening at happy hour we listened to the tape of a book entitled 'The Heart of the Sea", the true story of the sinking of the whaleship *Essex* by a whale in 1821 and the subsequent survival of the crew in small boats as they sailed thousands of miles across the Pacific. Ultimately they were reduced to cannibalism. I eyed Bill, he looked like tough enough eating to me. I hoped we wouldn't meet any aggressive whales. During the trip I had almost daily radio contacts with my friend Mike on the 21 MHz ham band. He lives only a few hundreds yards from my house in Brookhaven. As we approached the Caribbean, the swells grew larger and *Fiona* began to surf down the slopes. This had the effect of momentarily backing the mainsail which filled with a crack as we lost speed on the next backslope. Finally, very early one morning, the sail split from luff to leech from so much slatting, and we doused it. As we were only a couple of days from St. Martin by then, we sailed under the jib alone and dropped our anchor at the usual spot in Marigot Bay without further difficulty. The trip from Lisbon had taken us 30 days. It was my tenth Atlantic crossing, ninth as captain.

"Things started happening after our arrival. Bill flew home for a Christmas in California. My daughter Brenda flew in for a Christmas with me. We all had Christmas dinner with my old friend Kay and her daughter Victoria, who both live in St. Martin. A highlight of the holiday season was a visit to the Chinese circus. I was struck by the thought that Marco Polo probably saw a similar circus seven hundred years ago, as the acrobats and jugglers used minimal props, mostly chairs and umbrellas. After Brenda flew home, two new crew members joined the boat — Teresa, an Italian lady living in Switzerland who sailed with me in Maine in 1999, and Theresa (known as 'Tee') who crossed the Atlantic on another boat the same time as Bill and I. I have visited St. martin on many occasions, but this year I was a little disappointed. When Edith and I first came to Marigot in 1963, it was a village of typical West Indian shacks on the sea shore with a swamp behind. Now there is traffic gridlock; the swamp has been converted to Port Royale marina and the shacks have given way to boutiques and fancy shops. No doubt everyone is much more prosperous, but the price is dirt, noise and crime. Perhaps I am soured by the theft of items from the dinghy almost as soon as we arrived. After a month on the (mostly) quiet Atlantic, I found the noise almost unbearable. Jetskis in the harbor, powerful motorbikes on the roads, blaring loudspeakers from the restaurants and bars, and the jackhammers of endless construction. On the good side were morning coffee and croissants in the Port Royale complex and those wonderful French baguettes, not to mention cheap Mount Gay rum.

"After a few minor repairs and refueling, we pushed off early in the New Year for a crossing of the Anegada Passage to the British Virgin Islands. We cleared in at Virgin Gorda early in the morning and visited the Baths during the afternoon — a crowded anchorage. The next day we sailed to Anegada island. Located in the middle of a reef, it used to be considered dangerous to visit. But now, one advantage of the bare-boat chartering I guess, there is a buoyed channel to the anchorage. The miles of white sand beaches, the clear green water and a friendly bar on the shore make Anegada the epitome of the perfect tropical anchorage. The ladies were entranced and went for long walks collecting shells, driftwood and other flotsam. After a couple of days, paradise was too much to take and we headed for St. John in the U.S. Virgin Islands. Here we ran into a bureaucratic problem: Teresa and Tee are Italian and British respectively; normally both would be given temporary visas on arrival in the U.S. When I took the ship's papers and our passports to the customs and immigration office in Cruz Bay, they wanted to know where the visas were. 'Don't you issue them?' I said. 'Oh no,' was the reply, 'that only applies to arrivals on a scheduled carrier, a foreigner on a private yacht must get a visa first.' I must have looked dumbfounded for the officer quickly said, 'But there is a loophole, you can take your boat back to the British Virgin Islands and return on the ferry. That counts as a scheduled carrier and we can issue a visa. Then you can return with the yacht.' So that is just what we did. We anchored at West End, Tortola and took the ferry, a beaten-up steel boat that got to Cruz Bay in twenty minutes. Actually I was quite pleased to see West End again. Edith and I often anchored there during *Fiona's* 1968-69 cruise. It is, of course, greatly expanded with jazzy restaurants, a big marina, and even a Pusser's Rum bar. From there we sailed to Jost van Dyke and had a drink at Foxy's beach bar before returning to St. John. No problem on entry this time. The ladies had the all-important green slip. We greatly enjoyed St. John. It was not crowded, with several free moorings in nice bays provided by the National Park Service. The visit to the old sugar mill on Leinster bay was especially fascinating, as the ruins are in quite good shape and it was possible to imagine what it was like in the hey-day of the slave-operated plantations. One day we took the ferry to St. Thomas, an act of nostalgia on my part, as it was our base for several months during the 1968-69 cruise and it has been many years since my last visit. It is humming with cruise-ship tourists, but the old Yachthaven marina is very run down. We anchored on the north side of St. Thomas for a night and then sailed to Culebra, a pleasant island about 15 miles east of Puerto Rico. From there we sailed to Vieques, an island mostly owned by the U.S. Navy. They use it as a weapons range and for amphibious training. The Puerto Ricans would like them to go away and there is considerable animosity on the issue. When we landed at a small village on the south shore, we found dozens of signs hanging in the street demanding a 'free' Vieques. The local paper carried stories of hotels in dire straits because the navy had restricted beach access.

"It was getting time to return to the States. I had been asked to attend a meeting of the Cruising Club of America (CCA) in New York City at the end of January as I was about to receive an award. Teresa decided to visit New York at the same time. Unfortunately, when it came to Tee we mutually decided it would be best if she signed off at this stage. She returned to England via New York and I managed to recruit a replacement, Chris, while I was home. While in New York I left *Fiona* at a sumptuous, if expensive, marina near Fajardo. Before we left I rented a car. We drove to San Juan for an interesting day in the old part of town. It was many years since I first visited El Morro, the massive fort guarding the entrance to San Juan harbor. On my first visit, there was an old execution chair in the courtyard. In years past, prisoners were garroted by a metal band attached to the back of the chair. Now it is gone — the National park Service wants a family type experience. No mention either, as there used to be, of the thousands of slaves who died of exhaustion and disease building the massive structure for the Spanish. On the last day before departure for the mainland, Teresa and I drove into the rain forest which covers the slopes of a high mountain called 'El Junque' - the rain-maker. When we stopped to ask directions, a lady invited us into her house, which had a wonderful view of the valley below. After coffee I asked if I could take a shot of the panorama from her patio. Returning with a camera, I petted a large dog and then, perhaps out of jealousy, a small dog, almost unnoticed in the corner, shot across and sank its teeth in my calf. Dogs hate me, I think. I popped in to see a doctor when I was back in New York, with visions of rabies, but she was reassuring — don't worry. The week at home was as frantic as usual. Julie and Red Hårting, my daughter Brenda and Teresa all went to the CCA ceremony at the New York yacht Club, which is described separately on the website. Chris met us at JFK and we flew to San Juan, took a taxi to the marina and shoved off the next day. What a change — back to the peaceful cruising life. We jogged along the south coast of Puerto Rico, anchoring every night. One stopover was a spectacular modern development built to look like one of those vertical villages on the Mediterranean coast. The problem was, there were no people. It was like walking through an empty movie set. The Ponce yacht club used to be very exclusive. It is built on a small cay connected to the mainland by a man-made causeway, so access is very controlled. However, in recent years, a vast parking field has been built at the end of the causeway, and a boardwalk along the shore sports dozens of bars, snack stands and even small dance halls. At weekends the whole of Ponce seems to come down for a good time, so the exclusivity of the club is somewhat degraded by the loud Latin music emanating from the area and thousands of people milling about. The city of Ponce itself is located a few miles from the beach. It is quite a pleasant city with a very impressive municipal art gallery. The old Parque de Bomberos, a wonderful Victorian firehouse, has been moved to the center of the city for the benefit of tourists, and converted into a museum.

"We left Puerto Rico from Boqueron and crossed the Mona Passage to Samana in the Dominican Republic. I'm afraid the officials here, and the water taximan, are quite corrupt and avaricious. The place has a bad reputation for dinghy theft too. Nevertheless, after we got through the thicket of waterfront thieves, some uniformed and some not, we found it interesting. We had a very reasonably priced lunch at a 'French' restaurant which featured linen napkins — a pleasant change. We took a ride in a motorized rickshaw to a waterfall which was a 15-minute walk from the road through a beautiful woods. An old man attached himself to our party and proceeded to name all the trees and bushes. He found us some grapefruit (full of seeds, it turned out) and gave us aniseed, oregano, cocoa, taramind, pina de Colada, etc. to taste or small, The south end of the harbor at Samana has a solitary cay with nothing on it, but it is connected to the mainland by an impressive bridge supported by a series of arches — a bridge to nowhere. We were told the story: when Trujillo was dictator he and some cronies bought the cay intending to build a fancy hotel and restaurant. Of course, people had to be able to get there, and so the government built the bridge. The hotel was never built. Residents can take a nice stroll to the cay on Sunday afternoons, but there is nothing to do except turn back. Our next stop in the Dominican Republic was Luperon, on the north coast. Luperon is a good example of the tendency of yachties to nucleate — there were over forty boats there when we arrived, despite the relatively small size of the bay. The officials were pleasant and not very corrupt. A small contribution was asked for, but it was purely voluntary, it was emphasized. Shortly after we arrived, a familiar face looked up at us from a dinghy, a fellow boater from Weeks Yachtyard in Patchogue had spotted *Fiona.* He was on a long winter cruise to the Caribbean and had sailed as far as Luperon single-handed. Off to one side from the village is a small marina with a very active bar. In the village a new generation has discovered wheels. Young men roar up and down on large motorbikes, mostly modified by removing the insides of the muffler. Many of the older buildings are typically West Indian — weathered planks with corrugated iron roofs. Chickens scratch away in the debris, roosters crow their presence. Chris and I took the publico to Puerto Plata. There were seven of us squeezed into a medium-sized car. I sat on the transmission hump at the front. Every time I eased my leg a little, I inadvertently shifted gear and the driver patiently re-selected. The ten-mile ride cost about two dollars. We visited the old fort and the unique amber museum. For some reason there are extensive amber deposits in the Dominican Republic, and it is mined. The most impressive pieces have an encapsulated insect inside. We saw a very rare piece with a captive 50 million year-old lizard trapped inside. When it came time to return, we couldn't find out where to catch the proper publico. Suddenly a young man seemed to understand, gestured for us both to mount his motorbike, and we careened off through the crowded streets. I had joked about the locals riding three to a bike (without crash-helmets) and now I was doing it. He dropped us off next to the Luperon publico, all for 65 cents. Teresa actually took a bus to Santo Domingo on the south coast. She left at 6 a.m. and got back rather exhausted at 10 p.m. I asked her what she thought of Santo Domingo. 'Dirty,' was the short reply. Soon it was time to leave. Our destination was the forbidden worker's paradise of Cuba.

"Perhaps I should explain that due to the U.S. embargo, citizens are not allowed to spend dollars in Cuba, but nothing prevents them from visiting there if the trip is sponsored i.e., someone else picks up the tab. In our case, Teresa wanted to visit a professor she was acquainted with at the University of Santiago, and she agreed to sponsor *Fiona's* trip. We left Luperon with a brisk easterly wind and enjoyed a great two-day run past the coast of Haiti, across the Windward passage and along the north coast of Cuba to a port of entry called Puerto de Vita. It is a new marina built specifically to lure yachtsmen and foreign fishermen to Cuba. It was obviously laid out by some anonymous planning committee. There is a large parking lot, properly striped and signposted, but no cars. There are slips for about thirty boats, but very few yachts. During our stay the number varied between five and ten. The bathrooms for each sex are sparkling clean, each with five hot showers. It was all very luxurious compared to Luperon, where one rather dirty cold water shower at the marina served the needs of over forty yachts. The resident facilitator, Ernestina, worked in an air-conditioned office, spoke good English, and was our point of contact. She greeted us on the dock when we arrived and told us not to leave the boat until cleared by customs, immigration, police and health authorities. She was horrified when Chris jumped on the dock to adjust the mooring lines. Quite literally, we had to stay on the boat. The relevant officials showed up shortly afterwards. Two customs officers roamed around the boat, opening drawers and lockers. They even brought a sniffer dog. However, I have to say in their defense that although the search was quite intrusive by the standards of most ports I have visited, Cuba is, by and large, drug free. Throughout our stay I was struck by the contradictory aims of the two branches of the Cuban government we encountered: on one hand the tourism people had provided an excellent marina, obviously at great expenses; on the other hand, the Guarda Frontera were very concerned at the freedom of yachties to move at will. The compromise was to restrict the yachts to selected marinas and to make it difficult to anchor anywhere else. On our first afternoon we took a walk down the road outside the marina. The entrance gate was guarded day and night to keep out the great unwashed. Cubans were obviously very poor, but the fields were cultivated and neatly tended. There was absolutely no litter by the roadside. I'm afraid the average Cuban is too poor to buy goods packaged in plastic. Most people walked or pedaled. A few drove by on small mopeds, one even had a live pig tied on the back! Very few private cars passed us. There were quite a few buses, all crowded. Now and again vast trucks roared by, crowded with workers standing in the back.

"Cuba has a two-tier economic system, the peso being officially price at one to the dollar. They will solemnly give you a peso for a dollar at any bank, but don't expect to get a dollar for a peso. Outside, on the street, touts offer about 20 pesos to the dollar. However, pesos are not much use to tourists, as shopkeepers, restaurants, etc. will only accept dollars. Most items are priced in dollars, even in shops patronized only by Cubans. We rented a car and drove it to Santiago de Cuba; the cost was $60/day. The drive to Santiago was quite an adventure, as roads in Cuba are not numbered and signs of any kind are rare. We got hopelessly lost and wound up driving down rutted roads in the middle of extensive sugar can fields. Some were being harvested and the workers looked at this apparition emerging from the dust with amazement. Teresa's friend at the university had arranged a bed and breakfast place for us. Chris and I shared a room at $20/night. Many homeowners rent rooms in order to get some dollars. Most of the buildings in Santiago are very shabby, with peeling paint and rotted timber. The Casa Granda Hotel is an exception and we greatly enjoyed our first evening in town there. We were entertained by an eclectic Cuban band, and a magician wandering among the tables performed for the tourists. The streets were crowded, but fortunately cars with tourist plates get reserved parking places. They really want your money.

"Teresa's friend Lionel arranged a little party at his house the next night. We showed a sailing video and met several of his English students. Lionel said his pay as a professor was 500 pesos a month, which illustrates how important dollars are to every Cuban. At the unofficial exchange rate (but one on which prices are based) he is making $25 a month. Television is everywhere, but there aren't many channels. An old lady living at the B&B watched continuously, although much of the content seemed to be government controlled news. I was fascinated by the shower in the bathroom. Warm water is produced by flowing the water through a small electric heater next to the shower head. It is about the size of a large mug. To turn it on, the 230 volt switch is conveniently placed next to it, on the wall, so you can reach it standing in the bathtub. Any building inspector in the States would have a fit at the set-up. There is no doubt that Cuba is a controlled society. In Santiago, policemen were ubiquitous, frequently checking I.D.s of Cubans. On the open road control check points stop all civilian traffic — except tourists. We were able to use a computer terminal at a ritzy tourist hotel to check our e-mail. The average Cuban can send and receive e-mail but cannot plug into the net and would not be allowed to use terminals in tourist hotels. Political posters are the only ones in good shape. Almost everything else needs a coat of paint. But I must say the Cubans I met are well educated, intelligent and very pleasant. Our landlady, for example, had written a book. As I said earlier, Cubans are very poor. The famous 1950's cars, acquired prior to the revolution, are fairly common in Santiago but were mostly in sad shape. My simple-minded impression of the U.S. embargo is that it is counterproductive. Posters urge unity at this special time. The failures of the government can be attributed to the embargo, not internal problems. The Cubans are a proud nation, I felt, and change will only come slowly, even if Castro steps down. There must have been some terrible diplomatic failures on both sides in the late fifties to produce this situation. My final thought on politics: Americans should be thankful the Mafia is still not running Cuba, as if it did, the drug problem in Florida would be worse than it is.

"Teresa decided to stay in Santiago for a few weeks to improve her Spanish. Chris and I drove back to the marina with the idea of heading to the Bahamas the next day. When we left we got the same going over by customs, except they kept the dog at home. What they were looking for remains a mystery. A curious incident occurred just before we shoved off. Chris took a video of the marina from the boat. It included a uniformed officer coming down to the dock. He came to the boat and got Chris to erase that section of the video. He didn't want his picture taken. We left as the sun set with a norther brewing up, much to the amazement of the more staid cruisers at the marina. Despite heavy weather, we made it to the Jumentos Cays in the Bahamas by lunch the next day. These islands are some of the least visited in the Bahamas. In fact, we encountered only two other cruisers in the three places we dropped our anchor. Our first stop was the south end of Ragged Island. A local entrepreneur, Percy, had salvaged a wrecked DC 3 and made it into a restaurant/bar right on the beach. It was closed when we were there, which isn't surprising, as hardly anyone ever goes to Ragged Island, let alone the lonely south end. Our next stop was Raccoon Cay. It is, in Chris' opinion, the loveliest of all the anchorages he had encountered so far. A sheltered bay, white sand, crystal clear water — what else do you need? From there we went to Jamaica Cay, where we discovered two very lonely men slowly building a holiday resort for the ever enterprising Percy of Ragged Cay. When Chris and I showed up we got a royal welcome and a tour of the simple foundations they were making from coral blocks which would perhaps some day support small cottages. There is no runway on Jamaica Cay, so Percy would be dependent on seaplanes to deliver his potential customers. He supports the workers by sending a boat twice a week with some fish and basic supplies. I went back to the boat to get them some smokes and rum to cheer them up.

"At Jamaica I studied the charts carefully and found there was no exit across the sand banks to the north for a boat of *Fiona's* draft. Consequently, we sailed east overnight to the south cape of Long Island and anchored a day later at Clarence Town. Edith and I had sailed into the harbor in 1969. There seemed to be fewer residents now than then. A curious feature of Clarence Town are two magnificent churches. One, St. Paul's, was built by a young Anglican missionary called Jerome Hawes, who had studied architecture. He then left, converted to Roman Catholicism, and returned as Father Jerome, determined to build a new church to outclass St. Paul's. The result was the impressive Sts. Peter and Paul. Now Clarence Town has two great churches to save the few hundred souls that live there. We spent a couple of nights at George Town in the Exumas. This has become a major nucleation center for yachties. Several hundred boats were anchored there when we arrived. When Edith and I visited in 1969, there were two — ourselves and a Canadian yacht. Most of the yachts stay there for weeks, snow birds escaping winter but not willing to go too far. They hold regattas and play lots of volleyball on the beach at Stocking Island. We refueled and moved up the Exuma chain. At Norman Cay there was another wrecked plane lying half submerged in the anchorage. It looked like a C-46. During our visit there in 1969 we found a small hotel at the south end with a few yachts that stayed a couple of nights. A few years later a developer built some private homes towards the north end, mostly for wealthy Americans attracted by the lovely surroundings and the convenience of a 3000-ft .runway not too far from Nassau. In the late '70s, a gentleman with a Columbian mother and German father and connections to the Medellin drug cartel, bought out the hotel, imported some heavily armed thugs who vandalized the private homes, shot at yachties (it is rumored some were killed but the bodies never found) and soon became the undisputed king of Norman Cay. His name was Carlos Lehder. For several years he ran a drug running operation centered on Norman Cay. Ultimately, I believe, he was jailed in the U.S. Now there is a very quaint bar/restaurant just north of the runway, called MacDuffs. They have a few vacation cottages for rent at $200/night if you are interested. From Norman Cay we had a great sail to Rock Sound at the south end of Eleuthera. Chris called his parents from there and discovered they had booked him a ticket home from Marsh Harbour in the Abacos five days hence. From the weather forecast we learned a cold front was due to cross the area in a couple of days, thus the logical thing was to get to the Abacos ASAP. The next day we left bright and early, aiming to be at a pass in northern Eluethera called Current Cut by slack high tide in the late afternoon. From there it would be an overnight sail to the Abacos. As we got within a few hundred yards of the cut, we had a series of small rocks on our left and a shallow sand bank on the right. The depth of water under the keel slowly fell to a foot — which way to turn? From the sketch chart in the cruising guide it appeared deeper water was on the right, so we turned that way. Wrong! We bumped and were hard aground. I quickly rowed a kedge out in the dinghy, but we couldn't get off. The tide fell and we were firmly stuck. That night the bad weather ahead of the front arrived. As poor *Fiona* creaked and groaned on her sandy bed, the wind increased to 25 kts with driving rain and lightning. It was a long night. Just after 4 a.m. there were signs she was coming free. The compass began to swing and soon we were able to kedge her off and stay in deeper water until it was light enough to traverse the cut. In full accordance with Murphy's law, the wind fell and we had to power to the Abacos in heavy swells. We anchored behind the reef with little protection from the stiff NW'ly wind that sprang up behind the front. To cap it all, the anchor winch made loud noises when we shifted our anchor to just north of Little Harbour. Investigation showed a thrust bearing had fractured. Before we fixed it we were invited to a delicious lunch by two friends belonging to the CCA who had a charming cottage on Little Harbour. The next day we moved to Man of War Cay, 15 miles to the north, for a CCA cocktail party, part of their Abacos 2001 Cruise. The next day we shifted to March Harbour. Chris flew to Tampa, and there was a final CCA blow-out at Mangoes Restaurant. I am now sitting at anchor doing a few repairs and waiting for the fresh crew, Chip and Al, who will sail with me to Bermuda and New York. Since leaving last June we have put 13,057 nautical miles on the log.

— *Best wishes", Eric*

Member Eric B. Forsyth wrote this Newsletter #4 from Brookhaven, New York in May 2001:

NEWSLETTER #4

"When Chris flew to Florida I was left with a few days to kill at Mash Harbour before the arrival of Chip and Al. In fact the days passed very quickly as I wrote newsletter #3 and carried out a few maintenance chores. There were also two amazing coincidences. The first occurred when I saw another Westsail 42 dropping anchor nearby. The boat was called *Consort*. She was crewed by Russ and Pat. I soon discovered over a couple of rums that she was hull #1, i.e., the very Westsail Edith and I saw on the stocks at the Westsail yard back in 1974, the one mentioned in 'Fiona — a brief history' on the website. The very one, indeed, that inspired Edith to call our boat *Fiona*. The second coincidence involved a small ketch anchored in the harbor called *Arvin Court III*. Now *Arvin Court II* was the boat Edith and I first sailed across the Atlantic in 1964 when she was captained by John Knight.

"It turns out John sold the boat to Gillian and Tom, who sailed her for many years before reluctantly selling her. But they loved her so much that they named their subsequent boat *Arvin Court* too. When Chip and Al arrived we cruised the Bahamas for a few days before leaving for Bermuda. Our first night out of Marsh Harbour was spent at Guana Cay. Unfortunately, the wind sprang up from the west, which put us on a lee shore. We had difficulty getting the anchor to set, but after three tries it finally dug in. Good job too. During the night the wind piped up enough to cause the anchor chain to jump over the cogs on the gypsy, link by link. The racket soon brought us all on deck. We let out more scope and slept soundly after that. In the morning we crossed over to the west side of Abaco Sound to get some protection. We anchored at Treasure Cay, where there is a very ritzy hotel and marina complex. However, as we wandered around it seemed almost deserted, probably only about twenty percent of the slips contained boats. The beach there is quite fantastic. Our next stop was New Plymouth, on Green Turtle Cay. This is a quaint village that was a center for Loyalists after the American Revolution (or the 'Rebellion', as it is called there). We spent some time at an interesting museum which was located in a house owned by a family that could trace its roots to those turbulent days.

"We left the Bahamas for Bermuda with a stationary high pressure system in place and experienced light winds all the way except for the last day. On that day, about forty miles from Bermuda, when we were sailing on a nice reach with Victor the vane in control, we espied a large red sailboat rapidly overhauling us from astern. It turned out to be an 80-ft Norwegian maxi, returning home from the round-the-world Whitbread Race. As they came alongside, they eased up to within a couple of feet on our starboard and started tossing freeze-dried food packages on the boat. Apparently they were heartily sick of them after weeks at sea! Within a few hours we tied up at the customs dock at St. Georges. Standing on the dock waiting to greet us was Selena, a friend of Chip's. I expressed surprise at seeing her and she said, 'Well, your schedule called for an arrival in Bermuda on April 10th, so here I am.' It was indeed the 10th. I refrained from pointing out that sailboats do not behave exactly like airlines. Chip and Al had never visited Bermuda and so had a wonderful time exploring the island on the pink buses. An old friend and former crew member, Louise, flew down for a long weekend. We managed to squeeze in some cruising to the lovely anchorages at the west end of Bermuda and spent a night at the impressive old naval dockyard. As we rounded Daniel's Head, formerly an unspoiled pristine beach, I was horrified to see dozens of tacky huts built on stilts over the beach. Apparently this is Bermuda's latest attempt to entice the dwindling hotel tourists — an eco-resort. It is a paradox. For years Bermudians complained about falling tourist numbers, and yet they build more hotels, thus slowly destroying the very beauty that makes the place so attractive in the first place.

"Although violent crime is relatively rare in Bermuda, there seems to be a lot of petty theft. The local daily, 'The Royal Gazette', features a column 'Around the Courts', which makes interesting reading. I was amused by a story about two young men who stole a few thousand dollars from a store and went on a binge at a fancy hotel. They purchased drinks and drugs and hired some professional ladies. They both had lengthy records, one covered seventeen pages going back to 1982. The poor defending attorney was hard pressed to think of any mitigating circumstances but finally pleaded (I quote) 'He had not really benefited from the activity with the ladies of the night. They weren't up to the quality that one would expect from ladies that professional,' said their lawyer. One got three years and the other five years.

Perhaps if the ladies had been better, they would have got more time to reflect on their misdeeds.

"We attended the annual Agricultural Fair and the Peppercorn Ceremony at which the Masons pay a nominal rent to the government for the use of their HQ with great pomp and ceremony. One day Princess Anne showed up to grant St. Georges UNESCO World Heritage status. When we left, another high pressure system had settled in. This produced record-breaking temperatures in New England and gave us five days of NW winds — on the nose. We were pushed east and crossed the Gulf Stream with light winds most of the time, but we had strong currents on the day we crossed the eddies on the north edge of the stream. At one time we were sailing with a good wind and the log read about 7 knots. The GPS, which shows speed over the bottom, indicated we were making good only 2 knots. Finally, as we got to the south of Cape Cod, the wind veered to the N and then NE and we had a nice sail past Nantucket, Martha's Vineyard, Block Island and the south shore of Long Island. We entered Fire Island Inlet in the dark and anchored east of the bridge until the morning. We then threaded our way through the shallow channels of Great South Bay and came up the Patchogue River to Week's yard at high tide on May 7th (a day early, Selena). The mileage logged for this cruise since last June is 14,832 nm." — *Until the next cruise, best wishes, Eric.*

EARLIER *FIONA* VOYAGES

Circumnavigation 1995-97

Issue 51 (Spring 1996)	Newsletter #1 from Georgetown, Guyana
Issue 52 (Summer 1996)	Newsletter #2 from Colon, Panama on February 10, 1996: 'The Wind is Free, It's the Sails That Cost Money.' Newsletter #3 from Papeete, Tahiti, on May 10, 1996
Issue 53 (Fall 1996)	Letter from Penrhyn Atoll, Cook Islands in June 1996 with brief comment on *Fiona* as a Westsail 42.
Issue 55 (Spring 1997)	Newsletter #4 from Cairns, Australia
Issue 56 (Spring 1997)	Newsletter #5 from Aden
Issue 57 (Fall 1997)	Newsletter #6 from Almeria, Spain Newsletter #7 from Block Island, New York

1998-99 CRUISE

Issue 62 (Winter 1998-99)	Newsletter #1 from Puerto Montt, Chile in October 1998 following visits to Galapagos Islands and Easter Island
Issue 65 (Fall 1999)	Newsletter #2 from Cape Town, South Africa, in February 1999, following rounding Cape Horn and reaching farthest south of 64°53'S in Antarctic waters in a fragile glass hulled boat. Visit to Port Lockroy, Antarctica.
Issue 66 (Winter 1999-00)	Newsletter #3 from Long Island, New York, in May 1999

NAVIGATION NOTES

A Time Sight at Bald-pated Prairie

By Bruce Stark

On July 17th, 1804, Lewis and Clark laid over a day at Bald-pated Prairie, near the present Missouri-Nebraska state line. The men needed rest. The captains needed astronomical observations.

Two days earlier the chronometer had stopped. Now it was going again, set to local apparent time, approximately, by the noon latitude observation. Lewis wanted its precise error. He also wanted to establish the latitude and longitude of this camp, to get a new departure for Clark's dead reckoning. Lastly, he needed to find the magnetic variation so when a map was made of this section of the Corps of Discovery's route it could be oriented to true north.

Past editions of the Newsletter have covered other observations the captains took that day, and explained how the old nautical astronomy worked. This paper will show how to work the altitude-azimuth they took for magnetic variation. But it will also show how to work the observation as a time sight — and the main focus will be on the time sight.

This might seem a digression, since Lewis and Clark used equal altitudes rather than time sights. But the fact they did so is of considerable interest. To understand why, you need to be familiar with the "observation for the time," as it was then called, and to know that — weather allowing — it was a daily routine for careful navigators from the late eighteenth century on through the first decade of the twentieth. Because of its convenience (no plotting required) some navigators continued to use it long after that.

On pages 387-390 of Moulton's *The Journals of the Lewis & Clark Expedition*, Volume 2, there are three copies of two altitude-azimuths the captains took on the afternoon of the 17th. Arrangement and labeling varies but the numbers in all three copies agree. Here is the first one, the one we will work:

Sextant	Compass	Chronometer
28°51.45"	N 85° W	5:53:10

The index correction for the sextant is given on page 411 of the same volume: 8.45", subtractive. Apply that and halve the angle (it was taken with a reflecting pool artificial horizon) to find the apparent altitude of the sun's lower limb: 14°21.30". Then subtract 3.35" for refraction and parallax and add 15.47" for semi diameter to find the true altitude of the sun's center: 14°33.42".

The latitude, according to Clark's meridian altitude of the sun, is 40°27..1 north.

The chronometer read 5:53:10 and at noon was one minute, nine seconds slow on local apparent time, according to the equal altitudes observation (issue #66 of this Newsletter). That makes it 5:54:19 PM July 17th civil time. Since the astronomical day begins at noon, in the middle of the civil day of the same date, it is also 5:54:19, July 17 astronomical time.

According to the lunar distance (issue #71) the longitude, rounded to the nearest degree, was 95° west. So it's 6:20:00 later at Greenwich, and the time there is about 12:14:00. Although it's past midnight it's still the 17th in the astronomical way of reckoning.

There's no reason to convert to mean time. The Almanac was calculated by apparent time.

The sun's declination is given only at noon, the beginning of the astronomical day. On the 17th it was 21°13.32" north. The next day it was 21°3.11". By linear interpolation it was 21°8.15" at the time of this observation.

As you can see, our estimate of Greenwich time was not at all critical. The only thing we took from the Almanac was the sun's declination and that was changing less than 0..5 per hour.

We now have all three sides of the triangle formed by the sun, the North Pole, and the zenith of Lewis and Clark's camp at Bald-pated Prairie. Or rather, we have the *complements* of those sides.

Altitude	14° 33..7
Latitude	40° 27..1 North
Declination	21° 8..2 North

We want two angles. The one at the camp's zenith is the azimuth of the sun. We can compare it with the compass azimuth to find the magnetic variation.

The angle at the pole is local apparent time.

The simplest formula for finding an angle from the three sides is the "law of cosines for spherical triangles." It's the one to use with mechanical or electronic calculators. But with the trig-log tables it's a poor choice. That's why mathematicians devised other methods.

The navigator himself wasn't expected to know how to read an equation, let alone know any spherical trigonometry. Rather than show him the equation, navigation manuals showed him how to lay out and do the calculation.

He would have been expert at that part. Every day he found his dead reckoning position by traverse table — "worked a day's work" as it was called. After a voyage or two it would have been second nature for him to look up the numbers in a table and do the arithmetic, checking as he went along.

The form used here can be found in World War II era editions of "Bowditch." By then navigation, along with everything else, had changed unimaginably. Local Apparent Time was no longer THE time — Greenwich Mean Time was. The chronometer and time sight had long since switched positions, so that chronometers gave the time and time sights the longitude.

Moreover, longitude observations were obsolete. The WWII Bowditch gave the time sight as a line of position method.

The beauty of this particular arrangement is that it combines the calculation for azimuth with the one for time (or longitude) so none of the work has to be repeated.

The polar distance, "p," is the angle between the body and the "elevated" pole — the pole of the same name as the latitude. Since latitude and declination are both north, subtract the declination from 90° to find that the polar distance is 68°51..8.

Half the sum of altitude, latitude, and polar distance is called "s."

Drop the unwanted tens from the characteristic when adding the columns of logarithms. The left-hand column gives the log haversine of the time, the right-hand column gives the log haversine of the azimuth. No need of a fifth decimal place in that column.

h	14° 33..7			log sec.	0.01 42
L	40° 27..1	log sec.	0.11 864		0.11 86
p	68° 51..8	log csc.	0.03 025		
	2)123° 52..6				
s	61° 56..3	log cos.	9.67 249		
s-h	47° 22..6	log sin.	9.86 677		9.86 67
s-L	21° 29,.2			log sin.	9.56 38
		log. hav.	9.68 815	log hav.	9.56 33
		(of the time)		(of the azimuth)	
Time		5:54:22		True azimuth	N 74.°5 W
Chronometer		5:53:10		Compass az.	N 85.°0 W
Chro. slow		1:12		Variation	10.°5 east

The "Correct add east" mnemonic doesn't work with a quadrantal style compass because the numbers in the NW and SE quadrants increase to the left. Imagine you are in the center of the compass looking out on its N 85° W azimuth. The true azimuth is N 74.°5 W. That's to your right hand. So the 10.°5 correction for variation is applied "To the right hand."

The ideal situation for finding local time is when the sun is due east or west. The altitude is changing fastest then and results tend to be more accurate. Also, an error in latitude won't cause problems.

In this case, though, the effect of an error in latitude has to be considered. The sun is more than 15° north of west and the time found changes nearly one and a half seconds for each 1. change in latitude.

If the captains had been interested in using this observation for time, rather than just azimuth, they might have taken it earlier, when the sun was due west of them. Just as navigators preferred to get their latitude when the sun was on the meridian, they preferred to get their time when the sun was on the "prime vertical" — due east or west.

But the sun doesn't cross the prime vertical in the fall or winter, and clouds can get in the way at any season. In such cases, if the latitude found differed much from his dead reckoning latitude a navigator had to apply a correction — or else repeat the calculation.

But the worst problem was that if latitude was much in doubt, and conditions prevented it being found, a time sight could be worthless.

Captain Sumner, caught in a dangerous situation, found a way around this problem. He worked his time sight more than once, using different latitudes, and drew a line on the chart through the resulting positions. Although his latitude and longitude remained a mystery, he got the information he needed for the safety of his ship — and the Sumner Line of Position was born.

The form we took from the WWII Bowditch gives the Sumner line with less work than the original procedure, which required two separate time sight calculations. Also, if a compass bearing is taken along with the altitude this arrangement gives the correction for variation (and deviation, if any) with no further effort.

Checking the Alignment of a Modern Surveying Sextant

By John M. Luykx

Hydrographic surveys conducted either aboard large ships or from smaller vessels often entail the use of a sextant to measure horizontal angles between three or more well defined visible objects on shore: objects which are also well marked on a nautical chart of the area. These angles when accurately set on a station pointer (3-arm protractor) which is then aligned on the chart will provide a very accurate determination of the observer's position. The largest angle which can be measured with a sextant is limited, however, to the maximum angle graduated on the arc of the sextant. For most sextants this angle may vary from 120 degrees (e.g., C Plath sextant) to 140 degrees (e.g., USN Mark II sextant).

To measure angles greater than these a special surveying sextant is employed, one whose optical arrangement differs significantly from the standard marine sextant. The author recently undertook the very interesting project of overhauling and adjusting for the U.S. Coast Guard three Weems and Plath surveying sextants each fitted with a penta prism. No sun filters were installed on these sextants. Because no instructions were available for the proper method for checking surveying sextant optical alignment, the procedure described in this article was developed after some experimentation and a little bit of trial and error. Perhaps some of the details concerning this procedure may be of interest to Foundation members.

The basic surveying sextant as previously mentioned does not include index or horizon filters but does incorporate a pentagonal (penta) prism in addition to the standard index and horizon mirror. When in use the penta prism is positioned on the frame of the sextant just forward of the horizon mirror where the horizon filter assembly would normally be located (See Figure 1). The pivot base mounting of the penta prism assembly permits the setting of the prism in two positions: one for measuring angles clockwise from a direction 90 degrees to the left of the sextant line of sight (sextant held horizontally) and the other for measuring angles counter clockwise from a direction 90 degrees to the right of the sextant line of sight. The installation of the penta prism extends the angle measuring capability of the sextant by 90 degrees. Hence it is possible to measure horizontal angles up to 210 degrees assuming a sextant graduated to 120 degrees such as the German C. Plath sextants. 120 degrees + 90 degrees = 210 degrees.

Although a mirror installed forward of the horizon mirror perpendicular to the frame of the sextant and in-

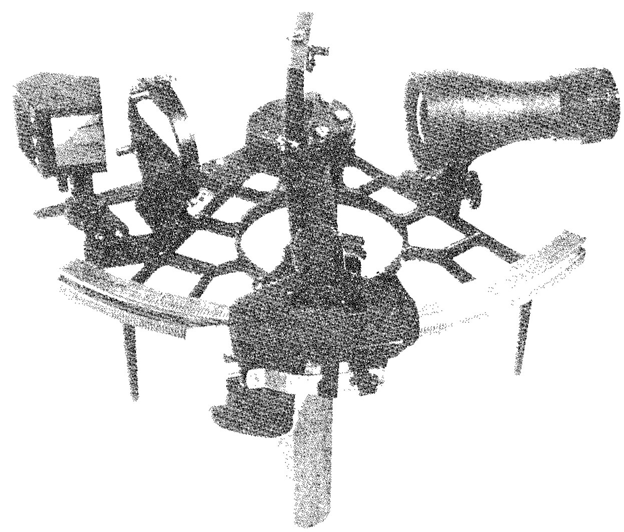


Figure 1 used by permission of Weems & Plath, Inc., Annapolis, MD.

clined 45 degrees to the horizon mirror would also provide the capability of measuring 90 degree greater angles, the image observed by the single reflection of this mirror would be <u>reversed</u> right to left in the line of sight. The double reflecting principle of the penta prism <u>insures</u> that the reflected image is true. Left to right. (See Figures 2 and 3).

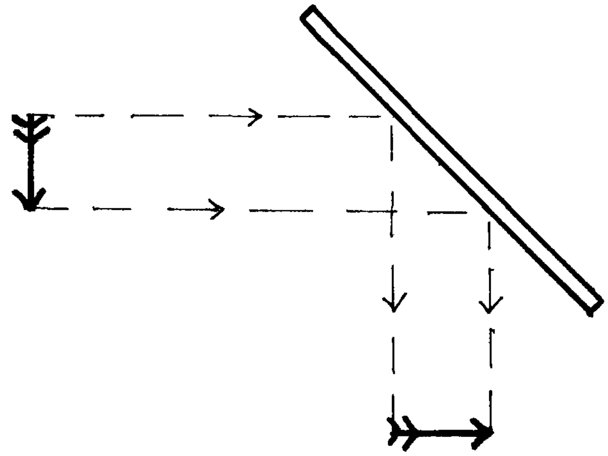


Figure 2.

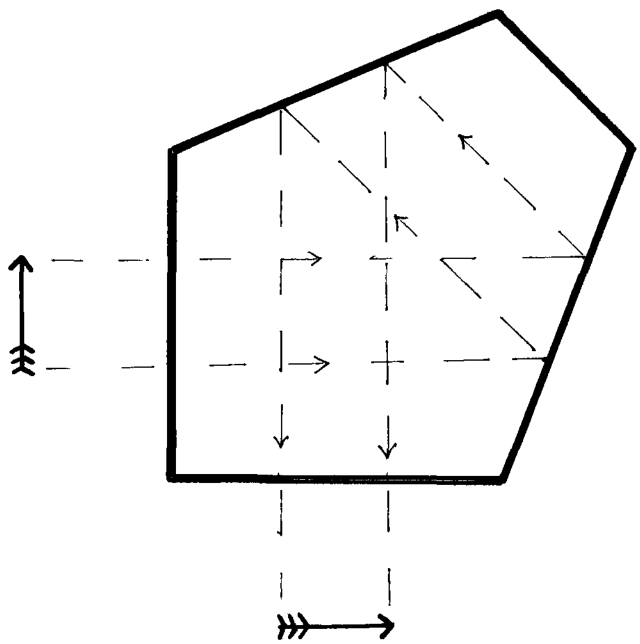


Figure 3.

The accuracy of a horizontal angle measured by a surveying sextant may readily be determined by comparing a known angle with the angle measured by the surveying sextant. This is usually done by measuring an angle using a well aligned sextant with the penta prism removed and then measuring the angle with the penta prism installed. The difference between the two is an error caused by the penta prism.

A practical method for checking penta prism error (if any) is as follows:

1. Adjust the sextant mirrors so that the sextant I.C. is as close to zero as possible.
2. Select two objects (designated Point A to the left and Point B to the right) which are over a mile or two distant from the observer. The angle between them must be greater than 90 degrees but less than the upper scale reading of the sextant arc.
3. Measure this angle accurately using the sextant without penta prism and record its value.
4. Install and set the penta prism to measure angles *clockwise from a direction 90 degrees to the left of* the sextant line of sight. (See figure 4.)
5. Set the sextant index arm and micrometer to a value on the sextant arc which is exactly equal to the angle measure in 3 above minus 90 degrees.
6. Holding the sextant horizontally point the sextant line of sight in a clockwise direction from Point A approximately equal to the horizontal angle measured in 3 above. The image of Point A will then be seen in the penta prism and the image of Point B will be seen in the horizon mirror. If the two images appear *horizontally aligned then no error exists in the penta* prism. If, however, they are not aligned then error exists in the penta prism. Adjusting the micrometer will bring the two images into alignment. The difference between angle A-B measured by the aligned sextant without penta prism compared to the same angle measured with the penta prism is the error of the penta prism. To obtain the correct angle, this error with sign reversed is applied as a correction to the angle measured by the sextant using the penta prism.

An auxiliary method of checking penta prism accuracy is to install the penta prism in its second position on the pivot such that angles can be measured counter clockwise from a direction 90 degrees to the right of the sextant line of sight. (See Figure 5.) Once the penta prism is positioned in this manner, the sextant index arm and micrometer are set to 90 00.0. The sextant is then held horizontally such that the sextant line of sight is pointed 90 degrees to the left (counter clockwise) from a well defined object. The reflected images of the object should be seen in the line of sight reflected by the index mirror and the penta prism. If the two images are in alignment, there is no error in the penta prism. If not aligned a small adjustment of the micrometer drum will align them. The error of the penta prism is equal to the difference between measured angle and the value 90 00.0. The error with sign reversed is the I.C. of the penta prism when used to measure angles counter clockwise from a direction 90 degrees to the right of the line of sight.

Penta prism errors caused by the prism itself are unadjustable since prismatic or optical error is established in the manufacturing process. However, penta prism error may also be caused by improper machining of the two slots in the penta prism pivot base

The total error in angle measurement when using a surveying sextant is equal to the sum of the sextant index error and the penta prism error.

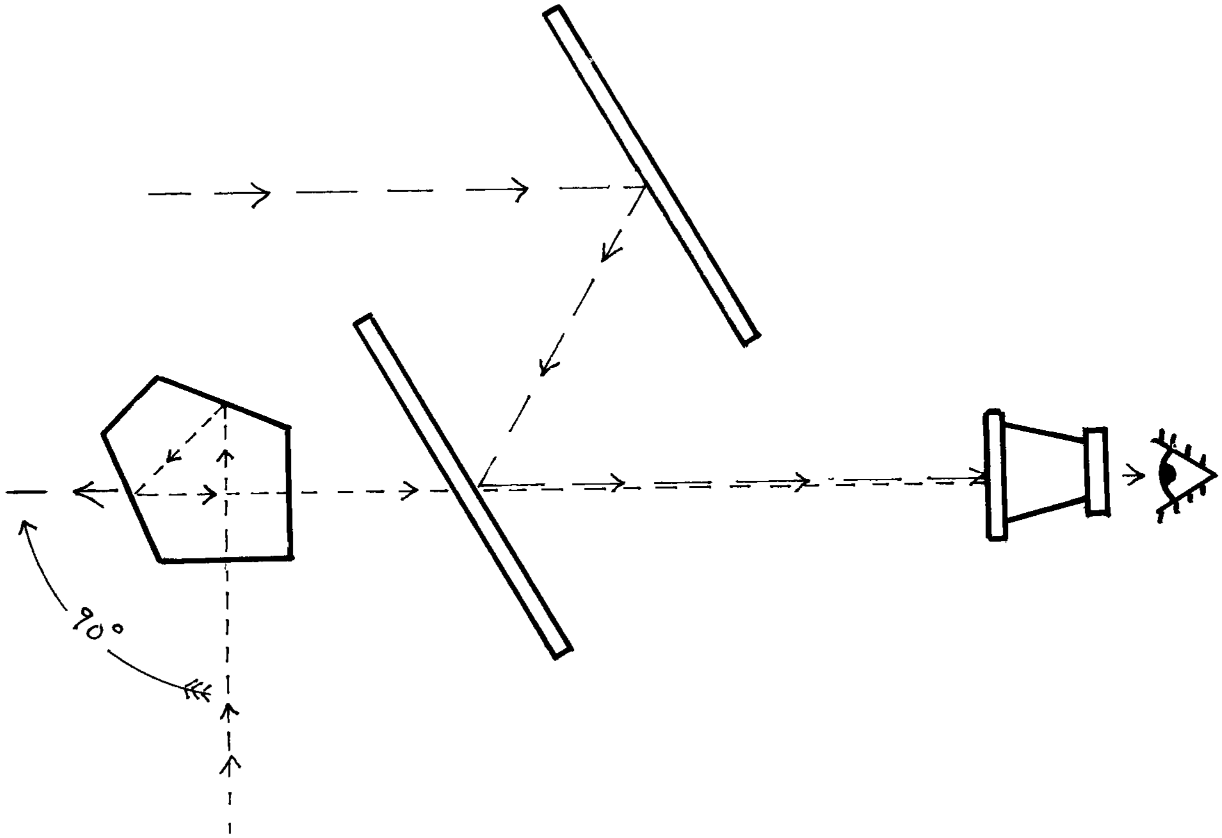


Figure 4.

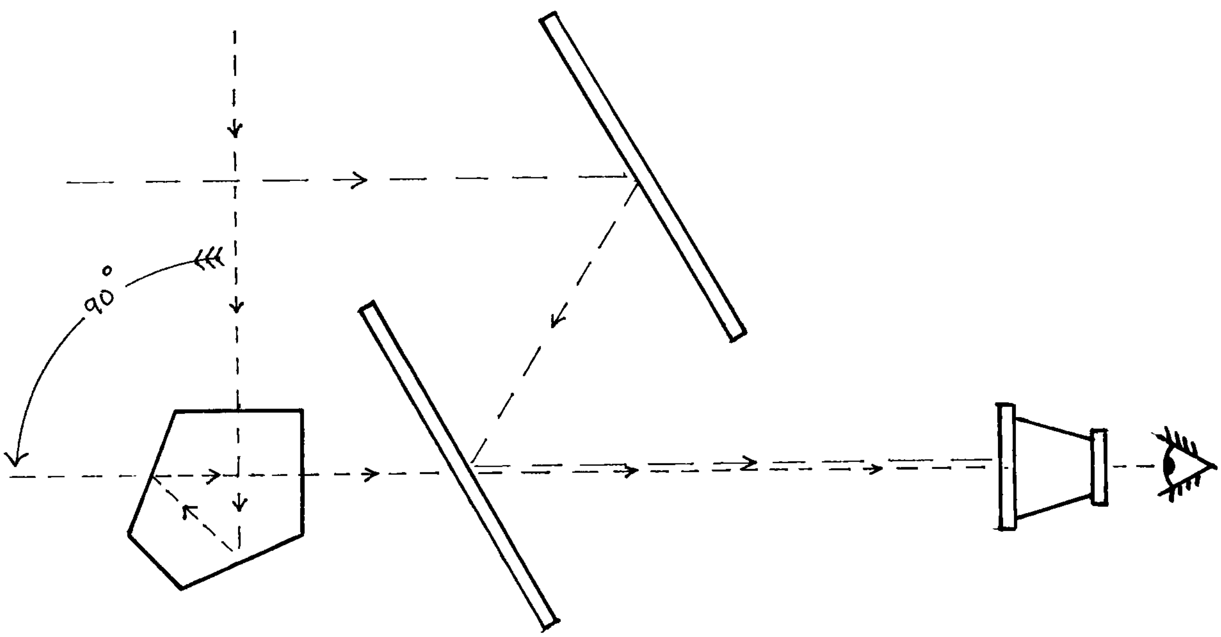


Figure 5 —

The overhaul and alignment of the three U.S. Coast Guard surveying sextants mentioned above turned out to be relatively straightforward once a procedure had been developed. In each case penta prism error did not exceed 1.5 arc minutes.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

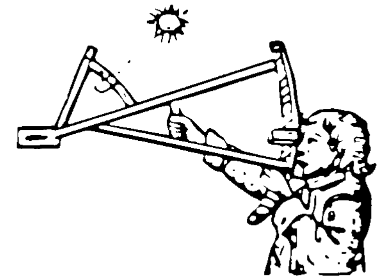
The *Norge* had been in fog which lifted just before reaching the North Pole. This enabled First Lieutenant Hjalmar Riiser-Larsen, Royal Norwegian Navy, to follow the sun with his sextant. At 0125 GMT on May 12, 1926, he announced, "Now we are there."

First the double-sewn silk Norwegian flag was dropped, then the U.S. flag was dropped by Lincoln Ellworth whose 46th birthday had been celebrated earlier that day, and finally the Italian flag was dropped. All flags were correctly planted in the ice, standing only a few yards apart.

As the *Norge* hovered low above the Pole, the ice was observed to be much broken up. Small ice-floes were seen.

See under NAVIGATION PERSONALITIES: Roald Amundsen, Issues 46, 47, 50, 51, and 53

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION ISSUE SEVENTY-SIX, SUMMER 2002

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Two awards for excellence in navigation have been presented this Spring. The recipient of the award presented at the United States Naval Academy was MIDN 3/C Jeanne Hart Cameron. The recipient of the award at Tabor Academy was Jonathan E. S. Bean.

Captain James E. Geil, Chairman of the Nautical Science Department of Tabor Academy, wrote: "The *Tabor Boy* was in the Virgin Islands last winter. I brought her back north in March with my regular group of 15 student crew members — five of them are in my celestial navigation class. We used the voyage for a practical component of the course, and the students were able to actually practice taking and working sights while at sea. They successfully plotted the vessel's position along the way. Their last observations were stars at evening twilight as we passed Cuttyhunk on April 1. All plotted fixes were within Buzzards Bay — not bad for beginning navigators."

The commercial Print On Demand chart people offered The Foundation the "honor" of being a chart agent for their charts. We only had to purchase and sell $5,000.00 worth of charts per year to get a discount. We respectfully declined their offer.

There are 2 web sites that are of interest to members: The Government Printing Office at www.bookstore.gpo.gov and NOAA chart site at www.NauticalCharts.gov. Members can look up celestial and nautical publications and charts before they order through The Foundation. The Government Printing Office prices may cause "sticker shock" but most publications have been reproduced by commercial organizations and sold at a much less price and a 20% discount. Let us know what you need and we can get the commercial version for you at a reasonable price or the government edition as usual with the now 15% discount.

Celestaire has a great Guide for teachers. It is "Celestial Positioning" a Teacher's Guide to an Earth Science Project. It includes History, Mathematics and Astronomy Integration. The tools required are simple — a globe, a couple of sticks, and this book. One can add tools as desired by making them with the help of books showing cut-outs, or using actual kits. Presentation can be enhanced with videos, audio tapes and computer programs — all available at the rear of the book. If you know of some school that is starting an astronomy program they should check out this guide.

Heather Leary is now Editor, *Navigation News*, The Royal Institute of Navigation, 1 Kensington Gore, London SW7 2AT. E-mail: info@rin.org.uk; Internet: http://www.rin.org.uk.

This has been a quiet Spring and early Summer compared to the last two. (Cancer treatment in 2000 and my son's plane crash last year. He is doing great and travels to 20 countries a year for the Department of State). Nothing of great importance has arisen. We did spend several months convincing the State of Maryland that we are truly a non-profit organization and had been for 20 years. As usual the States are trying to squeeze every dime out of every type of business to support the usual run of programs.

DO YOU KNOW . . .?

By Ernest Brown

What is the basic principle of the atomic clock?

(Answer at back of this issue)

READERS FORUM

Edited by Ernest Brown

Member Bruce Stark wrote on March 6, 2002:

"I just sent in the following 'correspondence' to the *Ocean Navigator* magazine. In an explanatory note I pointed out again that The Foundation was nonprofit and all volunteer, so it should be OK for my letter to promote it.

"Probably be several months before it comes out, supposing they do print it. Hope it will get a few new members." — *Sincerely, Bruce*

Member Peter Ifland wrote in May 2002:"Captain Joshua Slocum, a retired American merchant marine captain, was the first to perform a solo circumnavigation of the world. This feat, completed after three years, two months and two days on June 17, 1898, was reported in a delightful, easy to read narrative written by Slocum himself. His book, *Sailing Alone Around the World* ,was first published in Boston in 1900. The book has been reprinted many times, most recently in pocket size by Shambhala Publications, Inc. Boston, 1999. The complete text also can be found on the web at http://www.humboldtl.com/ar/literary/slocum2.htm.

"There is an interesting transposition of technical terms in the Shambhala book. On page 218 Slocum says: 'There is more or less the constant state of the winter trades in latitude 12°S. where I 'ran down the longitude' for weeks.' A common practice of the times, and at least for two centuries before, was to 'run down the latitude', not to 'run down the longitude'. When departing on a voyage, navigators would measure the altitude of Polaris to determine the latitude of home-port. To return home they would sail north or south until Polaris was at the altitude measured when they left home-port and then turn east or west, as appropriate, to 'run down the latitude' by keeping Polaris at a constant altitude. In fact, Slocum did not sail north and south to 'run down a selected longitude' but rather he sailed westward enroute to Christmas Island at 10°30'S, running down the latitude of 10°25'S. See pages 313-314. Slocum had a sextant with him that he used to find latitude from the sun at noon and by the stars at night. Interestingly, Slocum had no chronometer on board, only a 'tin clock' that lost its minute hand about half-way through the voyage. Thus, he had no way of determining longitude except by dead reckoning.

The use of the term 'run down the longitude' in the Shambhala book is simply an incorrect transposition from the original text that correctly reads '. . .run down the latitude . . .' See about two-thirds of the way through Chapter XI on the web site given above." — *Peter Ifland*

Editor's note — from the web site given above, "Boys who do not like this book ought to be drowned at once." Arthur Ransome

Member Oscar W. Underwood wrote on February 11, 2002:

"Your recent mailing sadly indicated the waning interest in celestial navigation in today's world. I have written numerous celestial programs. I'm willing to share but hardly anybody is interested. It sounds as if the days of the Nav. Foundation are numbered. I suppose the current supporters are old guys, like me.

"You asked what might be of interest for future articles. I have a suggestion. I know the science behind Greenwich Mean time, the classical way of keeping track of it by observing the heavenly bodies. Now, I believe, the time is kept using an atomic clock, whatever that is. Are the heavenly bodies ignored these days? Is a brief explanation of an atomic clock possible? An article answering some of these questions would be of interest to me, and I suspect others." — *Oscar W. Underwood*

Member Oscar W. Underwood wrote on March 23, 2002:

"I can understand the lack of interest among young navigators in celestial but I still think it is short sighted to let a reliable backup system just fade away. (Didn't MacArthur say something like this about Old Soldiers?)

"The celestial program I have written started out in ZBasic, a language which compiled the programs into executable programs by just typing the file name and hitting ENTER in MSDOS. Microsoft is letting DOS become obsolete. My operating system is Windows Me, which permits running compiled programs but does not allow writing them, unlike Window 98, and earlier versions. I have some programs written this way that contain a Sun Almanac and Sight Reduction. I'll be happy to share them with anyone who wants them via e-mail attachment, but I doubt if there will be much interest.

"In the last several years I've written a program for an HP32SII handheld calculator which contains a Sun Almanac and does a sight reduction. This calculator costs new only about $50 but the down side is that it takes person with RPN programming knowledge to learn how to use it. (It's easy for me but I spent an engineering career doing this type of thing.) The HP32 programs have been available on several Internet sites for the last year or two, and to date I've had only two replies. I've now written a revised version, not on the Internet, which I could send to you or any Member if there's interest. Years ago I reduced Sun sights from a small sailboat using an HP 35, the first one that handled trig functions. If I had had the HP 32 then, it would have been a world easier .

"Perhaps you are familiar with the book *The Calculator Afloat* by Shufeldt and Newcomer. This book contained sun yearly coefficients for the 1979-99 period, and an explanation for calculating Declination and GHA. I wrote a program extending the coefficients through the year 2020, and one program on the Internet is based on this data.

"If you are interested in looking at some of my effort on the Internet, check these URLs:

http://www.info.gov.hk/mardep/javascpt.htm

From above, click on Sun's Information & Sight Reduction.

http://www.geocities.com/CapCanaveral/Runway/3568/index.htm

From above, look under Useful Programs, see HP Calculator just under Sun's Information and Sight Reduction." — *Regards, Oscar W. Underwood III*

The Executive Director responded to member Oscar W. Underwood:

"I believe I have answered your E-mail of 11 February concerning the demise of the Navigation Foundation but found it in a stack of mail and wanted to be certain that I had responded.

"I FAXed your E-mail to Ernest Brown for inclusion in The Navigator's Newsletter and asked that he include the information about the atomic clock. He is the final authority for all information that goes into the Newsletter so we will have to leave it up to him.

"If it is printed in the Newsletter it may be the Summer issue. We had such a wonderful response to my request for letters that the Spring Issue is full.

"We are all 'old guys.' John Luykx just celebrated his 75th. My 75th was in February and Ernest Brown is about the same age. The only youngster is Roger Jones who is in his 60s. When we are gone there will be no one who strives to keep celestial alive except the U.S.C.G. and Tabor Academy in Maine.

"Maybe someone will pick up the thread and continue. We get many offers to take over the Foundation but when I inform them that we wrote the Corporate Charter so that no officials, directors or others can be paid by the Foundation they suddenly lose interest. I wonder why ????

"We would like a little more information about your programs that you have written." — *Best regards, Terry Carraway,*

Member Erving Arundale wrote from Yarmouthport, MA on February 7, 2002:

"In response to your request in the most recent issue of *The Navigator's Newsletter*, I wish to offer a suggestion. Would it be possible to include, in each quarterly newsletter, one or two celestial navigation problems (and their answers) using the current Nautical Almanac as a basis? Such problems could include the conventional fixes, running fixes, meridian transits, prime vertical and time sights for longitude, star and planet identifications etc. For those members interested in maintaining the practice of celestial navigation, these problems would serve as very useful refreshers in their efforts to keep their celestial tools sharp.

"We are deeply indebted to you for your diligent and devoted efforts in behalf of The Navigation Foundation." — *With sincere thanks, Erving Arundale*

Member Erving Arundale wrote again on March 14, 2002:

"Thank you for your reply to my letter of February 7th suggesting the inclusion of one or two problems in *The Navigator's Newsletter.* Having been house-bound for the past month because of an injury, I took the occasion to prepare the enclosed celestial navigation problems for your consideration. Perhaps Roger Jones and Ernest Brown could also provide their professional opinions as to their utility. Hopefully they will be helpful. If not, I will understand.

"Thank you for your kind consideration of my suggestion." — *With best regards, Erving Arundale*

Editor's note: See NAVIGATION PROBLEMS this issue.

Member Carey Stead wrote from Dorval, QC on February 4, 2002:

"In your 'editorial' in the 74th issue of the Newsletter, you requested that efforts be made to canvass for new members. If you were to let me have about 30 copies of the Foundation leaflet designed for distribution to potential members, I would see that they are distributed, later this spring, to graduates of the Canadian Power and Sail Squadron's celestial navigation courses who reside in or about Montreal.

"The last time I distributed the list, the result was at least one new member. Potential members would be more interested in applying for membership if they could be provided with more detailed information as to texts and navigation materials available through the Foundation, including pricing and discounts available, than is set out in Issue 74.

"As a matter of curiosity, do you keep track of the number of residents who reside in Canada and, if so, is your information compiled by provinces or cities?" — *Carey Stead*

Editor's note: The number of Canadian members was provided as requested

Member Carey Stead wrote again on February 9, 2002:

"Thank you for arranging the delivery of a nautical almanac to me. Could you also provide me with vol I for the current epoch of the Air Sight reduction Tables - pub 249. It would be appreciated.

"I am an instructor to a group of five students currently studying celestial navigation. At the current price for Bowditch, I doubt that any of them will buy a copy. Instead, they will rely on the 'on-line' texts of the publication. I have, so far, located three sources for the theory part of the publication, being that part that was in volume I or earlier editions. One of these sources or URL's also provides the tables which are to be found in Vol II of earlier editions. None-the-less, I would like to be in a position to inform these students of the price, including a shipping charge (or estimated shipping charge) of the Foundation for the current (1995) edition.

Could you provide this information? It also would be appreciated." — *Carey Stead*

Member Al L. Szymanski wrote from Oregon:

"In Issue 74, you asked for input on how the Foundation has been doing. As a rule I don't reply to such requests — usually feeling that my opinion really is not worthy of scrutiny. In this case, however, I am stepping up to the plate.

"My first experience with the newsletter was in a 'freebie' packed with some stuff that I purchased from Celestaire. It was a particularly interesting issue, discussing clearing lunars and the algorithms needed to calculate the ephemeris tables. I was hooked! In my next order, I paid for the membership and waited. Since then I have been disappointed. This is not to say that the histories in the last few issues were un-interesting, but it was not what I signed up for. For a bit of perspective, consider this: When I receive the latest issue of *Ocean Navigator*, my wife is assured of about an hour's free time as I dive directly to the back and work the problem. The next few weeks follow on with an occasional e-mail to Mr. Burke discussing the problem. All in all, a great time.

"As a relative newcomer to the 'art' I am looking for problems with solutions, so that I can better my skill and understanding. One of my current frustrations is that I am working through '100 problems in Celestial Navigation' and do really wish that there was a complementary book that actually showed the plots and in some of the cases, showed the reduction. I am also looking for variations on a theme — the article on lunars made me order Stark's book in an attempt to understand it better (I don't). Historical perspective on how to do the job as done by our predecessors who didn't have the current wealth of books, tables and computers would be enjoyable.

"Another item in issue 74 makes me ask a question: are back issues available — either on the net or by post? If so, there's at least 20 that I'd order up, if not then perhaps they should be.

— *Al. J. Szymanski*

The Executive Director responded to Member Szymanski on March 24, 2002:

"Thank you for your letter and rest assured your opinion is very worthy of scrutiny. Your letter will be sent to our Editor Ernest Brown . . .

"I am sorry that the past 2 issues did not come up to your expectation. These issues of *The Navigator's Newsletter* had a dearth of material. Our usual contributors did not submit material, we had very few letters from members, and Mr. Brown was ill for a time and then had to spend several weeks in the hospital. He is now recovered and our Spring Issue will be back up to standard.

"All issues of the newsletter are available. Pricing is as follows: One - 3 issues are $5.00 each, 4 - 10 issues are $4.00 each and 10+ issues are $3.00 each. Shipping and handling is paid and members get 20% discount on their total order. Just let us know which issues you desire and I will mail them to you via the U.S. mail. You can order via the Internet to navigate@ix.netcom.com or by regular mail. I will get the issues in the mail to you immediately.

"There is a book available from the Naval Institute Press called *Problems and Answers in Navigation and Piloting*. The remarks say, by Elbert S. Maloney. Suitable for both classroom use and self study, this workbook provides over 200 navigational problems and answers dealing with dead reckoning, piloting and celestial navigation. 1985, 83 pages, 8_ by 11", ISBN: 0-87021-150. $21.95. If you are interested we can order it for you and if they have not lost my record again, we can give you a 20% discount plus you pay the cost of mailing."

Editor's note: Elbert S. Maloney, a retired U.S. Marine Corps colonel, is probably best known as the editor of Chapman's.

Member Robert M. Girder wrote from Aiken, South Carolina on February 16, 2002:

"I feel your pain from the paucity of contributions to *The Navigator's Newsletter*, as expressed in the Seventy-four issue. I guess we can only blame G.P.S. Here is a contribution from some years ago, that I don't believe I have ever submitted. I can make more if anybody is interested. — *Regards, Robert M. Girder*

Editor's note: See GREAT CIRCLE SLIDE RULE in this issue.

Member Michael Allen sent the following e-mail on July 11, 2001:

"Members who have or are planning to get a Palm OS Handheld might be interested trying CelestNav which can be downloaded for a 30 day free tryout and purchased for $49.95. I've been using it to determine fixes and work problems from Leonard Gray's book of 100 Navigation Problems. It has a good user interface, performs many functions and makes timing the sight easy with its delay popup trigger and 'NOW' button which uses the Palm's built-in clock to record the observation time. Here are the listed features:

- computation of fix position from celestial observations;
- perpetual nautical almanac for navigational stars, Moon, Sun, planets;
- Mercator and Great Circle sailing computation;
- computes range, height, sextant angle for lighthouses and other terrestrial objects;
- twilight, rise, set, meridian passage computation;
- automatic timing of sextant observations and adjustment to UTC;
- handles backsights, non-standard atmospheric conditions, and more; sight reduction screen with the functionality

found in publications H.O. 229 and H.O. 249; continuously updated dead reckoning position; 'finger friendly' data entry screens for celestial observations, angles, dates, and times.

"A complete description and download link for CelestNav can be found online at http://www.mobilegeographics.com" — *Mike Allen*

Member John Barnett (jmbart2@prodigy.net sent the following e-mail January 22, 2002:

"I am trying to program an old TI-66 programmable calculator for celestial navigation. In the past I've programmed it for binary star orbital mechanics, and for Jovian central meridian determinations. I believe it should be capable of celestial navigation routines. This would eliminate the need for sight reduction tables and such. The item is expendable: easily and cheaply replaced — which is the point of doing it this way rather than exposing an expensive laptop to the marine elements. I am using an old (1989) book by Mike Harris, *Astro Navigation by pocket computer*, but it's a bit obscure for me as yet.

"If anyone has a better reference to the subject I would appreciate hearing about it. — *Fair winds, John Barnett*

Editor's note: Unfortunately, an e-mail from Mary Taylor was misplaced following its receipt on October 15, 2000. The e-mail reported a new website written to introduce people to the history, theory and practice of celestial navigation while providing pointers to schools, online tutorials, and online resources from starfinders to books to HO 229 and HO 249. It covers non-instrument wayfinding as well, and provides an extensive list of classroom links for school teachers who would like to enrich their astronomy, math, history, and literature classes with information about celestial navigation. There is also a section on navigational instruments and navigational astronomy. The website is http://celestial navigation.net

Member F. R. Bailey wrote from Grove City, PA on May 10, 2002:

"I understand from recent newsletters you need some more letters. Here is one. If it helps the Foundation monetarily, I would be pleased to purchase a 2003 Nautical Almanac from you...

"Here are a few other comments.

"I have enjoyed immensely the newsletters. I got my feet wet in celestial through a U.S. Power Squadron course and have been interested (unfortunately off and on) ever since.

"I can appreciate the fact that Foundation membership may be declining due to G.P.S., etc. That is of course extremely unfortunate. I think it most valuable that one understands the basic wheeling around the earth of the sun, moon, planets, and stars. Ideally, I would like to think that every high school graduate could understand and explain by way of simple diagrams used in basic navigation courses the motions of the celestial bodies. However, I understand the average high school graduate has an abysmal understanding of U.S. history so what chance has such a basic science course?

"I once traveled to Iowa from Pittsburgh PA by automobile and stopped now and again to plot my position and worked up the position while my son continued to drive. I used an A-12 bubble sextant.

"I have enclosed a copy of a common diagram: the coordinate system, meridian diagram, and true bearing diagram. With a bit of plane geometry, the basic Sin Hc and cosZc readily fall out. It is an interesting exercise.

"I was reviewing some past newsletters for information on the sun compass. See at least issues 42 and 45, concerning the astrocompass and a sundial with compass. It is truly an amazing electronic world we live in and as an example of that plug into your Internet search engine the words 'sun compass'. You could spend the rest of the summer with this subject alone.

"About a decade ago, I picked up far from the sea, a John Bliss and Co. sextant. It is truly a beautiful piece of equipment. Do you ever consider articles on companies that have constructed sextants?

"Finally, I am reminded of a brief anecdote I read somewhere back in the forties that has remained embedded in my memory ever since. Consider a vehicle carrying four or five people across the western African desert trying to escape and stay ahead of Gen. Rommel's advancing troops. It is night and at one point the driver is uncertain of the direction in which to proceed. He makes a decision but is brought up short by one of the passengers, an elderly English lady who says to him: 'You are going in the wrong direction.' Not believing the lady, he asks her how she knows this. I do not of course remember her words after all these years but she said something like this: All you have to do is look at the sky and the stars. There is Orion wheeling overhead and I have been keeping track of it and the time and watching the other constellations. Would that all of us, young and old, could generally plot our course from watching the stars, sun, moon, and planets.

"Keep up the good work. Though land locked with other sod busters in western Pennsylvania, I will this summer be taking a few sights with my Bliss and Hezzanith on a nice lake nearby." — *Frank Bailey*

Member Jim Regan wrote from Darwin, Australia on February 8, 2002:

"I was very sorry to read of the potential plight of "The Navigator's Newsletter" since I looked forward to each issue . . ."

Editor's note: Member Jim Regan enclosed a star chart and a brief explanation for its use. The star chart will be addressed in the next issue.

Member Richard C. Gibson wrote from Blue Hill, Maine on March 12, 2002:

"A relative of mine recently sent me a bound 80-page autobiography written by her great grandfather. He was commissioned as a Navy officer in 1861, and subsequently served a 35-year career in the regular Navy. Although he had no formal education beyond high school, he became an accomplished astronomical observer. I am enclosing a one-page writeup of Commander Francis Green. If the Foundation has an interest in having the complete autobiography I would be glad to try to arrange for one. It is entertaining reading.

"He includes a description of his youth, running away to join the merchant marine, service in the blockading Union Fleet during the Civil War and his post war assignments in the USN Hydrographic Office. Although he lacked any formal education in the astronomy and math fields it is obvious that he must have been a highly motivated self-teacher." — *Richard C. Gibson*

NAVIGATION NOTES

GREAT CIRCLE SLIDE RULE

By Robert M. Girder

Explanation, With Instructions And Example:

Mathematical Basis

Determination of Great Circle course and distance between two points involves the solution of a spherical triangle whose corners are North pole, Departure point, and Destination. The known values are the Latitudes of these points and the difference in longitude between them. The desired unknowns are the Initial Course and Distance (bottom line of triangle). (Except for the names of the parts, this problem is identical to the finding of the Hc and Z in the reduction of a Calculated Altitude sight to determine a Line of Position)* The Course and Distance can be readily found by spherical trig. calculations, special tables, or by graphic methods. The graphic method, used here, is by far the fastest. In addition, it provides continuous position information along the Track. In brief, this is accomplished by using the meridians and parallels of the stereographic projection to plot the position of the destination. Further rotation of the cursor places the bottom line of triangle along a meridian, thereby making possible the measurement of the desired unknowns: **Initial course** and **distance.**

Preparation

Where marking of the plastic cursor disk is called for, use either a sharp crayon, removable with dry tissue, or a suitable felt-tip pen, removable with moist tissue. After some experience the detailed instructions below can be replaced by following the **Steps**, shown on the face of the instrument.

Course and Distance

Assuming a trip from San Francisco (N38°,W122°) to Tokyo (N36°. E140°). First, determine the difference in longitude: by *subtracting* if the direction of the longitudes are the same, or by *adding* if the directions are different. If the sum exceeds 180°, subtract from 360°. In this case: @122°+E140°=262°, 360°-262°=98°.

....

***QUIK-DRI Sight Reduction Tables for Marine Navigation, including Celestial Rule** uses the same graphic method to determine the Azimuth and verify the Altitude. Copies are available from the author.

....

Next, set the cursor line on the rotatable plastic disk to 90° N Lat. Then, dot the intersection of the Diff Long (98°), interpolated between the marked meridians 90° and 100°, (top horizontal row of numbers) and the destination Lat. (N36°, interpolated between the marked parallels N30 and N40, right-hand edge). Circle the dot so it can be found later.

Now, rotate the disk clockwise, to put the cursor line over the Lat. Of Departure on the calibrated right hand edge scale. The new position of the dot will show the **Initial Course**, estimated from the bracketing Meridians on the bottom horizontal row of numbers (56°). The initial course is stated in degrees East or West of North, depending upon the direction of sailing (in this case, West). The compass course, then, is 360°-56°, or 304°.

Likewise, the dot's new position will show the **Distance**, estimated from the bracketing Parallels, evaluated by the miles scale on the left hand edge (4450 N. miles).

Track

To determine the **Track**, proceed as follows: Without moving the cursor, draw a **meridian line** from the dot to its North Point (90°). (Note: All meridian lines are arcs of circles on this stereographic projection. It can be sketched by hand with sufficient accuracy for most purposes. Next, rotate the cursor line back to 90°N. The new position of the drawn line will represent the **Track** from the Point of Departure (on the left hand edge) to the Destination (at the Dot). Waypoints along this line can be evaluated directly from the indicated Latitudes, and the difference in Longitude successively applied to the departure Longitude. These waypoints, conveniently every 10° change in Long. Or Lat., can then be transferred to an actual chart. In doing so, remember that on the "Slide Rule" the track always goes from Left to Right, regardless of the direction of sailing.

New Courses at Waypoints

The cutting angle of the track at each marked meridian or parallel makes possible an estimate of the changing course all along the route (for planning purposes). During the actual voyage, the new course would be recalculated at each waypoint.

Lewis and Clark Nailed the Continental Divide

By Bruce Stark

Lewis's sextant observations at Camp Fortunate, just a day's walk from the Continental Divide at Lemhi Pass, got his east-west position within three nautical miles of the truth. Had they been worked they'd have provided a badly needed anchor-point for the accurate map President Jefferson wanted, but didn't get, after the expedition returned.

What makes these observations valuable is that the longitude they give is not just a random hit, as would be expected to happen now and then according to the laws or probability. It is the outcome of a series of good observations. That's why the observations can shed light on two questions of considerable interest to Lewis and Clark scholars.

The first question has to do with the index error of the sextant. Year after year Lewis continued to use the correction that had been established before the expedition began. Normally, index error is measured nearly every time a series of observations is taken. This would have been especially important for the Corps of Discovery. Index error isn't expected to remain constant under normal conditions, let alone the condition of that expedition. But as far as I know, there are no numbers recorded that show Lewis ever measured the error after he left Philadelphia. Year after year the "Standing error" remained 8′45″, to be subtracted.

The second question has to do with Lewis's skill with a sextant. Those of his star-lunars I'd worked had given me a poor opinion of that. Nor did I understand how he could have been expected to develop skill except by taking and working observations at a known longitude, or with a known Greenwich time. Apparently he'd had little, if any, opportunity for that.

I first worked the observations in the spring of 2001. Carole Harne, an archaeological forester working in Idaho, had asked me to see how accurately Lewis and Clark's astronomical observations fixed the longitude of the continental divide. She'd convinced me that placing the Divide was an important part of the Corp's mission.

I chose to do everything the old way, using only tables, pencil and paper, and the 1805 Nautical Almanac. Nor was it necessary to make use of any information other than would have been available to the man charged with working the observations after the Corps of Discovery's return. That supposes, of course, that Ferdinand Hassler, the expert who was given the observations, had as good a copy of them as we have in Volume 5 of Moulton's *The Journals of the Lewis & Clark Expedition*. There's reason to believe he didn't.

Before working the equal altitudes to get local apparent time and chronometer rate I checked them for wild numbers. One of the advantages of the special way Lewis and Clark took equal altitudes is that bad numbers are easy to spot and correct. The captains recorded the times of contact, overlap, and separation of the two images of the sun's disk. In the few minutes this takes, change in the rate of rise or fall is barely noticeable. Large interval differences are absurd. They show that an error was made in reading the chronometer, recording the reading, or making the copy.

A huge error in the captains' latitude was found and corrected using their other observations. The latitude error, and the method of checking and correcting it, deserve separate treatment.

The lunar distances were taken as recorded. After they were worked the resulting Greenwich time was compared with local time to get the longitude by observation.

To find how accurate this longitude was I had to turn to Robert Bergantino, a retired, but active, research professor at Montana Tech's Bureau of Mines. Work Bergantino has done as a hobby has, I believe been the foundation for all sound research into the Corps of Discovery's navigation.

Perhaps the most indispensable part of that work was in going over the ground to determine where the various camps and "points of observation" were. Considering how the landscape between St. Louis and the mouth of the Columbia has changed in two hundred years — especially how often the creeks and rivers have changed course — two of Bergantino's specialities, cartography and hydrogeology, must have been useful.

The actual longitude of Camp Fortunate was within 4′ of the average of the longitudes found by lunar. At that latitude 4′ amounts to less than three nautical miles. This, of itself, was only mildly interesting. It didn't prove anything. What caught my attention was the fact that the worst of the four sets missed by only 11′.

The next problem was to rule out the possibility an unknown change in the sextant's index error had been canceled by a "personal error" in the way Lewis saw the contact between the sun's and moon's limbs. If personal and index errors were canceling in these observations — with the sun east of the moon — they would add to each other in sun-west lunars.

So I worked the observations Lewis had taken earlier at the three forks of the Missouri, which included two sun-west lunars. One put him 16.′7 east of the longitude Bergantino established for that camp, the other 14.′3 west. These are normal, acceptable errors for lunars. Averaged, they give a very good longitude.

These results were so gratifying that, to be sure they were correct, I repeated all the calculations, more carefully, that fall.

The agreement of sun-east and sun-west lunars seems to me reasonable proof that the sextant's index error was very close to what Lewis believed it to be. This is useful information for anyone working observations the captains took along that part of the Trail. Whether the error had remained stable all the way from Philadelphia — or just happened to drift back to the original value — is another matter.

As to Lewis's ability with a sextant, one thing is clear. By the time he reached the headwaters of the Missouri River he was a competent observer, at least as far as sun-lunars are concerned.

The questions surrounding Lewis and Clark's astronomical observations are far from settled. But the numbers recorded at the Three Forks of the Missouri and Camp Fortunate are the most encouraging I've seen.

NAVIGATION PROBLEMS

CELESTIAL NAVIGATION PROBLEMS

By Erving Arundale

PROBLEM #	SUBJECT
1	STAR-PLANET FIX
2A	SIGHT PLANNING-STARS
2A	THREE STAR FIX
2B	MERIDIAN TRANSIT OF SUN
2C	TIME SIGHT (SUMMER LINE)
3	RUNNING FIX OF SUN
4	POLARIS-MOON FIX
5A	PRIME VERTICAL SIGHT FOR LONGITUDE
5B	STAR IDENTIFICATION ANSWERS

Problem #1 Star-planet Fix

Approaching his destination, the captain of a 42-foot yawl is sailing on a southerly course from New York to Nassau in the Bahamas. With clear skies, he takes two sights in the early morning hours of October 14, 2002 at which time his D.R. position (as plotted) is Latitude 29°05′ North, longitude 76°01′ West. His watch is keeping Zone Description (+5) time and is 4 seconds fast. His sextant's index correction is -2.1′ and his height of eye 10 feet. His sights:

Body	Watch Time (10/14/2002)	Sextant Alt. hs
Saturn	5-40-32	72°46.1′
Sirius	05-42-45	44°58.4′

What are the coordinates of the yawl's position?

Problem #2:
Part A Sight Planning And Three Star Fix

On a passage from Los Angeles to Honolulu, the navigator is planning his sights for morning twilight on September 20, 2002, at which time he has plotted his D.R. position as Latitude 25°58′ North, Longitude 143°18′ West. His watch is set for Zone Description +10 time and is 6 seconds fast. The sextant's index correction is +1.2′ and his height of eye is 11.5 feet.

(1) What are the Zone time and Greenwich Mean Time of civil twilight before sunrise on that day?

(2) The "Local Mean Time of Meridian Passage" diagram in the Year 2002 Nautical Almanac indicates that Jupiter will be available for observation. What Right Ascension value should be used to plot Jupiter on the 2102D Star Finder?

(3) What is the Local Hour Angles of Aries at the time of civil twilight for orientation of the Star Finder?

(4) Using the 2102D Star Finder, what are the approximate altitudes and azimuths of the following bodies:
Jupiter Procyon Rigel
Regulus Sirius

(5) The navigator takes the following sights.

Body	Watch time (9/20/2002)	Sextant Alt. Hs
Procyon	04-57-28	51°11.6′
Sirius	04-59-35	43°05.2′
Rigel	05-01-39	55°50.4′

What is the vessel's position?

Part B: Meridian Transit Of Sun

Later in the day, while sailing on a course of 250° true at an average speed of 6.3 knots, the navigator takes a meridian transit sight of the Sun's LL to check his latitude. (For watch, sextant correction, etc. see Part A above)

(1) What is the estimated Zone Time and Greenwich Mean Time of the sun's Meridian Transit that day?

(2) From several sights taken around the estimated time of transit he selects the following
For his "top out" sight.

Body	Watch time (9/20/2002)	Sextant Alt. Hs
Sun LL	11-28-06	64°56.5′

What is the ship's latitude?

Part C: Time Sight (Sumner Line)

In Part B, the navigator established his position at Local Apparent Noon (GMT 2128,ZT 1128) on September 20, 2002 as Latitude 25°44.North and Longitude 143°40′West. After running on a course of 250° for 25 miles, he took another sight of the Sun's LL at watch time 15-26-16 with a sextant altitude of 28°02.4′ (See Part A for corrections, etc.)

Using the "Time Sight" method, what was the vessel's afternoon position?

Problem #3: Running Fix

On December 4, 2002, and having crossed the South Atlantic, a vessel is headed for the Falkland Islands. It is on course 227° True and traveling at a speed of 8 knots. At mid-morning, it's D.R. Latitude is 45°24′South, Longitude 49°12′West and the navigator takes a sight of the Sun's LL. He takes another sight after Meridian Transit. The navigator's watch is set for Zone Description +3 time and is 10 seconds fast. His sextant's index correction is -3.1′ and the height of eye 13 feet. (Plot the run from the given D.R. position).

(1) What are the Zone Time and Greenwich Mean Time of Meridian Transit that day?

(2) The sights of the Sun's LL are:

	Watch Time (12/4/2002)	Sextant Alt. hs
AM	10-36-58	60°15.6′
PM	13-38-02	60°17.7′

What are the coordinates of the Running Fix?

Problem #4: Polaris - Moon Fix

At civil twilight on the morning of June 3, 2002, the navigator of a vessel on fisheries patrol in the Gulf of Maine takes two sextant observations in order to check the position given on his GPS unit. His D.R. position at the time is Latitude 43°30′North and Longitude 66°15′West. His watch is set for Zone Description +4 time and is 6 seconds fast. The height of eye is 21.5 feet and the sextant's index correction is +4.0′.

(1) What are the Zone and Greenwich Mean times of civil twilight before sunrise?

(2) The sights:

Body	Watch time (6/3/2002)	Sextant Alt. hs
Polaris	04-11-08	43°31.2′
Moon LL	04-15-20	23°46.4′

What is the vessel's position?

Problem #5: Part A—prime Vertical Sight For Longitude

On August 5, 2002, and in order to establish his longitude, the navigator of a vessel cruising in the Eastern Mediterranean takes a sight of the Sun's LL at the time it crosses the vessel's western prime vertical. At that time, the D.R. position is Latitude 34°59′North, Longitude 18°30′East. The navigator's watch is set for Zone Description -1 time and is 2 seconds fast. The sextant's index correction is -3.6′ and the observer's height of eye is 10 feet. The sight:

Watch Time (8/5/2002)	Sextant Alt. Hs
6-09-12	30°25.3′

(1) What is the time of the Sun's Meridian Transit on August 5th?

(2) What is the time of the Sun's Prime Vertical crossing?

(3) What is the vessel's longitude?

Part B: Star Identification

At evening civil twilight on the same day, a bright star is seen in the West. This star bears 249-250°True. Its sextant altitude at 19-12-02 watch time is 58°. (See Part A for D.R. position, watch and sextant corrections, height of eye).

(1) What is the time of civil twilight after sunset?

(2) What is the star's identity?

ANSWERS TO CELESTIAL NAVIGATION PROBLEMS

Problem #1: Star — Planet Fix

Ship's position	Latitude	28°01′N
	Longitude	75°55′W

Problem #2: Part A—Sight Planning And Three Star Fix

(1) Times of Civil Twilight before Sunrise.
Greenwich Mean time 1457
Zone Time 0457

(2) Right Ascension of Jupiter 132 1/2°

(3) Local Hour Angle (Aries) at Civil Twilight 80°16.5′

(4) Approximate altitudes and azimuths:

Body	Altitude	Azimuth Zn
Jupiter	40°	87°
Regulus	22°	86 1/2°
Procyon	52°	115°
Sirius	43 1/2°	152°
Rigel	56°	184°

(5) Position:
Latitude 25°53′N
Longitude 143°14′W

Part B: Meridian Transit Of Sun (Noon Sight)

(1) Times of Meridian Transit:
Greenwich Mean Time 2128
Zone Time 1128

(2) Noon sight position: Latitude 25°44′N, Longitude 143°40′W

Part C : Time Sight

Position Lat. 25°35.5′N, Long. 144°06′W

Problem #3: Running Fix

(1) Time of Sun's Meridian Transit
Greenwich Mean Time 1508
Zone Time 1208

(2) Position of Running Fix:
Latitude 45°40′S Longitude 49°42.5′W

Problem #4: Polaris — Moon Fix

(1) Time of Civil Twilight (before Sunrise)
Greenwich Mean Time 0811
Zone Time 0411

(2) Position of fix:
Latitude 43°30′N
Longitude 66°21′W

Problem #5: Part A—prime Vertical Sight For Longitude

(1) Time of Sun's Meridian Transit
Greenwich Mean Time 1052
Zone Time 1152

(2) Time of Sun's Prime Vertical crossing:
Greenwich Mean Time 1509
Zone Time 1609

(3) The vessel's Longitude 18°21'East

Part B: Star Identification

(1) Time of civil twilight after sunset:

Greenwich Mean Time 1812

Zone Time 1912

(2) The star is Arcturus

HISTORY OF NAVIGATION

ON THE ASTRONOMISCHES RECHENGERAT ARG1

By David Charlwood

Introduction.

There have been many and varied attempts in the past to solve the PZX navigational triangle utilising graphical-mechanical solutions. The great majority, however, have not possessed sufficient accuracy and ease of use to make them capable of supplanting and superseding other established methods. This paper seeks to combine and present all the relevant reports and documentation pertaining to the origin, the development and the operational history of the Zeiss ARG1. Information recently declassified and released to the general public by the relevant authorities has been included.

Origins.

Perhaps the most immediate predecessor of the ARG1 was the Bastien-Morin Type 12 calculator. This instrument was originally conceived by Professor A. J. Bastien for Air France and produced by H. Morin in Paris, France in the late 1930's. This device comprises two superimposed circular concentric transparent engraved plates based on an orthographic projection. The fixed upper plate comprising a graticule of parallels and meridians with minimal divisions is used to give an idea of the measurements carried out. The lower rotating graticule is identical to the upper, but with much more detailed engraving of which the divisions are not visible to the naked eye, but only by means of three microscopes, two of which are mobile and allow complete exploration of the grid, and a third fixed microscope which enables the latitude rotation to be accomplished. It was heavy and expensive and although the accuracy of the instrument was professed to be in the order of one minute of arc, the accuracy attained was, however, reported to be insufficient.

Operational Requirements

The Luftwaffe had decided by the early 1940's that the further development of calculated altitude and azimuth tables was virtually concluded, and that use of the German copy of the Bygrave slide rule manufactured by Dennert & Pape, at Altona, and known as the HR1, possessed difficulties for the observer when used in poor light and when subjected to aeroplane vibration.

Their new requirement was for an instrument with the following properties:

- The solution of the spherical triangle must be so simplified that, by a single insertion of the three known quantities (Time Angle, Declination and Latitude), the two required quantities (Altitude and Azimuth) will be shown directly, without intermediate quantities and without rules concerning plus and minus signs, with an accuracy of about ±1' of altitude and ±1° of azimuth.
- It should be suitable for use in all latitudes and for all heavenly bodies.
- It should make the smallest possible demand on precision engineering capacity in obtaining the desired accuracy.
- There should be direct reading of all values and scales.

The method finally chosen was spherical co-ordinate transformation. Mechanical rotation is both simple and reliable, and in addition, the whole hemisphere can be represented without troublesome distortions.

Principle Of The Instrument

The basis of the ARG1 is a grid inscribed with an equatorial stereographic diagram of a hemisphere, projected on to a plane parallel to the plane of the observer's meridian.

Consider the following two diagrams:

In the polar mode (Latitude = + 90°) the grid represents the celestial equator system, and is made up of lines marking Hour Circles and Parallels of Declination.

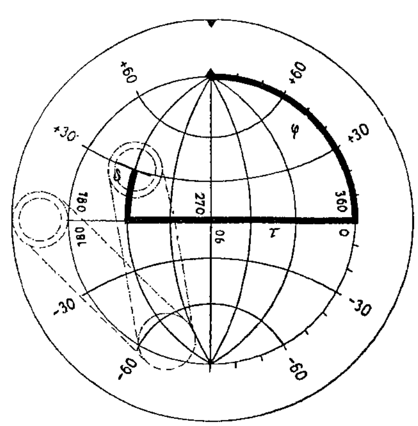


Figure 1 - ARG grid at celestial equator position in polar mode
Latitude = + (N) 90°
Time Angle = 150°
Declination = + (N) 30°

By rotating the grid from the polar mode to an angle equal to the co-latitude, the point previously marking the pole now marks the zenith, and the grid now represents the horizon system. The lines now represent Azimuth Circles and Parallels of Equal Altitude

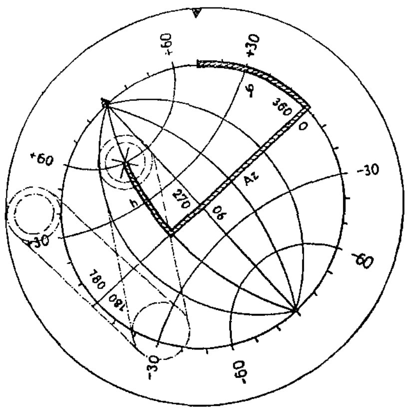


Figure 2. ARG grid at horizon system in zenith mode
Latitude = +(N) 50°
Altitude = 60°
Azimuth = 120°

Description Of The ARG1 And Accessories

The instrument (see photographs 1 & 2) has a diameter of 21.6 cm, a height of 19 cm and weighs 1.8 kgs. The front of the instrument is an alloy ring with a central plate-glass window of 10 cm diameter, through which the grid is visible. This grid is a photographic transfer on glass. The original drawing for the grid was made on a quadrant of one metre radius, and co-ordinate points were put in for intervals of 2° by means of a Zeiss stereo-comparator. Straight lines were then connected between adjacent points (the inaccuracy due to straight rather than curved lines does not exceed 0.5 minutes of arc). Intermediate lines were then interpolated and the quadrant was then photographed in four positions to form a master negative. Subsequently, over 4000 numbers were put in by hand. The declination circles are inscribed on the grid at 10 minute intervals, (as are the time angle circles) up to 60° of declination. Time angle and azimuth is figured from 0 to 180 degrees (right to left and below the equator line) and from 180 to 360 degrees (left to right and above the equator line) for the western celestial hemisphere. Near the poles the intervals of time angle become 30. at 60°, 1°at 80°, 2° at 86°, 5° at 88° and 10° at 89°. On the alloy ring is a focusing fixed microscope (1) of x14 power which enables the latitude to be set on a scale marked from +90° to -90° at intervals of 10', interpolation being possible to 1'. The latitude is set (and the grid therefore rotated) by turning a knob (4) which is set diametrically opposite the fixed microscope. Connected to the housing of the fixed microscope by an elbow joint linkage (5) is a focusing moveable microscope of x28 power (2) which can be moved to any part of the grid over the plate-glass window, and by which the grid co-ordinates are set and read after grid rotation. Fine adjustment of the moveable microscope is obtained by operation of the two knobs disposed at right-angles to it (3), in order that the cross in the field of view can be synchronised over the desired co-ordinates. The bottom of the moveable microscope has a spring-loaded cap which is covered with soft leather and which bears on the plate-glass window. This tends to both keep the window free of dust and adds a little friction to maintain the moveable microscope in position once it has been set. The markings on the grid enable settings to be made accurately to 10' and by estimation to 1'. Since on moving the grid the cross in the moveable microscope will not be parallel to the lines on the grid, a rotating spring-loaded ring is provided which rotates the cross about the optical axis of the microscope thus enabling the arms of the cross to be set temporarily parallel to the grid marking for ease of reading.

Shown in Figure 3 is the view through the moveable microscope with a typical reading of Hc +44° 13' and azimuth of 69° 51'.

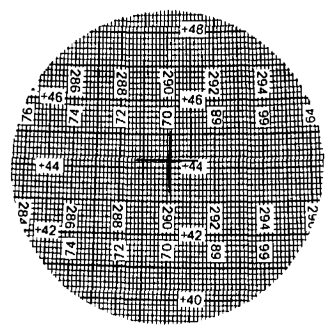


Figure 3 - View through moveable microscope.

The rear face of the instrument is a bakelite moulding (6) provided with a circular indented handle, in the centre of which is fitted a detachable lamp-holder (covered by a red filter), and reflector, which provides 24v illumination inside the instrument. On the rear face of the instrument is a two-pin plug used for the electrical lead (7) and a rheostat (8) for controlling the brightness. On some instruments the rheostat is omitted and the lamp is connected to a 2.5v supply or to a small accumulator provided in the storage box.

Mounted on the front face of the instrument are five plaques.

<u>Identification Plaque</u>

Astronomisches Rechengerät1.	= Astronomical Calculator
Gerät Nr..	= Part No.
Anforderz.	= Requisition No.
Werk Nr.	= Serial No.
Hersteller.	= Manufacturers code (bic = Zeiss)

<u>Instruction Plaque</u>

Stelle Breite auf +90°	= Set latitude to +90°
Stelle Gest. Zeitw.(..τ) und Abweichung (..δ) ein.	= Set time angle and declination
Stelle Breite des astr.	

Koppelortes ein.	= Set the altitude of the place of observation
Lies Höhe (hr) und Azimut (Az) ab.	= Read off the altitude (hr) and Azimuth (Az)

Note Plaque

Merke!	= Note
Nord = + Süd = -	= North = + South = -
Zahlen mit Vorzeichen δ oder hr	= Calculate with sign δ or hr
Zahlen ohne Vorzeichen τ oder Az	= Calculate without τ sign * and Azimuth (Az)

Auxiliary Plaques

Breite (on fixed microscope)	= latitude
Aus: Dunkel: Hell: (on rheostat)	= Off. Dim. Bright.

The storage box made of wood has fittings to enable it to be securely fixed at the navigation station and in addition provides stowage for the electrical power lead, spare bulbs, a black silk illumination hood to enable to instrument to be used in bright background light and an illustrated instruction booklet.

Requisition Numbers

Instrument:	Fl 23894
Storage box:	FL 23894-1
Electrical power lead:	FL 23894-2
Silk illumination hood:	FL 23894-3
Spare bulb:	FL 32777-1
Instruction booklet:	45 01 01-1

Operation Of The ARG1

1. Connect the instrument to the 24v supply and adjust the brightness.
2. Focus both the fixed and moveable microscopes.
3. Set the grid so that the value of +90° appears in the latitude scale as seen by the fixed microscope. This setting is effected by simply rotating the knob until it clicks into position and the two triangular marks are then seen to be opposite each other.
4. Move the moveable microscope until the cross in the field of view is set approximately at the time angle and declination of the heavenly body. The microscope is then rotated till arms of the cross are parallel to the lines of the chart and by means of the adjusting knobs the cross is set accurately on the required values of time angle and declination.
5. Turn the latitude knob until the latitude of the place of observation is set at the fiducial mark in the fixed microscope.
6. On the moveable microscope, the spring loaded ring is rotated to bring the arms of the cross into alignment with the chart markings, and the altitude and azimuth are read directly from the chart.

Note

The time angle (*) then used in Germany until about the middle of the 20th century, was counted from 0-360° or 0-24 hours from the lower meridian through east, south and west. M therefore differs from hour angle by 180° or 12 hours. This definition, which was introduced when astronomical time began to be reckoned from midnight to midnight, has numerous advantages and is closely related to local time. If LHA is less than 180° then time angle = LHA+180°, and if LHA is more than 180°, then time angle = LHA-180°.

Time angle and azimuth are numbered from 0-180° below, right to left, and from 180-360° above, left to right, in relation to the equator line on the grid.

If time angle is less than 180°, then azimuth is less than 180°, and if time angle is greater than 180°, then azimuth is greater than 180°. This is a simple rule according to whether the calculation is being made on the eastern or western celestial hemisphere.

Sample Sight Reduction With ARG1

Herewith the results of an observation of Altair that I made on the 6th November 1992 at DR position N 51° 17' & W 000° 27', using a Plath SKS-3D gyro-octant (#5501) with a two-minute averaging period. ARG1 (#297316) is utilised for the sight reduction.

	ASSUMED POSITION	DR POSITION
GHA Aries	326° 14'	326° 14'
GHA inc	001° 11'	001°11'
SHA Altair	062° 23'	062°23'
GHA Altair	029° 48'	029° 48'
Assumed Lon	000° 48' W	000° 27' W
LHA	029° 00'	029° 21'
± 180°°		
T	209° 00'	209° 21'
Dec Altair	08° 51' N	08° 51' N
Assumed Lat	51° 00' N	51°17' N
Azimuth	219° 47'	220° 00'
Ho	41° 13'	41° 13'
Hc	41° 34'	41° 12'
Λ	21' A	01' T

Accuracy And Comparison With Other Methods Of Sight Reduction

Comparative trials were conducted by the German Hydrographic Institute at Hamburg in the 1940's between the ARG1 and the S-Diagrams developed by K. Schütte. On the basis of 26 calculations, errors of the ARG1 were calculated to be ± 0.74' of altitude and ± 0.83' of azimuth. A comparison of other different methods of sight reduction is as follows:

Using Assumed Position

	Hc	Δ	Az
ZEISS ARG 1	41°34'	21'A	220°
WEEMS/LINE OF POSITION BOOK	41°33'	20' A	220°
DREISONSTOCK/HO 208	41°34'	21' A	220°
HUGHES TABLES	41°34'	21' A	220°
MYERSCOUGH & HAMILTON RNT	41°34'	21' A	219°
HO 249 / AP 3270 VOL III	41°34'	21' A	219°

Using Dr Position

	Hc	Λ	Az
ZEISS ARG 1	41°12'	01' T	220°
AGETON/HO 211	41°12'	01' T	220°

Sample Great Circle Distance And Initial Course Calculation

From: N 17° 22' & W 025° 28'

To: N 40° 08' & W 073° 17'

1. Set latitude to starting position (+90°)
2. Set time angle (difference of longitude 47° 49' + 180° = 227° 49'), against declination (destination latitude N 40° 08').
3. Set departure latitude (N 17° 22')
4. Read: altitude (ZD) of 46° 55', therefore distance = **2815 nm** and azimuth of **309° 10**' as initial great circle course.

Note that the Log Haversine method gave 2818.2 nms and IGC of 309° 11.5'.

The Instrument Revealed

The first indication that the Luftwaffe were using a new method to solve the problem of sight reduction was the discovery of a fragment of a photograph in the wreckage of a Dornier 217 of III/KG 100 that crashed near the town of Totnes in Devon, England on the 30th April 1944. This damaged portion later proved to be from the instruction booklet on the ARG1. Less than a month later, a Junkers 290 of 1/FAG 5 was shot down into the Atlantic Ocean, some of the aircrew including the observer survived, and during their subsequent interrogation, details of the ARG1 began to emerge. In addition, U-Boats that surrendered in May 1945, were found upon inspection to be equipped with the ARG1. After the cessation of hostilities with Germany, examples of the ARG1 were sent to the Admiralty Research Laboratory at Teddington, in Middlesex, the Royal Aircraft Establishment at Farnborough in Hampshire, and a large quantity of instruments and documents were transported to Wright Field in Dayton, Ohio.

Under interrogation in England in 1946, Dr. G. Forstner stated that Zeiss had made 100 instruments, and that the total order was for 5000 of which at least 3000 had been made by other contractors. Production of the ARG1 co-incided with the cessation of long range flights by the Luftwaffe and only one bomber squadron was known to have used the ARG1. They were greatly preferred to the previous use of tables and Forstner felt that the single insertion of time angle, declination and latitude was a major advantage over the Bygrave slide rule.

Appraisal By The Allies

In July 1945, Dr. S. M. Burka, a navigation specialist at Wright Field, indicated that the ARG1 was the most worthwhile non-electric navigation aid yet picked up in Germany.

In October 1945, the British Admiralty concluded that the apparatus was simple and easy to use and was well designed and constructed. Results were in most cases correct to 1. except when badly formed triangles were attempted, but the overall accuracy was probably similar to that obtainable from five figure logarithms.

In March 1946 the Royal Aircraft Establishment at Farnborough stated that the instrument was very similar to that produced by Bastien Morin in France before the war. The ARG1 computer solved the astronomical triangle with 1. accuracy in about the same time as that required for use of the Astronomical Navigation Tables (AP 1618).

Developments

A Ue R An ARG1 training instrument, known as the A Ue R, was produced by Dennert & Pape at Altona (see photographs 3 and 4). The grid is drawn on a luminous disc of 19 cm diameter, which fits into a circular recessed plastic dish, in which it may be rotated through finger holes in the bottom of the dish. The latitude scale, engraved at 1° intervals from +90° to -90° is set against a fiduciary mark on the dish. A link arm attached to the dish holds a bulls eye magnifier, (power x2) for setting time angle and declination and reading altitude and azimith. The observer's sighting line is fixed by a cross engraved on the plane undersurface of the magnifier and a circle on its top surface. The overall diameter is 24 cm and its weight is 0.4 kgs. The overall accuracy obtained was ± 10' which was sufficient for training purposes.

ARG2

This model (see photographs 5 and 6), made largely from steel, was developed to be more suitable for mass production than the ARG1, from which it differed in the following respects

1. The overall diameter was 29 cm, and its overall height 7.3 cm.
2. The grid diameter was 20 cm (twice the diameter of the ARG1).
3. The latitude scale was set by means of a vernier knob, calibrated at 5' intervals, thus eliminating the fixed microscope.
4. The moveable microscope was replaced by a simple magnifier with a power of x14.
5. The 24v lamp-holder underneath the instrument was eliminated by the substitution of overhead illumination, situated close to the viewer.
6. There is a small "dead zone" in the grid near the vernier knob which he magnifier cannot cover.

The accuracy of this variant was found under test to be in the order of ±0.86' of altitude. Only two instruments of this type were produced, one was taken to Wright Field in the USA and the other is presumed to be still in Germany.

ARG3

One of the disadvantages of the ARG 1 and 2, was that only one computation could be completed at a time. There existed an operational requirement to be able to observe two stars simultaneously. This would provide an instantaneous fix, as position lines would not have to be transferred according to the difference in time between observations. It was initially envisaged that this would necessitate two observers, but after the satisfactory development of a two-star sextant (work on which, was already in hand), only one observer would be required. The astronomical computer that would handle a simultaneous two-star observation was to have been the ARG 3. However, due to the cessation of hostilities in 1945, work on this project was discontinued and no production examples are known to exist.

Conclusion

The ARG1 was a most elegant solution to the problem of solving the astronomical triangle. A great advantage was the ability to use the DR position as easily as using the assumed position. The accuracy of the instrument was in the order of ±1' of altitude and ±1° in azimuth which is more than adequate for all practical purposes. It could be used on any heavenly body, world-wide, and therefore dispensed with the requirement to carry a number of volumes of altitude and azimuth tables. Finally, it is a pleasant and satisfying device to use.

Acknowledgments

My thanks are especially due to Dr. Gloria Clifton, Curator of Navigational Instruments at the National Maritime Museum, Greenwich, London, for her help and patience; to Lt. Cmdr. John Luykx, USN(Retd) of St. Mary's City, Maryland, USA,. For his enthusiasm and encouragement; to Dr. Stefania Riccini of Rome, Italy, for her translational skills, and finally to QinetiQ Ltd for access to the RAE photographic archives at Farnborough.

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Drawings

Figure 1: ARG grid at celestial equator position in polar mode.
Figure 2: ARG grid at horizon system in zenith mode.
Figure 3: View through moveable microscope.

Photographs

Photo 1: ARG1, Negative No/ 67728, dated 8-2-1946
Photo 2: ARG1, Negative No. 67727, dated 8-2-1946

Photo 3: Training model, Negative No. 67730, dated 8-2-1946
Photo 4: Training model, Negative No. 67729, dated 8-2-1946
Photo 5: ARG2, Negative No. 68245, dated 7-3-1946
Photo 6: ARG2, Negative No. 68244, dated 7-3-1946

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Symbols

φ	Greek	Latitude
λ	Greek	Longitude
τ	Greek	Time angle
δ	Greek	Declination
Δ	Greek	Delta

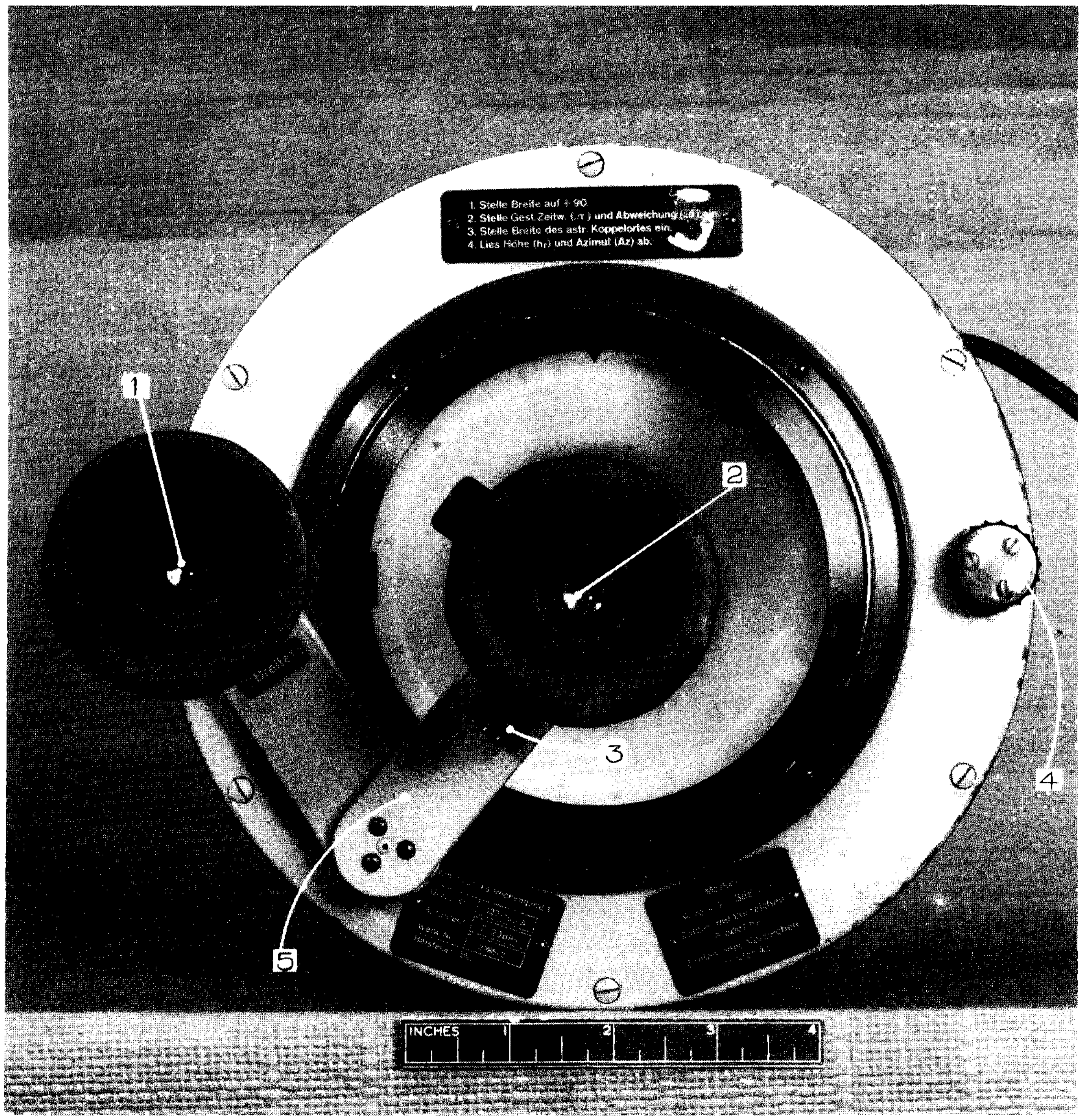


Photo 1: ARG 1. Used with permission of QinetiQ Ltd.

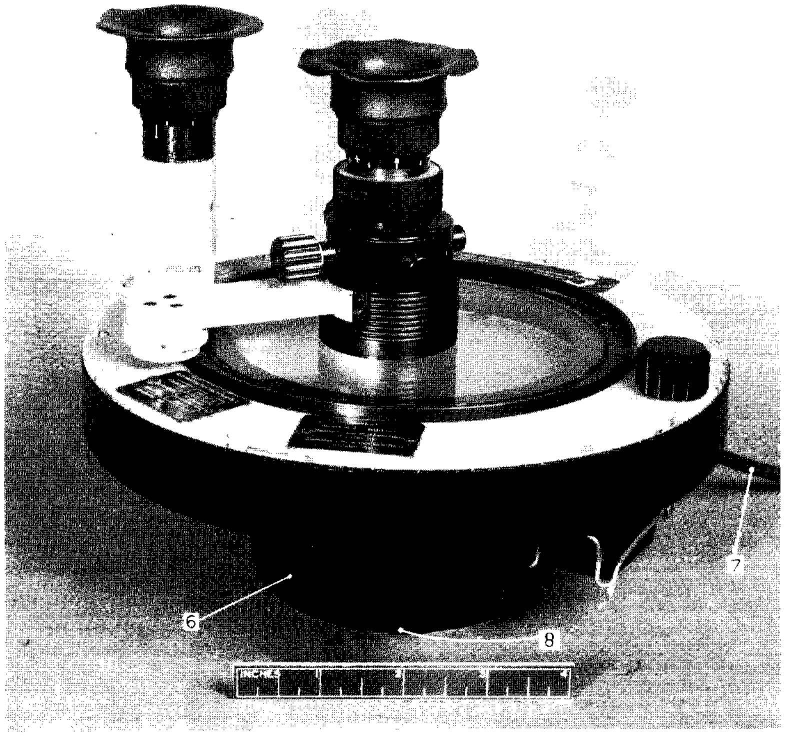


Photo 2: ARG 1. Used with permission of QinetiQ Ltd.

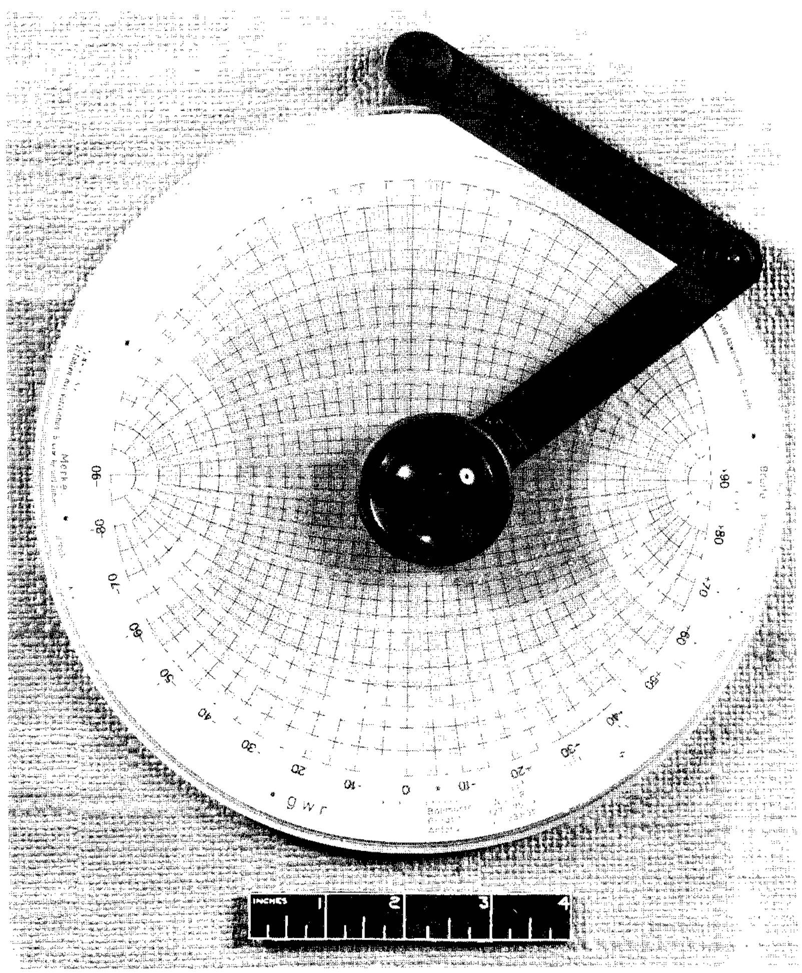


Photo 3: Training Model. Used with permission of QinetiQ Ltd.

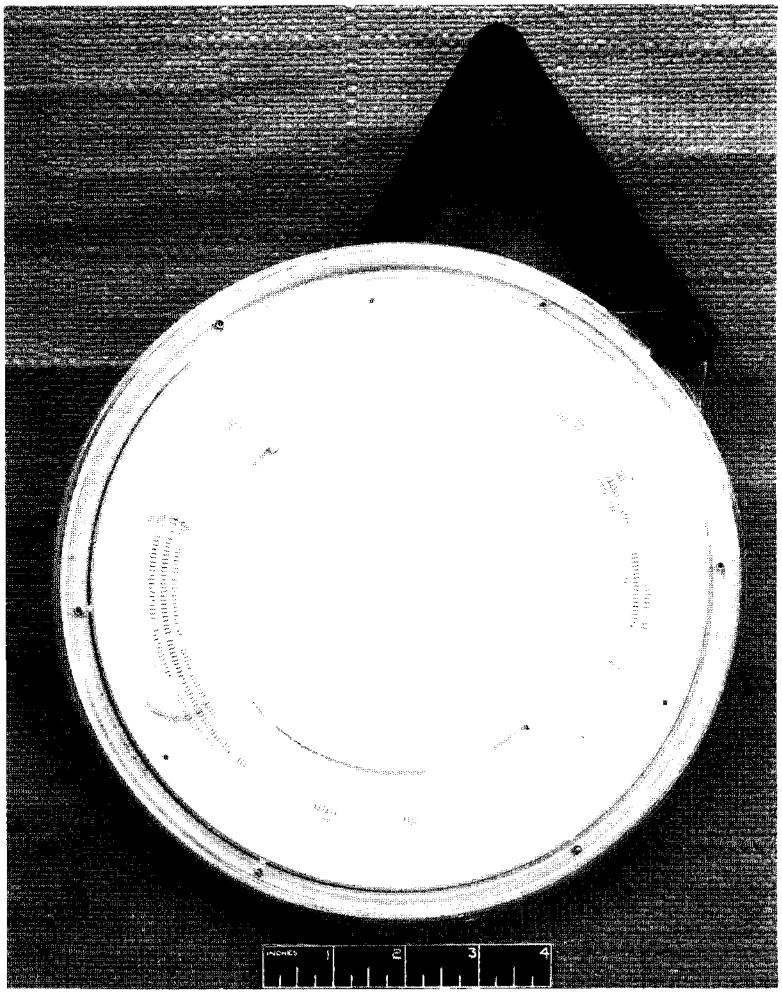


Photo 4: Training model. Used with permission of QinetiQ Ltd.

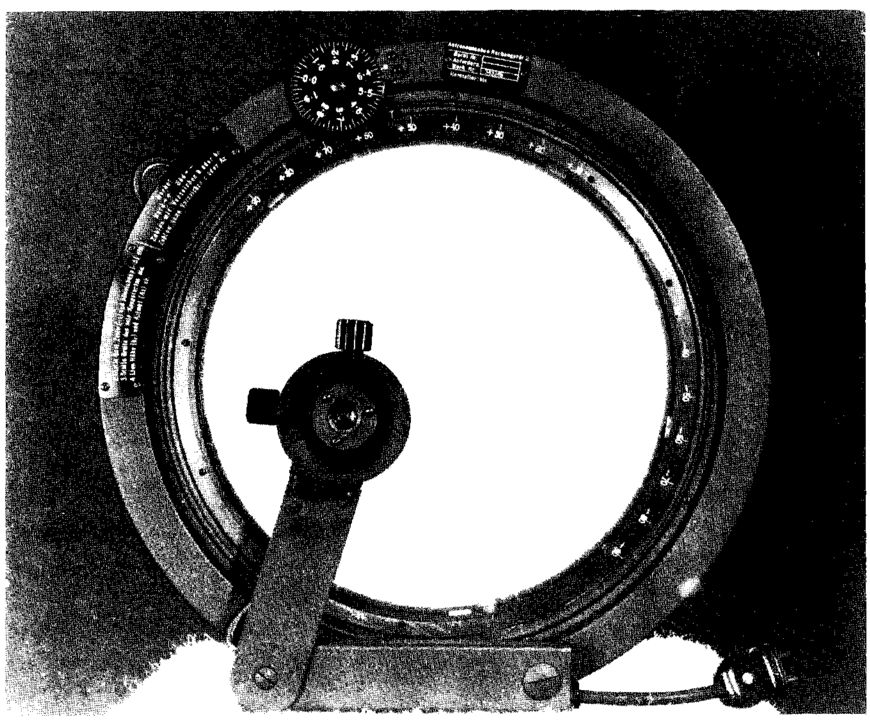


Photo 5: ARG2. Used with permission of QinetiQ Ltd.

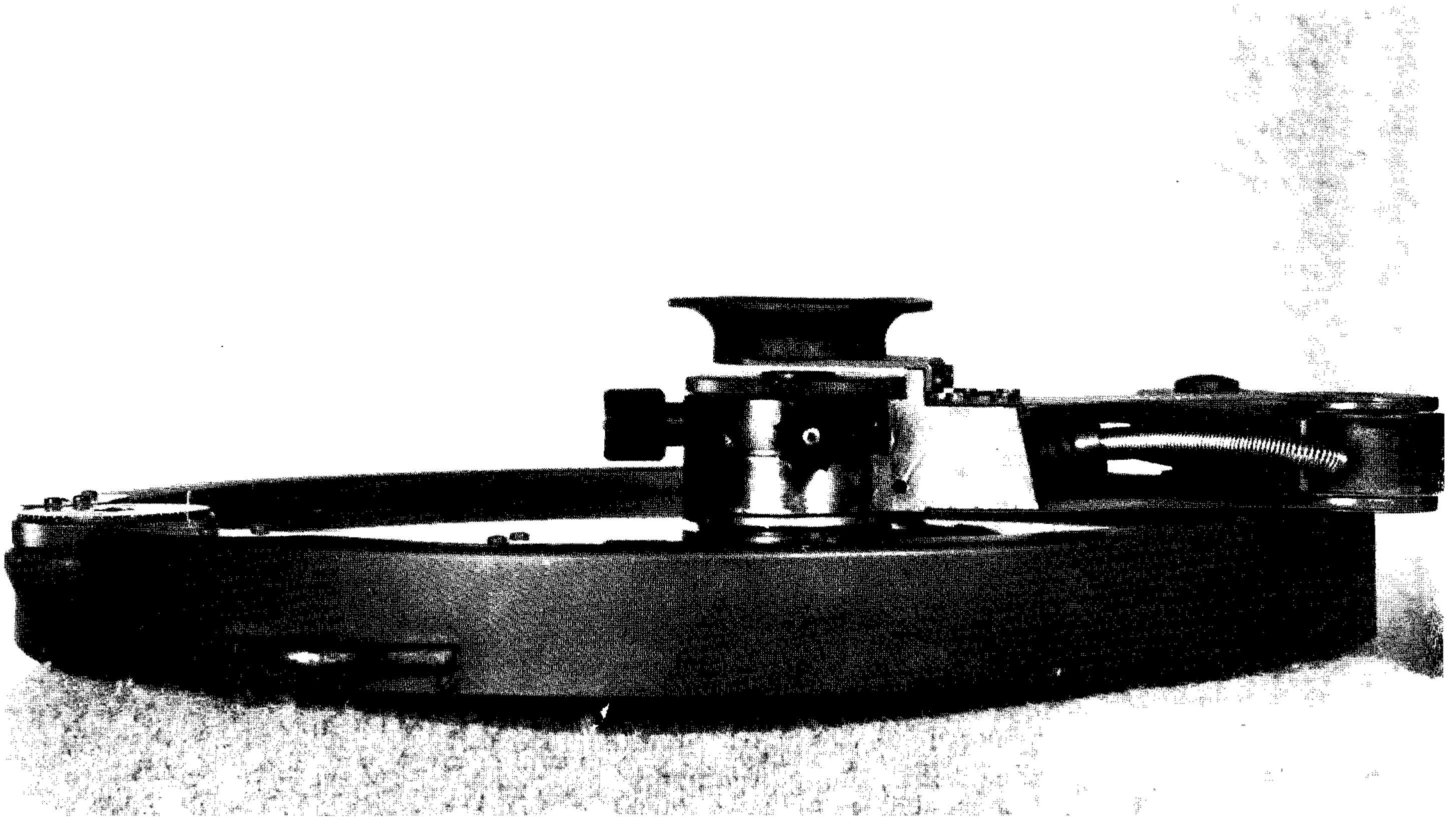
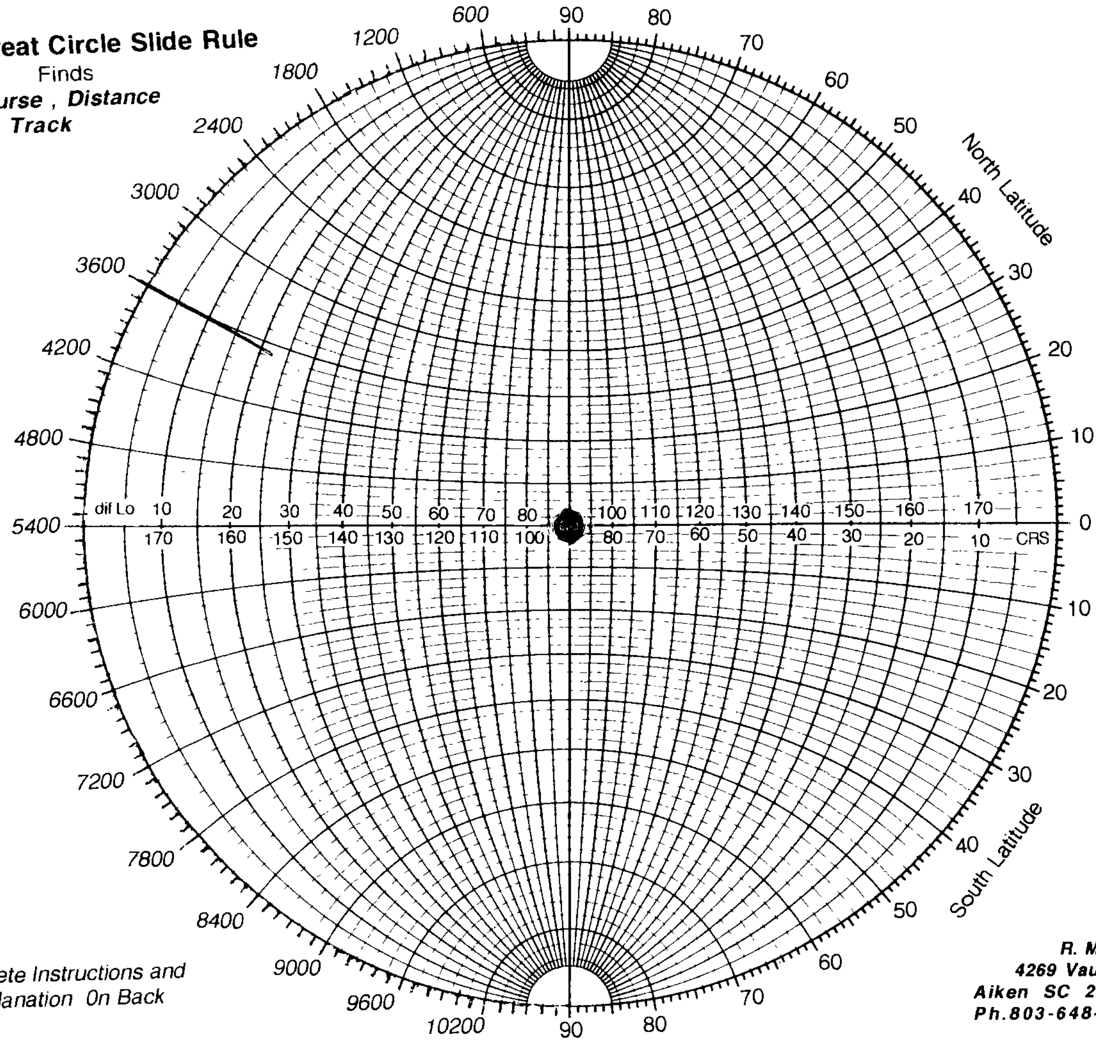


Photo 6: ARG 2. Used with permission of QinetiQ Ltd.

Great Circle Slide Rule

Finds
Course , Distance and Track



Steps

1 Rotate plastic disk to bring Line to 90° N

2. Dot intersection of destination Lat. and diff in Long (dif Lo)

3 Rotate disk to bring Line to Lat of Departure

4. Record Initial Course (CRS) and Distance under dot.

5. Draw Meridian Line from dot to 90° North point.

6 Rotate Disk to 90° N Line drawn in Step 5 will be the Track, in terms of the values of the meridians and parallels crossed by the line

Complete Instructions and Explanation On Back

R. M. Girdler
4269 Vaucluse Rd
Aiken SC 29801-8852
Ph.803-648-1393

ANSWER TO DO YOU KNOW . . .?

(from page 1)

See *American Practical Navigator* (Bowditch), 1977 and 1984 editions:

The basic principle of the **atomic clock** is that electromagnetic waves of a particular frequency are emitted when an atomic transition occurs. The frequency of the **cesium beam atomic clock** was found to be 9,192,631,770 cycles per second of Ephemeris Time in an experiment conducted jointly by the National Physical Laboratory, Teddington, England, and the U.S. Naval Observatory during 1955-1958.

In 1967 the **atomic second**, was defined by the thirteenth General Conference on Weights and Measures as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium atom 133. This value was established to agree as closely as possible with the ephemeris second. Thus, the atomic second became the unit of time in the **International System of Units (SI).**

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-SEVEN, FALL 2002

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

The Fall and Winter doldrums have begun. Boats are being laid up for the winter; land sailors have ceased purchasing navigation books and charts. Beginning in January and February sailors interests return to boating, and we begin the cycle over again.

We have started to receive articles written by our members as requested in a previous Newsletter. We are grateful for any and all contributions from our members. These submission help keep The Foundation alive and viable.

I remind everyone that our Editor, Ernest Brown, has the final say on what is printed in the Newsletter. If he has questions or comments, he will contact you directly if he has a telephone number or E-mail address. Please provide both on any article you submit for publication.

The Fall and Winter season for travel has begun. My wife and I did travel to Mongolia earlier this fall. Our son went on business and his wife, a friend and my wife and I joined him there for a week. It is a very interesting country with the herdsmen's tent-like homes called Herts by the Russians and Gairs by the Mongolians. They live in them year round even when the temperature reaches -40 C. Ulan Bator, the capital, shows the influence of Russian occupation from 1924 until 1992. It is very much like some of the Eastern European cities we visited just after the Russians departed. With a 15% relative humidity and a very arid climate the stars were so clear and visible that they would make a seagoing sailor weep. Transiting this area would be wonderful for desert navigators.

We will depart the end of October for a trip to Seoul, Korea and in January to Hawaii to celebrate the arrival of the first Koreans in 1902. A trip to China and Tibet is planned for the Spring. No further travel has been planned. However, we may also take our annual trip to Budapest, Hungary in the Spring.

In addition to the commercial versions of Sight Reduction Tables 229 and 249 mentioned in Issue #74 (Winter 2001-02) and in Issue #75 (Spring 2002) there is now a hard cover commercial printing of the bicentennial (2002) edition of Bowditch. The list price is $49.95 (members get a 20% discount) plus the cost of postage.

READERS FORUM

Edited by Ernest Brown

Member Erving Arundale wrote on October 9, 2002:

"The 76th issue of The Navigator's Newsletter came in the mail yesterday and I want to express my thanks for the inclusion of my navigation problems. However, to avoid difficulties with their solution, I must note two important typographical errors which appear in this newsletter.

(On Page 8) In Problem #1 Star-Planet Fix

The DR position should read 28° 05' N, Long. 76° 01' W

(On Page 9) In Problem #5 Part A Prime Vertical Sight

The watch time for the sight should read 16-09-12"

—*With best regards, Erving Arundale*

DO YOU KNOW . . .?

By Ernest Brown

Why the new United Kingdom version of Pub. 249 makes it more suitable for marine navigation than Pub. 249?

(Answer at back of this issue)

Member Erving Arundale wrote again on November 1, 2002:

"Thank you for your Oct. 28th letter and for your efforts to correct the typographical errors which appear in Navigation Problems #1 and 5A of Newsletter #76. Let's hope these errors did not create too much confusion for the members who have diligently attempted their solution. If concerns come to your attention, perhaps you may wish to send the corrections (or a copy of my Oct. 9 letter) to the members before the next issue of the newsletter is published). I deeply appreciate your efforts." *—Sincerely, Erving Arundale*

(Editor's note: Member Erving Arundale forwarded solutions to problems requested by another member)

Member Captain R. A. Bowling (U.S. Navy (Ret.) and Master Marine, Unlimited, Any Ocean, wrote on October 10, 2002:

"Enjoyed your issue 76, especially the Navigation Problems. In particular, I am intrigued with Probs. #2C and #5A (Time Sights). I've played with them once or twice using Bowditch Table 25, but would be interested in how Erving Arundale approached the problem. Will future issues of the Newsletter show the solutions?" *—Sincerely, R. A. Bowling*

Member Captain R. A. Bowling wrote again on November 14, 2002:

"Thank you for the information on Problems #2C and #5A in Issue 76 of the Newsletter. It reinforces the admiration I have for the navigators of yore, particularly in contract to the present ease of position finding with GPS.

Please extend my compliments and thanks to Erving Arundale for developing and providing the information." *—Sincerely, R. A. Bowling*

John C. Kelly wrote on October 17, 2002:

"I have read your concern about keeping the Foundation going, and I am interested in talking to you about this. I am retired, age 57, an active sailor with a keen interest in celestial navigation, and I would like to know more about this organization and its goals. Would you please give me a call when it is convenient. I will be traveling/sailing for the month of November." *— Thanks, John*

Member Jeremy C. Allen wrote on October 7, 2002:

"I have been a member of the Foundation for several years. I have noticed that there are not many members who write in with specific sea stories regarding navigation. I thought that I would try to fill in the gap by writing you with a few of my own.

" For the first half of 2002, I found myself the navigator of the MV *Ascension*. The *Ascension* is a US-flagged container/break-bulk containership that provides freight service to Ascension Island in the South Atlantic, as well as doing spot cargo work in the Caribbean, West African, and South American markets.

"The navigator's job description has changed a bit in recent times. With the nearly complete dominance of GPS in day to day navigation, my attentions focused mainly in voyage planning, noon slip calculation, and chart/publication correction. 'Day's runs' are calculated by Mercator sailing from successive 1200 LMT GPS positions, and the ship's position is neatly marked on the plotting sheet every hour with a GPS fix instead of hourly sun lines and star fixes. As a matter of fact, the watch system has been adjusted so that the 2nd mate is usually on the 12-4 watch, and the Chief Mate is on the 4-8 'star watch.'

"It is an unfortunate fact of life that the practice of celestial navigation is not a daily event on US merchant ships. The industry is still at a point where all of the captains can remember their days as a 2nd or 3rd mate when they still were using the sextant as the primary navigation tool on the high seas, but the new blood, such as me, never experienced those times. While the USCG still requires extensive celestial navigation knowledge and skills in their testing for licensure, the actual art of shooting the bodies and deriving useful information from them is being lost.

"When I reported to the *Ascension*, I brought my C. Plath Horizon Sextant with me. This is a professional grade sextant that I had gotten towards the end of my days as a cadet. This sextant is a bit different from older style sextants that I am sure most of the members have used. The primary innovation is the use of a semi-reflective horizon mirror instead of the split mirror/glass of the classic sextant. The horizon mirror on my sextant superimposes the body on the horizon enabling accurate sights across the whole horizon. Some may argue that this type of mirror reduces the low-light performance of the sextant, but I have not found this to be the case. A second innovation is that both the horizon and index shades have adjustable, polarizing lenses for one shade. These shades allow the user to quickly fine-tune the intensity of the body and is especially handy to cut down on the glare of the sea in certain situations which allows for a better picture of the visible horizon.

"During my six months at sea, I was the only one to use a sextant. While the 3rd mate was charged with daily azimuths of the sun for compass correction, the reduction of celestial LOP's was only done by me. If I decided to shoot some line in the afternoon, my first task was to set my watch to UTC. I would go to the clock screen on the GPS, and set my watch. The old habit of using stopwatches and chronometers is something I will not do in the days of accurate quartz watches. I found that I would lose all of a second or two a week on my $26 watch. After my watch was synchronized, I would take the sextant out of the case and check it for error. If I found error, I would correct it. Now some may be fearful of correcting their sextants, and I have met any number of old Captains who did not like adjusting sextants out of the fear of putting more error into it. I learned as a cadet that I was good at zeroing the correctable errors in sextants, and typically adjust my sextant to 0. index error. Once I was satisfied that my sextant was in good order, I would precalculate LAN and get ready to shoot it. Once LAN was finished, I typically shot a sun line every hour thereafter for a series of running fixes throughout the watch. My typical error was 2-4 nm depending on how well the LOP's cut and the accuracy of my sight.

"The most exciting day of the trip, from a celestial navigation viewpoint, was one day in March. We were sailing from Cape Canaveral, FL to Ascension Island on my Great Circle track. We had been out to sea for about 20 days and we were rapidly approaching the equator. As a matter of fact, based on my DR calculations, we would be crossing the line during my watch, and after a further check of the Nautical Almanac, we were neck and neck with the sun to see who was to reach 0 degrees Latitude first. We were racing down from the north, while the Sun was hurtling upwards from the South. Alas, the ship lost the race by about an hour, but at the time of LAN, the proximity of the sun did allow me to practice some high-altitude circles. I had a blast plotting the sun's GP and scribing a circle on the plotting sheet. I don't remember the exact number, but I believe the Ho was somewhere around 89-40. or so.

"While these sights typically made my day, especially seeing how close my LOP or fix was to the GPS numbers, most of the other Mates I have worked with do not share my enthusiasm for celestial navigation. While I am not a mathematician, nor am I very interested in different mathematical reduction techniques, I do enjoy exploring all of the different sights I can find to do. I have even made at-sea trials of Lunars with the help of Bruce Stark's Tables. As far as I can tell, lower transits are the only sights that I have not tried at sea, and that is only because I haven't been close enough to the poles during good weather to make the sights. Oh, I nearly forgot; has anyone out there actually shot an amplitude of the Moon? I have reduced the sight, but how do you take a bearing of the Moon's upper limb while it is on the visible horizon? I have only very rarely seen the moon actually rise, so I guess a fairly accurate pre-calculation coupled with luck can make it possible at all.

"Well there you have it, the celestial activities of a professional navigator in today's US Merchant Marine. If you have any comments or questions, I can be reached by mail or e-mail at anabasis@bellsouth.net. If I am at sea however, a reply might be a bit slow is coming. Fair winds and following seas." —*Warmest Regards, Jeremy C. Allen, 2nd Mate Unlimited Oceans; 2nd Engineer Steam, Motor, Gas Turbine Unlimited*

(Editor's notes: One needs to observe the moon's amplitude when the moon is centered on the visible horizon.

Member Jeremy C. Allen's sextant has a horizon glass called a Wide View Horizon Glass in THE SEXTANT HANDBOOK, Second Edition, by Cmdr. Bruce A. Bauer, USN (Ret.). International Marine, Camden, Maine 04843. Bauer states that this glass is called a beam converger by Davis Instruments. Bauer also states that the biggest disadvantage is the loss of the vertical reference that the edge of mirrored half provides on the standard glass.)

Member Frederic C. Kapp wrote:

"Over the many years that I was an ocean racing navigator, I had used many methods to solve for computed altitude and azimuth. I have previously written articles regarding this that the Foundation has published.

"Always in the back of m my mind was the term 'time sight.' I did not know what it was, nor did I need to know, since I could take a sight at any time I had a horizon. I did look it up in Bowditch and article 2106 Longitude Methods gives a description. Basically, it is a timed observation of a body, and longitude is ascertained by applying meridian angle to GHA to find longitude. Its usage came into being by the development of the marine chronometer in 1763. It was outmoded by the advent of both the Sumner LOP in 1837 and the Marcq St. Hilaire LOP method in 1875.

"About a year ago as I was cleaning up the clutter in my office, I came upon a book that I had purchased but never read. It was *Celestial for The Cruising Navigator* by Merle B. Turner, Cornel Maritime Press. I flipped a few pages and was hooked. The book features the solving of celestial problems by use of a trigonometric calculator. No need for tables. Just a Nautical Almanac. I was familiar with sight reduction by scientific calculator and I enjoy doing them in this manner without tables. I use a Texas Instruments TI 86 Calculator. One chapter featured longitude methods and there it was! The time sight. After doing a few problems I became very comfortable with finding longitude the way 18th century navigators did. Of course they did not have calculators, but the method is the same. The idea is that GHA + or - meridian angle (t) equals longitude. The problem is to find t. Once it is found, a time diagram is drawn, and the navigator can readily ascertain whether to add or subtract t from GHA. Remember that t is the angle at the poles between the meridian of the observer and the meridian of the body **measured eastward or westward to 180 degrees.**

"I can see that being able to do a time sight is a very handy 'wrinkle' for the navigator to have in his hip pocket. He must, however, be aware that he should have a solid latitude, as an error in latitude can lead to large errors in longitude. Usually the sight would be taken sometime after a meridian altitude of the sun.

"The following example will show the formula and its application. To use the formula with a trig calculator, latitude, declination, Ho (h), GHA must be converted to decimal numbers. Note that we only find GHA, not LHA as in LOP methods.

"October 8, 2002, at 1208 we took a Meridian Altitude of the Sun LL. This gave us a latitude of 33-13.ON and a DR longitude of 65-00W. Our course if 150T and we are making 6.0 knots.

"At 14-25-00 ZT in DR 33-01.1N 64-51.9W, we took a sight of the Sun LL. The Hs was 38-49.0. No IC, HE 8..

Hs 38-49.0
Dp - 2.7
ha 38-46.3
hac 14.9
Ho39-01.2

ZT 14-25-00
ZD+4
GMT 18-25-00 Date 8 October

The almanac gives us the following: Ghrs 93-07.5. Corrected **Dec 6-01.4S**

Gms 6-15.1
GHA 99-22.6

If one knows the GHA and can find t (MA) then by adding or subtracting t from GHA, longitude can be found.

The formula for t is: $t = \frac{(\sin h - (\sin L \sin d))}{(\cos L \cos d)}$ Note: h is Ho, L is Latitude, d is declination

h, L and d must be converted to decimals. GHA should be converted to decimal also.

Therefore, GHA 99-22.6 = **99.37666**
d 6-01.4S = **(-)6.02333**
L 33-01.1 = **33.01833**
h 39-01.2 = **39.02**

Thus: t = ((sin 39.02 - (sin 33.01833 sin (-)6.02333)) / (cos 33.01833 cos (-) 6.02333) = **34.55347**

GHA **99.37666 - 34.55347** = longitude 64.82319W or 64-49-23.5W. This is 2.30.5" East of our DR longitude.

Note: In this example declination was South, so the entry on the calculator must be preceded by the (-) key on the calculator."

Member Michael Perez wrote:

"My name is Michael Perez. I'm a new subscriber at the foundation of navigation and I'm happy to be a part of your family of great navigators.

"I'm a navigator from San Andres Island that is located in the latitude 12-32 north longitude 81-42 west. It is a small island that was a British colony in the past and now belongs to Columbia.

"In San Andres we are navigators by tradition and celestial navigation is what we like and understand. We don't really enjoy electronic navigation. Even though we used it, we don't criticize those who use it.

"Well, I'm trying to get familiar with the foundation and I want the foundation to get familiar with me.

"For your information, I'm a navigation buff. I love to collect old time sight reduction tables, the older the better, because I think that the real celestial navigation was in the old days when navigation was harder and less navigational means. For your information, I used a sight reduction table named Martellis Navigational Tables that was first published in 1873 in New Orleans by an Italian named G. F. Martellis and was revised in 1944 in Glasgow, England by Kelvin Hughes

"Well, I'm happy to be in the foundation and hoping to meet members in the future, and please send me any info you can about the foundation." —*Sincerely yours, Michael Perez.*

NAVIGATION NOTES

Sight Reduction Tables - Then and Now

By Catherine Hohenkerk

This article was first produced by the Royal Institute of Navigation (www.rin.org.uk) in NAVIGATION NEWS, *entitled SIGHT REDUCTION TABLES - THEN AND NOW by Catherine Hohenkerk of HM Nautical Almanac Office (www.nao.ac.uk) and is reproduced here by their kind permission.*

Catherine Hohenkerk, of the Nautical Almanac Office and co-author of Astro-Navigation and NavPac, discusses the history of Sight Reduction Tables and looks at the new Rapid Sight Reduction Tables for Navigation.

Tom Peppitt, in a letter to the Editor (*Sight Reduction Tables for Air Navigation* (AP3270)) in the November/ December 2001 issue of *Navigation News*, raised the question of the chronology of the introduction of air navigation tables to marine navigation. For me this was a pertinent question as I was in the process of updating the UK editions of these volumes. The US edition has had various designations, viz: HO 249, NVPUB 249 and Pub. No. 249, and at present is produced by their National Imagery and Mapping Agency.

For those unfamiliar with this publication, it consists of three volumes of altitude and azimuth tables for the solution of the spherical triangle to the nearest minute in altitude and degree in azimuth. Volume 1 contains tables of altitude and true azimuth of seven selected stars for the complete range of latitudes and hour angle of Aries. Volumes 2 & 3 contain altitude and azimuth angle for declination 0° - 29° , for all hour angles, and latitude 0° - 40° and 39° - 89°, respectively. Volume 2 and 3 may be used for any date but must be used in conjunction with an almanac such as *The Nautical Almanac* (NA). Volume 1 on the other hand is valid for about 5 years either side of the epoch date, and is a self-contained publication.

The question Tom Peppitt posed was very timely, not only was I in the process of updating Volume 1 from epoch 2000.0 to 2005.0, but we had also already decided that the title must better reflect the use to which the tables were being put — i.e. for marine navigation. Unfortunately I have not been able to pin down the transition from use in the air to use at sea. However, Dr. P.M. Janiczek, formerly at the US Naval Observatory, tells me that any of the official or experimental publications intended for air navigation could have found their way into military and merchant navies at any time.

The development of these tables is interesting, and Janiczek reports that a chronology is recorded in *The American Practical Navigator* (Bowditch, 1977). Between 1938 and 1944 the British Admiralty published 15 volumes of *Astronomical Navigation Tables* (AP1618), which were intended for aviation use. In 1941 the US Navy republished the first 14 volumes as HO Pub 218. In 1941 George G. Hoehne submitted his *Star Navigation Tables*. His tables were recognised as being superior in basic design to the star section of AP1618. Thus in 1942 Hoehne obtained permission to incorporate parts of Pub 218 into his preliminary edition of Volume 1 of *Celestial Air Navigation Tables*. That successful effort led to the publication of Volume II, *Practical Celestial Air Navigation Tables*, in 1943. Throughout the war years and until 1953 members of the Royal Air Force also offered many suggestions for improvements to AP1618 and even some experimental tables were published.

The first edition of the US Pub 249 (Volume 1 Selected Stars) appeared in 1947 with the title *Star Tables for Air Navigation* and incorporated the principles and features proposed by George Hoehne and Commander C.H. Hutchings, USN, and others. The first published edition was in 1951 for epoch 1955 and Volumes 2 and 3 followed in 1952. The British edition appeared in 1952 and 1953 as AP3270. The UK and US editions at that time were identical except for the explanation. It is recorded in Bowditch that more than 20,000 copies of the preliminary (1947) edition had been distributed by 1951. With so many copies in circulation it is possible that the preliminary edition crept into marine use almost immediately. It is also clear from Bowditch that there was continual improvement to the contents of this publication. In fact until the late 1980's the Air Standardisation Coordinating Committee (Working Party 53) of the English speaking Air Forces: the United States, the United Kingdom, Canada, Australia and New Zealand, coordinated the requirements for this joint publication. This ensured that not only were the same stars use, and the names were spelt the same, but also standardised examples, etc. were used.

We have now almost gone full circle, with the US and UK editions having the same main tabular pages, but with different explanations. However, this time we have gone a bit further by also enhancing the examples, and explanation for navigation at sea, which is reflected in the new title *Rapid Sight Reduction Tables for Navigation*.

The explanation clearly worked examples, with position line plots, that were provided in the new edition give the method in step by step fashion that all marine navigators can follow. A sight reduction form is also included that gives a short summary of each step. This form may be freely downloaded from our website at *www.nao.rl.ac.uk*.

Volume 1 may be used without an almanac, as the tables for dip and refraction, similar to those in *The Nautical Almanac* have also been included. When using Volumes 2 and 3 an almanac is essential for evaluating the GHA and declination of the observed object. However, a solar ephemeris is included (Table 4) valid for 2001-2036, with an accuracy of better than 2.. To make Volumes 2 and 3 complete the Altitude Correction Tables for the Sun that apply the corrections for refraction, parallax and semi-diameter are included (Table 6c). The tables for refraction have been updated using a more up-to-date model of the atmosphere and integration technique (see NAO Technical Note 63). The standard temperature and pressure specified in the NA are 10° C and 1010mb pressure, respectively. For the record, the refraction table is now tabulated for the NA standard atmospheric conditions which are, from 2004, a temperature of 10° C, 1010mb pressure, 80% humidity, wavelength 0.01569 _m, latitude 45° , and temperature gradient (lapse rate) of 0.0065° Km-1.

The calculated (tabulated) altitude (Hc) is given to the nearest minute of arc, but all corrections, dip, refraction, etc., are given, as in the NA, to the nearest 0..1. Although this is inconsistent, I hope that it encourages navigators to always make their observations as accurately as possible. It is essential that navigators develop and maintain their expertise in using their sextants to its full precision, whatever the method of sight reduction used.

Editor's note: As first produced in NAVIGATION NEWS, this article includes a position line plot from the example from the section 5.2.4, a Sight Reduction Form with the start of the worked example from section 5.2.4, the worked example from section 5.2.4 showing steps 5 to 8, and an extract from the tabular pages of Volume 1 for latitude 21° North.

Lewis and Clark Nailed the Continental Divide

By Bruce Stark (Issue Seventy-six, Summer 2002)

Correction

There is a mistake in what I wrote about Lewis and Clark at the continental Divide. I said that if personal and index errors were canceling in the sun-east lunars they would add to each other in the sun-west lunars. That's not true. Those six sets of excellent lunar observations Lewis took don't, of themselves, give us as much information about index error as I'd hoped.

HISTORY OF NAVIGATION

CP - 300/U USAF Star Finder

By Edward S. Popko, USPS SN

Introduction

Marine navigators have used the 2102-D star finder for many years as an aid to planning sights or identifying stars. The US Air Force developed a variation in the mid-1950s that incorporated a number of useful enhancements. This article highlights the main features of the CP-300/U and contrasts it to the better known 2102-D star finder. Both star finders give positions of stars included in both the American and British Almanacs and are primarily used by celestial navigators for planning sights or identifying unknown stars. CP-300/U consists of a star base with the Northern Sky on one side of the base and the Southern Sky on Figure 1 the other, an east-west longitude scale, and eight (8) removable discs with a grid projection at designated latitude increments of 10°.

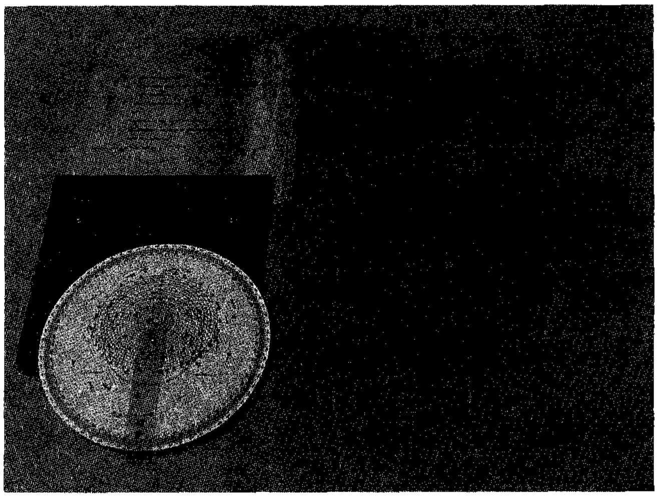


Figure 1: FSN 6605-557-0778
Computer Air Navigation Celestial Azimuth
TYPE CP-300/U
MIL-C-277333(USAF)
QTY 1
CONTRACT NO. AF36(600)9047
ALLEGHENY PLASTICS INC. MFG/CONTRACT
MFG NO. APAF-31
III PKG 5/61

Parts

- *star base with the Northern Sky on one side of the base and the Southern Sky on the other side*
- *East-West Longitude Scale*
- *Eight (8) removable discs with grid projections on the sphere with designed latitude in increments of 10°*
- *Instruction set*
- *Plastic case*

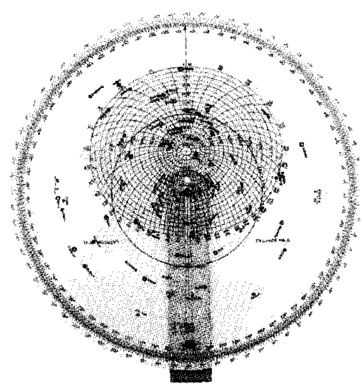
Knowing the GHA Aries and a dead reckoning latitude and longitude, this device can compute the LHA Aries and display the altitude (Hc), azimuth (Zn), SHA, Declination and LHA for a celestial body. For the celestial navigator, daily uses might include:

- predicting the altitude and azimuth (bearing) of stars for morning or evening star shots
- identifying unknown stars
- estimating sun rise/set, civil, nautical and astronomical twilight
- determining the time between sun/moon/Venus shots for optimal cut angles for running fixes
- time for sun, moon or Venus shots for specialty LOPs like latitude, longitude, speed or course lines.
- precomputing star-planet combinations
- precomputing daylight sights of sun/moon, Venus

In general use, the star finder is set up for an anticipated observation time. This is accomplished by setting the latitude grid overlay reference meridian to the LHA Aries on the rim scale. All bodies in the visible sky whose altitude range from -10° to 90° are located within the grid of the Altitude/Azimuth disk. Stars outside this grid are not visible at this time. An example of how to use the star finder is given later

Design and Layout

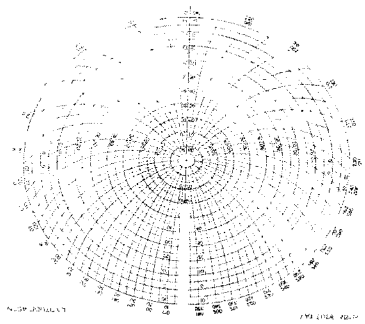
The CP-300/U's main body is a sandwich design of <u>three</u> thin white opaque plastic wheels with a common center pivot. The middle wheel displays east and west longitudes 0° - 180° around its rim. This scale is printed both sides (*see Figure 2(d)* and it's the largest wheel measuring 8 1/2″ in diameter. The other two wheels, top and bottom, are star bases for the northern and southern celestial spheres (*see Figure 2(a)*). They also have rim scales, the meaning of which depends on the application of the finder. Measuring 8″ in diameter, their scales can be aligned adjacent to and read along with the longitude scale. The most common use of star base rim scale is to set the LHA Aries (*see detailed image Figure 2(c)*). Each star base displays 66 navigation stars. The same set of stars is plotted on both wheels but their projection corresponds to viewpoints from the north or south hemisphere. The Celestial Equator is plotted on the star bases as well. It's labeled and graphically appears as a circle centered on the elevated pole (*see Figure 2 (e)*).



CP-300 U-13 b/c

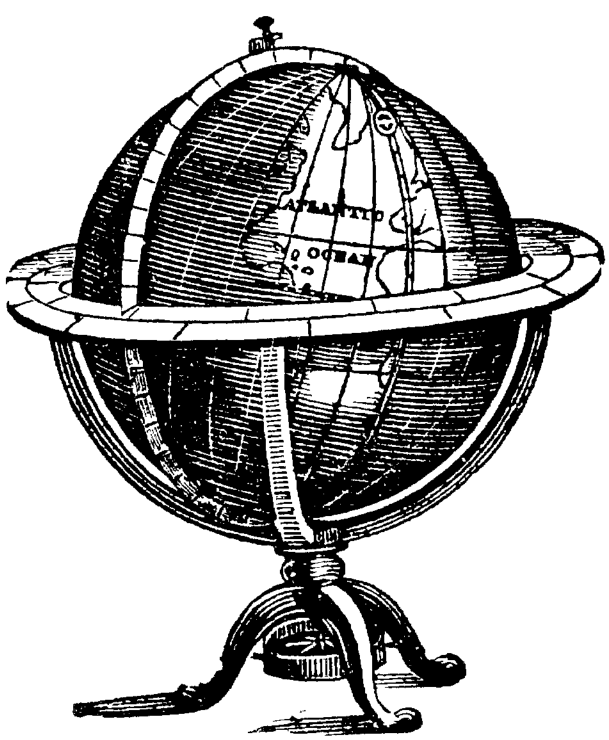
In addition to the latitude and star base wheels, the

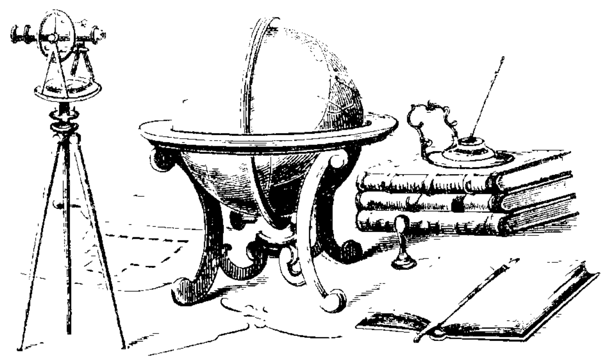
CP-300/U includes a transparent plastic rotation arm. It's a radial pointer and doubles as a mount for slip-in altitude/azimuth disks. *See Figure 2 (b)*. Disks are placed over the star base and tucked under rotation arm. A slot in the disk locks onto a key under the rotation arm. Some other features are covered later.



CP-300 U-05

The CP-300/U includes eight (8) transparent removable discs with projections[1] of the celestial reference grid. In effect, the grid represents the visible sky and when properly positioned over the star base, the stars that display through the grid are the ones that can be seen at that time from that longitude. The grid tells you where to look for them (altitude/azimuth). Each disk covers a 10° increment of terrestrial latitude starting at 5° and proceeding to 85°. Depending on which disk face is inserted "up", the grid represents either north or south latitudes. The north disks are only used with the north star base and visa versa. Each disk displays azimuth reference lines 0° -360° in 5° increments as well as altitude reference lines range from -10° to 90° in 5° increments. The grid system completely defines all the positions in the sky. The observer's meridian (due north and south) is indicated on the grid with reference line, one end of which has an arrow pointing 180° away from the elevated pole. For DRs in the northern hemisphere, the arrow points due south at 180°. (0° or 360° degrees for southern hemisphere DRs.)





An Example

Navigators with 2101-D experience will recognize the CP-300/U's setup. The example here is a typical day's work situation. The navigator is preparing a star list for tomorrow morning's observations. He wants to know what stars will be visible at twilight and where to look for them.[2] His goal is to make a star list with approximate altitudes/azimuths for samples around the horizon.

A schooner is on course 333° T within the Boston Harbor In-bound Traffic Lane. They are approximately 10 nm east of Cape Cod. By daybreak, they will reach a critical turn point where the In-bound lane takes a new course of 290° T directly to Boston. The navigator estimates that they will make this turn at day break and wants to fix their position before the course change. He prepares a star list of the best bodies to shoot in the morning. Consulting the Nautical Almanac and projecting his course and speed, he determines that their DR at dawn will be Latitude 42° 05.N Longitude 69° 51.W at 10:50GMT, the time of expected Nautical Sunrise on Saturday on December 7, 2002. Here are the steps:

1. Select the star base and altitude/azimuth overlay grid that corresponds to DR latitude expected at twilight. The "N" star base and overlay grid "LATITUDE 45° N" grid are selected because the DR latitude falls within it. It is inserted under the rotation arm. A slot in the disk slides around a keyway molded into the rotation arm. A quick check insures that the 45° N face is up and not 45° S which is only used with the southern star base.
2. Fine tune the grid to the DR latitude. The DR anticipated at twilight tomorrow is 42° N, not 45° N so a minor adjustment to the disk is needed. The disk can be slid in or out from under the rotation arm by +/-5° , here it is shifted -3° to more closely approximate the DR latitude. It's convenient to tape the disk and arm together to maintain the alignment when the finder is being handled.
3. Determine GHA Aries at twilight and set this angle across from 0° longitude (Greenwich)- use the daily pages of the Nautical Almanac, determine the GHA Aries at nautical sunrise. GHA Aries is approximately 238° 32.. GHA is measured from Greenwich, westward, to the First Point of Aries. Position the GHA

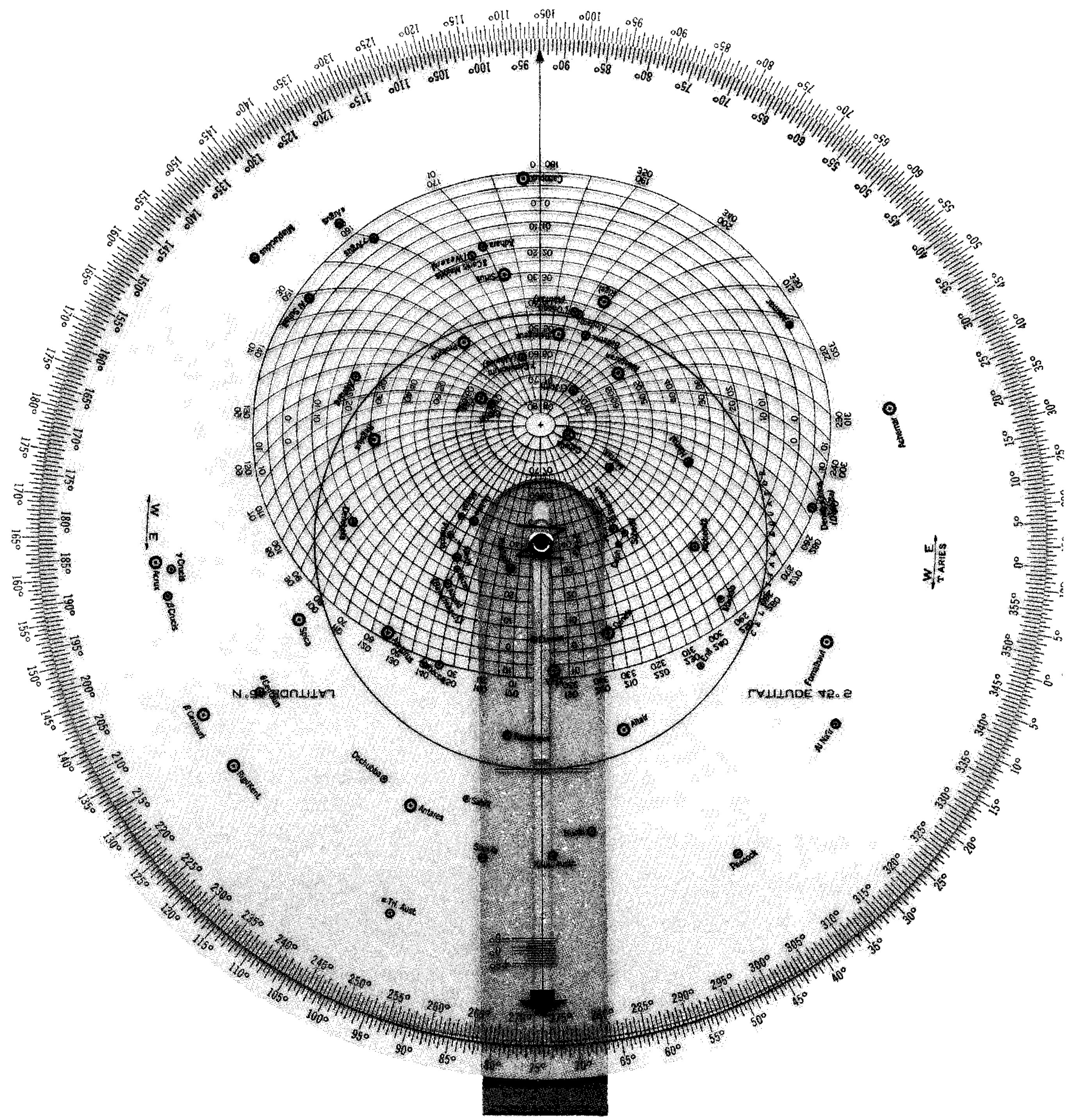


Figure 2 — Full view of the CP-300/U USAF Star Finder. Star base is northern hemisphere side (indicated by a large "N" in the center). The altitude/azimuth disk overlay is for latitude 45° N (a). The disk latitude has been adjusted -3° to more closely approximate 42° N (b). The disk's LHA Aries is set for 93° (c). The viewer's longitude is set for 74° West (d) (home location of the author).

Aries (238° 32' or 238.5°) of the star base across from 0° on the outer longitude wheel. The star base and longitude wheels are now in proper position to one another.

4. Align the observer's meridian to the DR longitude of sunrise. Using the rotation arm, rotate the altitude/azimuth grid so that the observer's meridian (indicated by an arrow at azimuth 180°) points to the DR longitude expected at sunrise. In this example, 70° west longitude is close enough. This step is similar to the 2102-D however the navigator only has to work with his DR longitude and need not calculate the LHA Aries to set the wheels.

The CP-300/U is now properly set up for the sample problem. All stars within the grid are visible at dawn from the DR position, date and time given.

Interpreting the Results

Even without the planets and the moon, the navigator has many choices assuming visibility is good. Navigators often have personal preferences for the stars they will shoot. In this example, only stars with altitudes greater than 15° and less than 70° were picked. The following are some of the stars that meet these conditions. Those in bold or underlines make good combinations for three-star fixes. Three planets are shown in italics.

The results shown in the Table 1 are only a sampling of the possible combinations. Although we did not plot planets on the star base, it should be noted that on this particular morning, four planets are visible. Venus and Jupiter are magnitude 1, excellent targets for sights. Mars, although of magnitude two, was so close to a very bright Venus that it offered no sight advantage and thus was not listed in the table.

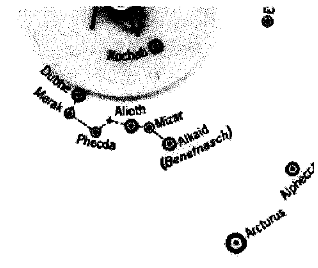
Body	Alt	Az
Kochab	**50**	021
Vega	13	048
Alkaid	60	061
Alphecca	35	085
Arcturus	45	105
Venus	*20*	*128*
Spica	27	144
Denobola	60	156
ElNath	23	288
Alphard	34	209
Regulus	56	204
Jupiter	*56*	*225*
Procyon	30	245
Pollux	46	266
Saturn	*23*	*289*
Capell	31	305
Mirfak	18	322

Table 1. — Altitude and azimuth for selected stars resulting from the sample problem.

Features not found on 2102-D

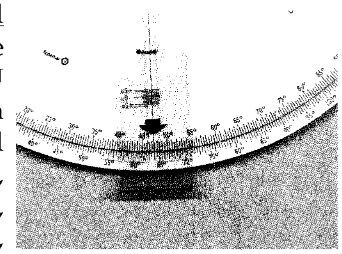
The CP-300/U is a refinement of the 2102-D star finder. Notable enhancements include:

- More base stars - the CP-300/U's star base displays the same 66 stars on both the north and south bases. The 2102-D displays 57. Both star finders display a common set of 53 (see Table 2 for a listing and comparison). Stars appear to be selected on the basis of magnitude and their even distribution across the sky; not necessarily because they are among the 57 designated Navigation Stars included in the Daily Pages of the Nautical Almanac. Almost all of the additional stars are in the Big Dipper, Cassiopeia, Orion's Belt, Canis Major and the Southern Cross areas. The likely intent was to offer more choices in areas that are easily recognized.

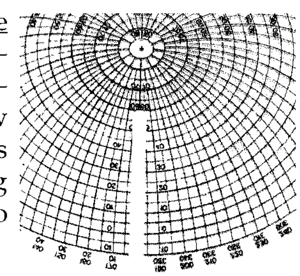


CP-300 U-09

- Constellation figures - Cassiopeia and Ursa Major (Big Dipper portion) are depicted on the star base.
- Longitude Wheel - one of the most significant differences, the CP-300/U includes an extra wheel for setting the viewer's longitude. The latitude wheel is particulary useful for quickly finding the LHA Aries based on an AP or DR position. Other computations for time and hour angles are possible.
- Altitude/Azimuth grid adjustment - like the 2102-D, the CP-300/U includes sky projection grids for north and south latitudes 5° , 15° , 25° , 35° , 45° , 55° , 65° , 75° , and 85°. However, a unique slot mounting allows for fine latitude adjustments of +/-5°. Thus it's possible to set the observer's position to any desired latitude north or south from 0° to 90°. In the adjacent image, scale (a) indicates that the grid for latitude N 45° is adjusted to better fit N 42°.


CP-300 U-04

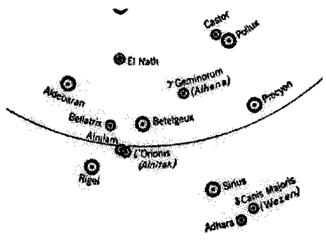
- Below the horizon altitude scales - the CP-330/U overlay disks extend the azimuth grids to - 10° below the celestial horizon. This is a useful addition allowing civil or nautical twilight to be estimated.


CP-300 U-17

But not all CP-300/U features are improvements:

- Bayer names - unlike the 2102-D star base where common star names are used throughout, the

CP-300/U uses Bayer names in some cases. For example, well known Menkent, is labeled θ Centauri, an unnecessary confusion. Some stars display both names. The result is a congested display that is somewhat difficult to read. Table 2 lists all stars displayed on both finders. The common and Bayer names are listed as they appear on the finders.



CP-300 U-10

- No declination overlay - while the 2102-D provides a special overlay template to assist in adding new bodies to the star base, the CP-300/U does not. This is certainly a design shortcoming. Unlike stars that have fixed celestial positions, the sun, moon and planets are never printed on the star base because they are constantly changing against the star backdrop. Many navigators will plot them, especially when they are bright and visible at twilight because their positions change little during a typical voyage. Plotting a new body on the CP-300/U involves using dividers to measure off the distance between the pole (star finder center) and the celestial equator circle. The declination is then estimated. The rotation arm acts as a ruler for intersecting the body's RA and the declination on the star base. The Nautical Almanac provides the necessary GHAs. Once located, they can be plotted in pencil on the star base. The base material is durable and withstands gentle erasures too. But nonetheless, this process is tedious compared to the overlay provided with the 2102-D.
- Terse instructions - the instruction sheet accompanying the CP-300/U is very brief and describes just a few setups. Only an experienced navigator, or one already familiar with the better documented 2102-D star finder, could understand how to use this device.

Conclusion

The CP-300/U is an enhanced version of the 2102-D star finder. Its additional complexity offers greater flexibility in locating stars and performing latitude, hour angle and time conversions. For many navigators, these benefits will outweigh its few design flaws. One can only speculate why the CP-300/U was not more widely used or made commercially available. Perhaps its additional manufacturing complexity and likely cost increase simply could not displace the venerable 2102-D star finder.

The author may be contacted at popko@ulster.net should any member seek more information on the CP-300/U.

(Endnotes)

1 For an explanation of the oblique azimuthal equidistant projection used for the latitude overlay grids, see Ernest Brown's "DO YOU KNOW. . ." column in *The Navigator's Newsletter*, Issue 49 (Fall 1995)

2 Readers interested in knowing more about star finders will benefit from David Birch's fine manual *"The Star Finders Book - A complete Guide to the many uses of the 2102-D Star Finder"*. It's quite readable and the many examples provide an excellent refresher on time, hour angles, the Nautical Almanac and the various interpretations of the scales and reference grids on the finder. The differences between the 2102-D and CP 300/U are minimal. See the Reference section for details.

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Star Name	SHA	Dec		RA	RA Hr	57	CP300	2102-D
Alpheratz	357	N	29	3	0	Y	Y	Y
Caph	357	N	59	3	0		Y	
Ankaa	353	S	42	7	0			Y
Schedar	349	N	56	11	1	Y	Y	Y
Deneb Kaitos (Diphda)	349	S	17	11	1		Y	Y
γ Cassopeia	345	N	60	15	1		Y	
Ruchbah	338	N	60	22	1		Y	
Achernar	335	S	57	25	2		Y	Y
Hamal	328	N	23	32	2	Y	Y	Y
Acamar	315	S	40	45	3	Y	Y	Y
Menkar	314	N	4	46	3	Y		Y
Mirfak	308	N	49	52	3	Y	Y	Y
Aldebaran	290	N	16	70	5		Y	Y
Rigel	281	S	8	79	5	Y	Y	Y
Capella	280	N	46	80	5	Y	Y	Y
Bellatrix	278	N	6	82	5	Y	Y	Y
El Nath	278	N	28	82	5	Y	Y	Y
Alnilam	275	S	1	85	6		Y	Y
ζ Orinois (Alnitak)	274	S	1	86	6		Y	
Betelgeuse	271	N	7	89	6	Y	Y	Y
Canopus	264	S	52	96	6	Y	Y	Y
γ Geminorum (Alhena)	260	N	16	100	7		Y	
Sirius	258	S	16	102	7	Y	Y	Y
Adhara	255	S	28	105	7		Y	Y
δ Canis Majoris (Wezen)	252	S	26	108	7		Y	
Castor	246	N	31	114	8		Y	
Procyon	245	N	5	115	8	Y	Y	Y
Pollux	243	N	28	117	8	Y	Y	Y
γ Argus	238	S	47	122	8		Y	
ε Argus	234	S	60	126	8		Y	Y Avoir
Al Suhail	222	S	43	138	9		Y	Y Suhail
Miaplacidus	221	S	69	139	9	Y	Y	Y
Alphard	218	S	8	142	9	Y	Y	Y
Regulus	207	N	11	153	10	Y	Y	Y
Dubhe	194	N	61	166	11	Y	Y	Y
Merak	194	N	56	166	11		Y	
Denebola	182	N	14	178	12	Y	Y	Y
Phecda	181	N	53	179	12		Y	
Gienah	176	S	17	184	12	Y		Y
Acrux (α Crucis)	173	S	63	187	12		Y	Y
γ Crucis (Gacrux)	172	S	57	188	13		Y	Y Gacrux
β Crucis (Mimosa)	168	S	59	192	13		Y	
Aloth	166	N	55	194	13	Y	Y	Y
Mizar	158	N	54	202	13		Y	
Spica	158	S	11	202	13	Y	Y	Y
Alkaid (Benetnasch)	153	N	49	207	14		Y	Y
β Centauri (Hadar or Agena)	148	S	60	212	14		Y	Y Hadar
θ Centauri (Menkent)	148	S	36	212	14		Y	Y Menkent
Arcturus	146	N	19	214	14	Y	Y	Y
Rigil Kent. (Toliman)	140	S	60	220	15	Y	Y	Y
Kochab	137	N	74	223	15	Y	Y	Y

Continued on next page.

Zubenelgenubi	137	S	16	223	15	Y		Y
Alphecca	126	N	26	234	16	Y	Y	Y
Dschubba	119	S	22	241	16		Y	
Antares	112	S	26	248	17	Y	Y	Y
α Tri Aust. (Atria)	107	S	69	253	17		Y	Y Atria
Sabik	102	S	15	258	17	Y	Y	Y
Rasalhague	96	N	12	264	18	Y	Y	Y
Shaula	96	S	37	264	18	Y	Y	Y
Eltanin	90	N	51	270	18	Y	Y	Y
Kaus Austr.	83	S	34	277	18	Y	Y	Y
Vega	80	N	38	280	19	Y	Y	Y
Nunki	76	S	26	284	19	Y	Y	Y
Altair	62	N	8	298	20	Y	Y	Y
Peacock	53	S	56	307	20	Y	Y	Y
Deneb	49	N	45	311	21	Y	Y	Y
Enif	33	N	9	327	22	Y	Y	Y
Al Na'ir	27	S	46	333	22	Y	Y	Y
Fomalhaut	15	S	29	345	23	Y	Y	Y
Markab	13	N	15	347	23	Y	Y	Y

Table 2. — Stars appearing on the CP-300/U and 2102-D star bases or listed in the selected 57 stars in the Nautical Almanac. Stars are listed in their ascending order of right ascension and declination, the same order printed on the star-bases.

MARINE INFORMATION NOTES

What's New at NIMA's Maritime Safety Information Division

Website - http://pollux.nss.nima.mil/index
(23 August 2002)

US Notice to Mariners

The US Notice to Mariners is now available for download in a single PDF file and in a zipped file which includes both the NTM in a single PDF and all graphics in JPG. These new files along with the PDF files of the individual NTM sections may be accessed via the US Notice to Mariners section of this website.

The American Practical Navigator (Bowditch)

The 2002 bicentennial edition of Bowditch is now on-line for download. Hard copies of this publication with a CD attached may be obtained from the Government Printing Office.

Magnetic Variation Charts

Magnetic Variation Chart of the World, Epoch 2000 and Magnetic Variation Chart of the North and South Poles, Epoch 2000 are available for viewing and downloading via the Miscellaneous Navigation products section of this website.

Website Survey Form

To better serve the needs of users, the Website Survey Form has been expanded and improved. Your input is critical to the continued success of this website and your feedback is encouraged.

(11 April 2002)
Sailing Directions (Enroutes and Planning Guides)

Sailing Directions (Enroutes and Planning Guides) are now available to Department of Defense (DoD) users. All forty-two volumes of the current edition can be accessed via the NIMA On-Line Navigation Publications section of this website.

Radar Navigation and Maneuvering Board Manual

The 2001 editions of the Radar Navigation Manual (Pub 1310) and the Maneuvering Board Manual (Pub 217) have been combined into a single volume and will now be issued under the name Radar Navigation and Maneuvering Board Manual (Pub 1310). Th seventh edition is available on CD-ROM from the Government Printing Office or via the NIMA On-Line Navigation Publications section of this website. This publication will not be issued in printed form.

Publications of HM Nautical Almanac Office

Website: http://nao.rl.ac.uk

The following is a partial listing of the publications:

NavPac and Compact Data

Formerly known as *Compact Data for Navigation and Astronomy*, this book contains formulae for calculating the positions of the Sun, Moon and planets to navigational precision over several years using a pocket calculator or personal computer. It includes a CD-ROM containing ASCII data files and *NavPac*, a software package which provides tools to find the position of astronomical objects in the sky and their rise/set times, your position from sextant observations and routes and directions between locations involving course, speed and time.

Editions currently in print: [NavPac and Compact Data 2001-2005]

AstroNavPC and Compact Data

This is the US counterpart of *NavPac and Compact Data 2001-2005* and contains the *NavPac* software under the name *AstroNavPC*. The software is identical to *NavPac* in all operational aspects and has undergone a name change to avoid confusion with another product available in the United States.

Editions currently in print [AstroNavPC and Compact Data 2001-2005]

The following from website: http://www.nao.rl.ac.uk/nao/ap3270

Rapid Sight Reduction Tables for Navigation AP 3270/NP303

Volume 1: Epoch 2005.0 selected Stars
ISBN 011 887555-8; Price £ 25.00
Volume 2: Latitudes 0° -40° and Declinations 0° -29°
ISBN 011 887556-6; Price £ 25.00
Volume 3: Latitudes 39° -89° and Declinations 0° -29°
ISBN 011 887557-4; Price £ 25.00
Publisher: The Stationery Office
Available from October 8th 2002

Rapid Sight Reduction Tables for Navigation, in three volumes, provides essential information for marine navigation. The specially-designed, comprehensive tables of altitude and azimuth, with explanation and detailed worked examples, enable rapid reduction of astronomical sights using traditional techniques. This updated and re-titled edition maintains the format of the main tabulations of *Sight Reduction Tables for Air Navigation,* however the change of emphasis of the explanation, examples and auxiliary tables reflect the popularity of this publication with navigators at sea.

HM Nautical Almanac Office and the Nautical Almanac Office of the US Naval Observatory designed the tabular ages which are used worldwide; by the US Navy, the Royal Navy, amateur and professional navigators alike. Positions derived from these volumes compare favourably with other astro-navigation publications. The explanation and clearly worked examples with position line plots give an easy method for all navigators to find their position at sea.

Volume 1 contains tables of altitude and azimuth of seven selected stars for the complete range of latitudes and hour angle of Aries. The arrangement provides, for any position and time, the best seven stars to use, their positions for presetting the sextant and their subsequent reduction. The volume, valid for 2001-2010, may be used without reference to an almanac, as it also contains tables for GHA Aries, dip and refraction. Other auxiliary tables include the conversion of arc to time, and corrections due to the movement of the vessel. There are star charts to aid identification and a sight reduction form to record the results.

Volumes 2 and 3 contains tables of altitude and azimuth for the complete range of hour angles valid for latitudes 0° to 40° north and south and 0° to 29° declination north and south (volume 2) and latitudes 39° to 89° north and south and 0° to 29° declination north and south (volume 3). The arrangement provides data for any time, for all objects within 29° of the celestial equator and for all locations for presetting the sextant and the subsequent reduction of the sights. Volumes 2 and 3, valid for any date, are designed for use with an almanac and are designed for use with an almanac, such as *The Nautical Almanac.* However, a table, valid for 2001-2036 (top better than 2.) together with the altitude corrections needed for reducing solar observations is included. Other auxiliary tables include dip, refraction for stars and planets, the conversion of arc to time and corrections due to the movement of the vessel. There are star charts to aid identification and a sight reduction form to record the results.

To buy these titles directly from The Stationery Office, please follow the links for Volume 1, Volume 2 or Volume 3.

Sight Reduction Forms

The sight reduction forms that are included with these publications are available here as downloadable pdf files (Adobe Portable Document Format files). The forms for Volume 2 and Volume 3 are identical, while that for Volume 1 is designed to be used with the selected stars published in Volume 1.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

The United Kingdom version of Pub. No. 249 retains the same main tabular data as *Sight Reduction Tables for Air Navigation* but has been retitled as *Rapid Sight Reduction Tables for Navigation* to reflect the application transition from air to marine use. Changes to other than main tabular data have been made to enhance the marine application.

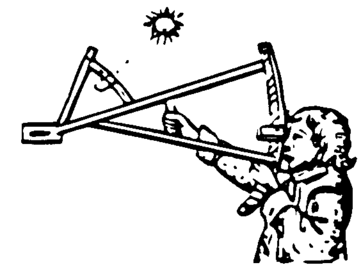
Catherine Hohenkerk of Her Majesty's Nautical Almanac Office reported on these changes in *Navigation News* of the Royal Institute of Navigation in an article entitled "Sight Reduction Tables - Then and Now" reproduced in the NAVIGATION NOTES section of this issue.

The National Imagery and Mapping Agency advises that NIMA has no plans at this time to change or rename Pub. 249, *Sight Reduction Tables for Air Navigation*. Note that in his article entitled "Celestial Navigation and the Air Almanac in the KC-135R Stratoliner," published in the Proceedings, Nautical Almanac Office Sesquicentennial Symposium, U.S. Naval Observatory, March 3-4, 1999, LCOL Ed. Sienkiewicz, USAF, reported that the USAF's RC-135 aircraft will continue to employ celestial navigation (and the navigator) at least until the year 2010.

If not the last, the RC-135 is one of the few USAF aircraft with sextant mounts.

The *Rapid Sight Reduction Tables for Navigation* are also addressed in the MARINE INFORMATION NOTES section. Members should find of interest the fact that the provision of a GHA Aries table in Volume 1 makes the almanac not necessary for the sight reduction

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-EIGHT, WINTER 2002-2003

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

It has been an uneventful winter and spring except for our record snowfall in the Washington, D.C. area. Travel has been curtailed until the international situation stabilizes. Energies now have to be directed to personal and Foundation taxes. With the squeeze on income and the Federal Government and States facing huge deficits it is more important than ever to check and re-check one's calculations to prevent a hassle with the State or Federal Government.

Member Jack Craven provided some very useful Internet addresses. They were included with some calculations he provided The Foundation. The sources are: The World Almanac and Book of Facts for 2003, astronomical data: The Online Nautical Almanac, http://www.tecepe/com.br/nav; Equation of Time Values for 2003 and to Compute Local Apparent Sidereal Time, http://www.minasi.com/doeot.htm; Sidereal time (local apparent sidereal time), http://www.tycho.usno.navy.mil/cgi-bin/sidereal-post.sh; U.S. Naval Observatory Astronomical Applications Department for Sun and Moon Data for one day, http://www.tycho.usno.navy.mil/time.html; Sky and Telescope Interactive Sky Chart, http://www.skyandtelescope.com/observing/skychart/skychart.asp.

The Navigation Foundation now has two E-mail addresses: navigate@ix.netcom, a 56K dial-up connection, for short text messages, and navigate1@comcast.net, a wide band digital connection, for pictures, scans and large data submissions. Either one can be used interchangeably.

Remember to purchase all of your navigation needs through The Foundation. As a member you will get a discount on: "Bowditch", Sight Reduction Tables, Nautical Almanacs, nautical charts and many books on navigation and seamanship. Use the Internet to order through The Foundation as well as the U.S. Postal Service. Do not pay the invoice you receive with the publications unless it is from The Navigation Foundation, to receive your discount. All orders help us continue to provide the services we currently provide.

READERS FORUM

Edited by Ernest Brown

Member George G. Bennett wrote:

"I agree with Mr. Kapp (Issue 77, Fall 2002) that there is some misunderstanding and confusion with the term 'time sight'. Like Mr. Kapp I believe its use was very widespread in celestial navigation, with many navigators eschewing Line of Position (LOP) techniques in favor of observing extra-meridian sights in the early forenoon and/or late afternoon to 'check' their longitude. The latitude of course was usually determined at Local Apparent Noon (LAN) as shown by Mr. Kapp in his example.

"Observations for both latitude and longitude could have been conveniently reduced by LOP methods which have the decided advantage of showing the locus of the ship's position in a very graphic way. One does not necessarily have to observe at LAN, in fact it is very difficult to get a good sun sight in tropical regions when the sun is near the zenith. An observation at a more convenient altitude close to LAN still gives excellent navigation information — a situation one may be forced into if the sun is obscured.

DO YOU KNOW . . . ?

By Ernest Brown

Why the correction for the amplitude observation of the moon on the visible horizon is one-half and in the opposite direction to the correction for the sun, star or planet?

(Answer at back of this issue)

"Mr. Kapp's statement about latitude errors should be heeded only if the 'time sight' is taken in a position away from the Prime Vertical (PV) i.e. in an East-West direction. It should be noted that it is impossible to observe a body in the PV when the latitude and declination have different names. If the observation is taken in close proximity to the PV then large errors in latitude can be tolerated. Once again this is demonstrated when the LOP plot is drawn.

"Finally, two sun or moon shots that give a good LOP intersection are just as good as the combination of a meridian and a PV shot. To get an 'instantaneous' fix, in all cases one needs to 'run up' or 'run back' the sights to allow for the ship's movement between shots."

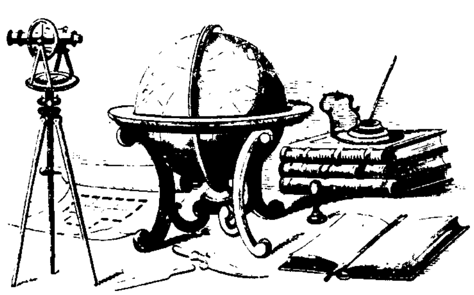
—*George G. Bennett*

Member Jackson B. Craven, Jr. wrote on February 8, 2003:

"Recently I found my H.O. #9 American Practical Navigator, Bowditch, Edition 1938, which I paid $2.50 for as a midshipman in the USNA. My class of '47 had our 50th reunion in 1996 and are planning for the 60th reunion in 3 more years. I am presently reviewing Chapter IX, Time and the Nautical Almanac, and I am sending to you copies of my favorite places which assist me in this review. I am able to retrieve 3 pages of the Nautical Almanac dated April 22-24, 1937 which is the date of one of the samples. I use the USS Seabrook, Tx for my current Navigation studies, which is about 12 mi from the USS Texas, the real battleship. I also went to sea on its sistership, the USS New York as a midshipman.

"New subject, looking for your address and cost of this year's dues I found and reread Newsletter #32, Summer '91. I have, I think, most of the information that the Foundation published on Adm Peary's trip to the north pole. I flew with his grandson E. P. Stafford as his co-pilot. I enclosed a copy of a DD 175 that I found in my files. EP and I supported project 'Blue Jay' while we were together. That project constructed the SAC Base at Thule, Greenland. We patroled the sea lanes to report ice conditions for the convoy taking construction material to Thule. I was elected as the navigator and used an astro compass and flew in the PB4Y-2S that Adm. Hoffman, the project manager for the Blue Jay operation, used to fly over the north pole. I needed GPS and an IMU but did not have them. The magnetic compass did not work and I updated a wind driven gyro compass every three minutes to maintain a heading. I think we made a good DR to the pole."

— *Sincerely, Jack B. Craven, Jr.*



Member Capt. R. A. Bowling, US Navy (Ret) wrote on 26 February 2003:

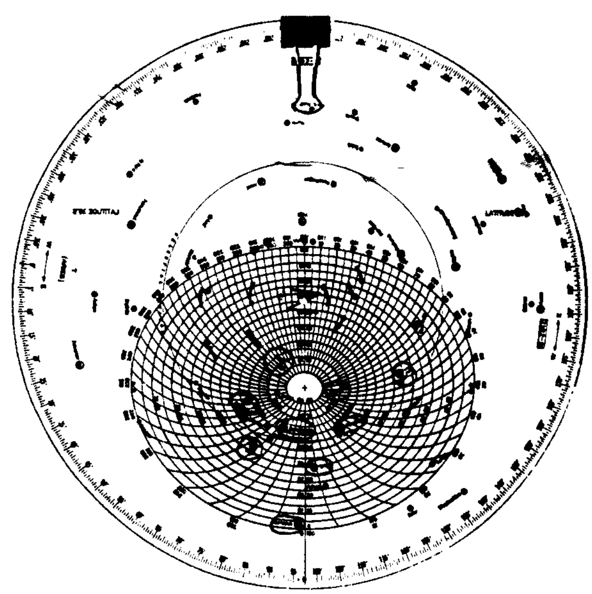
"Found the article 'History of Navigation: CP - 300/U USAF Star Finder' in the Fall 2002 issue very interesting. Too bad that it is not commercially available. However, since the differences between it and the 'Rude' Star Finder 2102-D are minimal, there is a usage tip that is equally applicable.

"On page 7 of the *Newsletter*, subparagraph 2, last sentence, states, 'It's convenient to tape the disk and arm together to maintain the alignment when the finder is being handled.' Years ago I learned from an old quartermaster the secret of using a BINDER CLIP to hold the finder together temporarily to maintain alignment. Enclosed is a copy of an illustration showing such use of a BINDER CLIP. I and innumerable others who have adopted the procedure have found it superior to any other, particularly the use of tape which invariably results in gummed up base and templates after even short usage.

"Hope this is of help to others who have gone through laborious calculation with obviously false results — are you sure Canopus should bear 175/20? — only to discover on check back that the alignment of the finder had slipped. Of course — never happen that you had miscalculated the LHA+!

"Keep the articles coming."

—*Warm regards, Chic*



Star Finder Base with Template for 35°N Latitude in Place. (Note the binder clip)

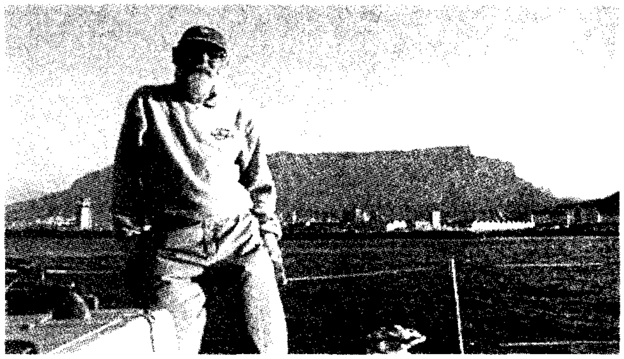
YACHT *FIONA*
ROUND THE WORLD THE WAY OF THE CLIPPER SHIPS, 2002-2003

Newsletter 1

Eric B. Forsyth, Master

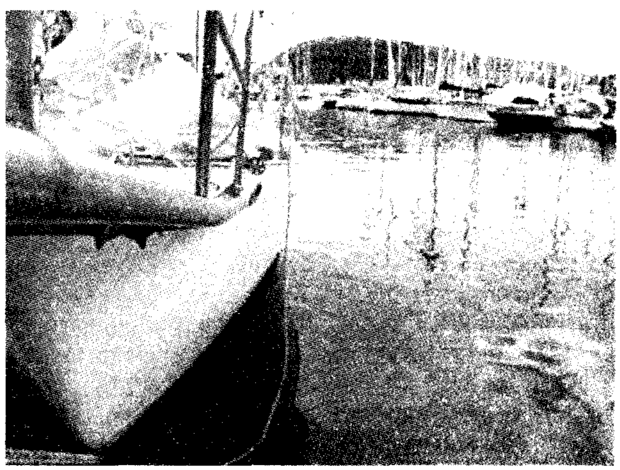
"A word of explanation about this cruise is due. The great clipper ships reached their apogee in the late 19th century. They were extraordinarily efficient, carrying thousands of tons of cargo with crews of thirty men or less. There was no fuel cost, of course, apart from what the cook used! But being so heavily laden they were slow, and because they did not sail too well to windward the captains sought routes that kept the wind behind the beam, on average. This often made the sea miles between ports much longer than the direct path. Over the years these routes between major ports became formalized and were published as sailing directions. Typical was the route from New York to Cape Town. First the ship sailed east across the Atlantic, keeping north of the permanent Azores-Bermuda high. When the wind shifted they would sail south into the prevailing NE trade winds. Near the equator lie the doldrums, an area of calms and fickle winds. Working their way through this region, usually with some difficulty, the ship would pick up the steady SE trades, and sail south for nearly two thousand sea miles. Finally, the captain would work through variable winds to reach the boisterous westerlies and then run before them to Cape Town, Australia, New Zealand and home via Cape Horn. That's the theory, anyway. Such a trip may well have lasted a year, depending on the time to unload and load in port. We will see what it is like in practice because, apart from a few diversions to interesting islands that lie near the route, this is the plan for *Fiona's* cruise.

"Quite a few friends and relatives came to see us off when Robert, David and myself left Weeks on schedule, June 10th. Bob Lyons, with Red and Jim aboard *Fireplace*, escorted us down the Patchogue River at high tide in case we got stuck. To avoid that embarrassment our water tanks were empty, which saved nearly a ton of weight. I don't know if that did the trick but we did not touch bottom all the way to the inlet. In order to water and refuel we stopped at Block Island for a couple of days. We walked to both the southeast and north lighthouses and had our last shore-side meals for a few weeks. Fully loaded, we left for the Canaries. Northeast winds in the vicinity of Georges Bank drove *Fiona* a little more south than I wanted and we did not get a significant boost from the Gulf Stream current. Rather, for several days, we had to fight an unexpected west-going counter current. Sometimes the GPS receiver tells you more than you really want to know — ignorance is bliss. We experienced mostly light winds, although we did have a spell when it gusted to 30 knots, necessitating a double-reefed mainsail. Thus it was a complete surprise on the twelfth day after leaving Block that David discovered, when he went forward to check the roller furling gear, that the bobstay had snapped, This heavy, 3/8 inch chain (listed breaking load 7 tons) attaches the bowsprit to the hull at the waterline and resists the upward force of the headstay. With this restraint missing the jib pulled up the bowsprit and allowed the stay to bend. However, the aluminum tubes around the stay do not like to bend too much and the lower piece cracked at the furling drum. Temporary repairs had to be made. Fortunately, if I can use that word, the break occurred in the middle of the chain, so we were able to snag the bottom bit with the gaff, pull it up and attach it to the upper piece with a shackle. A break near the bottom would have been much more difficult to deal with as we would not have been able to reach it from the bowsprit. We were able to turn the furling gear with a useful tool called a chain wrench, so that within a day or two we were sailing quite nicely again. However, permanent repairs were needed and I decided to make for the Azores where there were reasonable facilities.



Capt. Forsyth at The Royal Cape YC, Cape Town.

"On the way across the Atlantic, I used the ham radio and on one or two occasions even managed a contact with Mike, who lives just down the street in Brookhaven. We also had on board for the first time a satellite telephone that I used to call Brenda so that the yachtfiona website would have the latest info. Bob

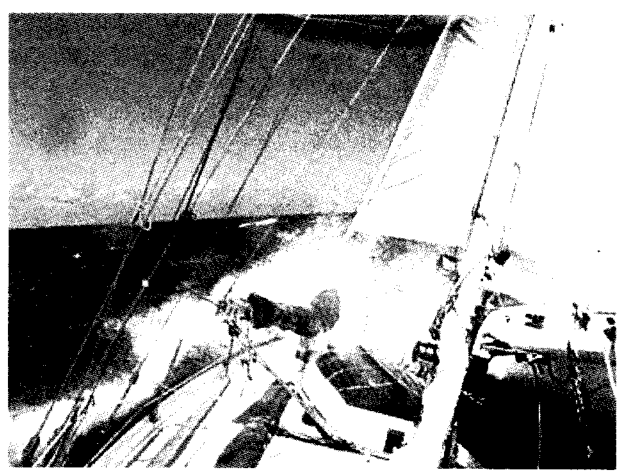


Distortion of the bow platform following failure of the bobstay.

Capt. Eric with WW1 guns at Fernando de Noronha.

also called Sue on a weekly basis and she kept all our friends in the SBCC up to date. *Fiona* communications have joined the 21st century! Shortly after we fixed the bobstay we sailed into the Azores-Bermuda high which extended much further north than usual. The pressure rose to 1040 mb (30.7 inches), higher than I can remember experiencing before, with light or zero winds. But we slowly made it to the most western island of the Azores — Flores. Here we hoped to pick up a little fuel so that if the calm conditions persisted we could motor to Horta, about 120 nm further east, where we planned to make our repairs. I last visited Flores on the 1986 cruise, and I vowed never to go there again. Although it is one of the most beautiful islands in the world (and I have seen a lot of them), the harbor was incredibly dangerous. A narrow rock-strewn passage led to a small cut swept by Atlantic swells. We nearly came to grief. However, the latest guide said that a new harbor had been built at the southeast corner with room for a couple of dozen yachts. And sure enough, there was a solid, large jetty that provided a dock for the ferry and shelter behind it. It was probably built with EU funds. We dropped our anchor near a few other boats, launched the rigid dinghy with its antique Seagull engine (the one I used during *Iona's* 1968-69 cruise) and treated ourselves to a beer and pizza at the Beira-Mar café handy to the dock. Entry is very informal, the marine policeman drives down to the port a couple of times a day. We spoke to him the next day. We trudged up a long hill with our jerry jugs but the gas station was out of diesel. But the market next door was nice enough to phone for a taxi from Santa Cruz and we enjoyed a perfectly breathtaking ride through the green hills and valleys. The driver gave us a short tour of Santa Cruz after we filled our jugs. I gazed at the old harbor and wondered how we ever squeezed *Fiona* in there. We left in the late afternoon and, sure enough, found ourselves motoring across a mirror-like sea. In the small hours during Bob's watch, he picked up a distress call from a yacht that had developed engine trouble. They were not too far away so we motored over to them. In the absence of wind they asked for a tow to Horta. Normally it would have been quite impossible for *Fiona* to tow a 39 foot boat on the open sea, but conditions were so calm we gave it a shot. We were slowed down, of course, but by the late afternoon we had covered the 60 nm to Horta. The boat was a Canadian yacht called *Tuaq* under delivery from the Caribbean by two British lads. The harbor was very crowded but we were given a berth rafted up to other boats. The next day we replaced the broken bobstay with a piece of our own anchor chain. We also cleaned up the bottom end of the jib furler and got that working again. We had lunch at the famous Peter's Café Sport and repainted *Fiona's* sign on the jetty wall. The original sign, painted during the 1986 cruise, had long weathered and been painted over by later visiting yachts. Besides repairs, the hectic four day layover included a taxi tour of the island, re-provisioning at the supermarket, checking our e-mail, sampling the local restaurants and chatting with other visiting crews. It was a nice break after the ocean passage, but it was not on the original schedule and set us back a few days which we never regained.

"The one-week passage to Santa Cruz, Tenerife was quiet and brought no surprises. It is quite an elegant city with many outdoor cafes and a pleasant climate. On the evening after we arrived, we witnessed a traditional ceremony in which a statue of the sailor's patron saint, Virgen del Carmen, was paraded round the harbor with a vast flotilla of local boats hooting away. There were lots of fireworks almost until midnight. It was all very Spanish. On the way to and from the boat we passed a large memorial to the siege of Santa Cruz by Admiral Nelson. He failed to take the city and lost an arm into the bargain, it gleefully noted. At the local chandlery I was amused to see a Seagull outboard just like mine on sale as a collectible antique. We could not linger, as we were pushed for time and left after a couple of days for Mindelo, on St. Vincent Island, the second largest city of the Cabo Verde group and almost on our direct route



Beating into the SE trade winds.

to Fernanco de Noronha, Brazil. We were now well into the tropics and picked up strong northeast trade winds. Each morning we found a crop of half a dozen flying fish that had unfortunately crashed onto the deck during the night. We planned only a brief stop at Mindelo, as much as anything so that Bob and David could experience a genuine third world African country and to pick up fresh fruit and vegetables. I had visited Praia, the capital, in 1992, on the way back to the U.S. from Tahiti. I had been rather horrified at the dire poverty, but this time things seemed a little better. At least young women weren't blatantly soliciting at the cafes. But unemployment was still rife and a bunch of men clustered at the dinghy dock offering to be guides or take care of your dinghy. A young man called Orlando had approached us in a dinghy as we were anchoring and I hired him to help us get through entrance formalities, etc. When I got some escudos at the bank, I gave him a couple of days pay to get it out of the way, but that was a tactical error. This windfall went to his head and the next day he was so hung over or zonked, he showed up very late and we had to get someone else to help do the fresh food shopping. When we left the next day, Orlando chased us out of the harbor in a borrowed dinghy, demanding to be paid. I pointed out I had paid him up front and he turned shorewards, looking very puzzled. We were not sorry to get on the open sea. That afternoon, with St. Vincent still in sight, I was below when we felt a slight bump. I rushed up the companionway just in time to see a vast iron-gray corrugated wall slide past the stern. We had grazed a whale. A whole pod of them surrounded the boat, serenely gliding to the east and paying not the slightest attention to us.

"The sailing directions for sail ships give very specific instructions on crossing the doldrums which lie a little to the north of the equator. Two strong currents must be crossed, and near the equator the ship runs into the edge of the southeast trade winds belt. The first current sets to the east and square-rigger captains are advised to sail southeast while they can so that when they encounter the west setting equatorial current and the trades, they go as far to windward as possible. The danger is that they may not be able to weather the great bulge of South America poking into the South Atlantic at Cabo Branco. As *Fiona* has a diesel engine with about a 500 nm range (in calm conditions) to assist with crossing the doldrums, I felt it was safe to ignore that injunction and head directly for Fernando de Noronha. In fact, we were able to sail close-hauled to the southeast trades and made it to the Baia de St. Antonio in one tack from the equator. When we crossed the equator, we were honored by a visit from old Father Neptune himself, who inducted our two pollywogs, Bob and David, as true sons of Neptune. Fernando de Noronha is a volcanic, lushly tropical island lying about two hundred miles south of the equator. For about two hundred years, until early in the 20th century, it was a prison for Brazil's most incorrigible political dissidents. When I walked to the fort down a path through the jungle, the cobblestones underfoot had the look of a make-work project for the prisoners. Now the government of the Pernambucco state is trying very hard to make it an attractive but low-key tourist resort. There is only one small hotel, but many homes function as posadas, or B and B's. A couple of dozen small charter boars operate sightseeing trips or scuba diving. David had his first underwater scuba experience on one of them. We sampled the many restaurants and bars, restocked the fresh food and shuttled a few jugs of fuel out to the boat. Also anchored there was a 39 foot South African yacht run by a retired surgeon. On board were his wife, two children and two crew. Goodness knows where they all slept. His wife was kind enough to bake us four loaves the morning we left for the long haul to Cape Town.

"The 4,100 nm leg to Cape Town is basically a beat; the SE trades blow directly from South Africa. For about 1,600 nm we sailed due south, the wind varied in strength. At one point we furled the jib entirely and set the staysail. After a few hours we found the forestay turnbuckle had snapped like a carrot; 5/8 inch diameter stainless. Fortunately, I had a spare. Near 30° S the wind became variable and we were finally able to sail east. The boat settled down into a daily routine: stand watch, eat, sleep. After we crossed the Greenwich meridian, the weather deteriorated and instead of the westerly winds we expected, we often had easterly winds. Twice we hove-to in winds that reached 45 kts. We tore the genoa jib, took it down when the wind moderated, and set the yankee jib. However, we slowly gained and the last day, almost within sight of Table Mountain, we had a great day of sailing. Sea otters basked on the surface of the sea. When we pulled into the Royal Cape Yacht Club, Sue, Bob's partner, was waiting on the dock. The leg from Fernando de Noronha had taken five weeks. The next few days were hectic: sail repairs, stainless welding, airline tickets, laundry, etc. etc., all had to be organized. We were a week late on the original schedule, due to extra days spent in Horta and the Cabo Verde Is. Thus we plan to leave Cape Town a little later than planned, probably October 15th. So far we have put 9,938 nm on the log since leaving Patchogue.

"Until the next time, when hopefully I will write from New Zealand," —*Best wishes from Eric*

NAVIGATION NOTES

A Lubber on the Quarterdeck: My Voyage on HM Bark *Endeavor*

By Kieran Kelly

I recently completed a ten-day voyage as a crew member on the square-rigged bark *Endeavor* 550 tonnes, Darwin bound for Dampier, Capt. Chris Black commanding. The *Endeavor* is an exact replica of the coastal collier known as a Whitby cat in which Capt. James Cook successfully circumnavigated the globe in 1768-71 in the process discovering the east coast of Australia.

I had never been to sea, never been out of sight of land and had previously not trod the deck of a sailing ship. I was motivated by a life-long fear of heights that I was determined to conquer before the age of fifty, and a love of traditional navigation. In my sea chest was a Plath Navistar Professional sextant, a nautical almanac and Pub 229 for sight reduction between latitudes 15°-30° degrees.

Embarkation was from Darwin, Australia's northernmost port, and we sailed in the equatorial swelter of late November. I occupied the cabin of Sydney Parkinson, an artist on Cook's voyage, but was expected to perform all duties associated with crewing the ship.

My first journey up the foremast shrouds was one I will never forget. Holding on like grim death and never looking down, I reached the lower side of the fighting top before ascending the futtock shrouds, clinging upside down with my back to the deck. It was a great relief to finally scramble onto the fighting top. Sliding gingerly out along the forecourse yard on a swaying footrope, I reached the end of the yard before flopping over and inevitably looking down. That first aerial view of the deck and blue green water, over the top of a yard with a tightly furled canvas sail, was one I will never forget.

The navigation was a challenge for a landlubber. I had many years experience navigating with a sextant in the Australian outback, a Dolland pan artificial horizon filled with mercury, water or sometimes black tea, was all I required. There were a myriad of stars to choose form and sights could be taken at any time during the night. This was different.

Firstly, I had to establish eye height and this was achieved with a d-shackle bolt tied to one end of a tape measure and thrown over the side. Height was established at three points — the stern rail, the break of the poop deck and in the waist. Because of the steep rake on the *Endeavour's* poop deck, the difference in height to the waist was marked.

I began with sun sights. The first problem was that looking up at the sun for long periods in the tropics produces instant sunburn. It was necessary to do this to get a good spread of sights ante and post meridian. The next problem was "bringing him down." The sun's declination at the time was about 19° south and we were sailing between 20° and 22° south so he was right overhead at noon. In a square-rigged ship with all sails set, I found it quite a job getting the body down without a sail or ship's rail or mast suddenly blocking the view. The *Endeavour* has an added trap for the unwary as it possesses a giant tiller that is connected to the wheel by above-deck chains and ropes and has a kick-up to clear the stove chimney from the Great Cabin below decks. The tiller sweeps across the poop deck on any change of course and can catch the neophyte navigator and knock him and his sextant overboard if a sight is attempted near the stern.

The motion of the ship was also difficult to get used to, particulary trying to gauge that delicate moment when the sun culminates. It would have been easier to brace against either the main or mizzen masts, but due to the deck layout this is not possible on the *Endeavour* and inevitably sights were taken looking over the rail just near the break of the poop,

With several days practice I ascended to the fighting top on the main mast and eventually made it to the main-mast crosstrees. Standing on the crosstrees above the Tops'l, hanging onto the stump of the T'gallant mast and watching the straining topsail below and the T'gallant sail above, both filled by a hot westerly wind blowing off the Australian desert, I felt the awe enjoyed by the generations of sailors who manned these ships in the days when the world was wide.

I persevered with the navigation and took evening stars whenever possible. This was indeed tricky. The wet season was building and in the evenings, clouds would often obscure either stars or horizon, sometimes both. This was a revelation to me as desert navigating means you can see *all* the stars *all* the time. Days would go by on the *Endeavour* when an evening star sight was impossible, and I felt for the old ship's captains anxiously watching the sky as dusk approached.

There were other problems. Time for sights is limited and often by the time I could see the stars, beginning on the eastern side of the ship, I could not see the horizon, or at best would have to judge its position. The time when both a sharp horizon and a visible star is present seemed to be very short. Prediction was also a problem, as I would calculate time and azimuth, then come on deck at sunset to find that it was impossible to shoot the nominated celestial body as some of the ship's regalia was blocking the view. Often I shot what I could, took the azimuth and worked out later what star ir was.

On a square-rigger the easiest way to take a star sight is directly over the port or starboard rails about the waist of the ship. This however gives two non-intersecting lines of position, which is no use unless combined with a shot at an oblique angle, and this can be tricky. I found shots on the forecastle impossible on the *Endeavour*, as the movement of the ship is so exaggerated and the deck would sometimes be awash.

The other conundrum when navigating from the poop or in the waist is that both areas of a square-rigger can be very busy. The captain commands the poop and has people coming and going. In the waist, you can be knocked over by a sudden rush of the watch tumbling up from below and going aloft or by heaving lines of tars working the running rigging from the deck. When yards are being hauled aloft or braced, you had best step lively or be killed in the rush.

Nevertheless, navigating at sea has its advantages. The main one is not handling the artificial horizon. Handling mercury in the bush is a nightmare, where the liquid attracts all type of dirt and leaves and stubbornly refuses to go back into the metal cruet without spilling everywhere. Try it by the campfire one night if you don't believe me. The other problem avoided is the fog that collects under the glass canopy of a horizon when shooting noon sights in the very hot temperatures that prevail in the Australian interior. At least at sea, you just point and shoot even if at dusk there is sometimes nothing to shoot at. Also, the flies, mosquitoes and ants that plunder the eyes, nose and ears of desert sextant navigators at critical times are absent at sea.

The fact that the sextant is stowed safely below means that it is not subject to the constant abuse suffered in packhorse or camel travel, which is a definite advantage as index error does not fluctuate widely on a ship. Nor is the instrument likely to be completely ruined as it usually is when ejected from the back of a bucking packhorse.

Finally, I could get nothing like the accuracy at sea that I achieve on land. Sitting cross-legged with elbows resting on knees and the tiny point of a reflected star in the mercury as a non-debatable horizon, I am very disappointed if I cannot get a position accurate to within 1.5 kilometres. At sea swaying with the ship, trying to bring the body down and losing it and often not being certain if I was really looking at the horizon, I was lucky to record positions within six nautical miles of the ships GPS location. On land, looking for a waterhole that may be only two metres wide, this level of accuracy would not be sufficient.

At the end of ten days, I knew the difference between a mizzen tops'l halyard and a cro'jack brace, between a timberhead belay and a bowline. I had conquered my fear of heights and learned new respect for captains of old who navigated with compass and sextant and prayed for clear evenings. Finally, I discovered there is no feeling in the world like standing on the end of a bowsprit with your feet in the Indian Ocean one minute and then thirty feet in the air, while looking back at the action on the deck of a well manned, well organised, square-rigged sailing ship. I recommend it to anyone.

—Kieran Kelly, Sydney Australia

A Timed Sight to Determine Local Mean Time

By Kieran Kelley (kkelly@bigpond.net.au

I read with interest Mr. Frederic Kapp's working of a timed sight to find longitude (*Issue 77 Fall 2002).* I have spent considerable time with member George Bennett, analysing the timed sights and lunars of the great Australian land explorer, Augustus Gregory. As Mr. Kapp demonstrates, a timed sight is a simple and quick method of finding longitude if the navigator has a calculator and his GMT is known.

However, when this method was in its prime in the 19^{th} century, life was not so simple.

The Kapp problem

October 8, 2002 at GMT $18^h25^m0^s$ at Lat 33° 13′ north, a sextant sight gives Ho sun 39° 01.2′. Find longitude.

The Theory

The theory of the Timed Sight procedure is based on the standard formula quoted by Mr. Kapp. It is found in Bowditch:

$$\cos t = \frac{\sin h - \sin L \sin d}{\cos L \cos d}$$

Where:

t = Meridian angle	L = Latitude (+N - S)
d = declination	h = Height of body (Ho)

Because nineteenth century navigators and explorers did not have calculators, solution of the formula quoted by Mr. Kapp, was usually undertaken using logarithms. Solution of navigational problems using logarithms was easier and not as prone to error. A popular method of solving for the meridian angle t was provided by a derivative of the formula above using logs of haversines viz:

$\log \text{haversine } t = \log \sin^2 \tfrac{1}{2} t = \log \sec L + \log \text{cosec } p + \log \cos s + \log \sin (s-h)$

in which p is the Polar Distance from the visible pole (90° - d if L and d are same name and 90° +d if contrary names) and s = ½ (h+L+p). To solve this problem the navigator needed a special set of log tables, which in Norie were known as *Logarithms for finding the Apparent Time or Horary Angle* and which in later years were known simply as Haversine Tables. Haversine Tables are alas, no longer published in Bowditch. The log of a haversine had a great advantage in that it is positive for all angles. In days past, t was also known as the horary angle and we know it today as the local hour angle. The use of logs was a great boon to the navigator as it allows Trig functions to be added and subtracted rather than multiplied and divided. As was the custom in days past the 10 is ignored when using logs.

The calculation

a) Right Ascension

To complete the calculation the explorer needed to know the celestial body's right ascension. Here the old timers were guided by astronomers and used their terminology to specify celestial longitude. Today navigators measure a body's sidereal hour angle in degrees *west* of γ; back then its right ascension was measured in time units (1 hour for each 15°) *east* from γ. Each means the same — it's the equivalent of the body's celestial longitude, with the important difference that the astronomical longitude presented in the old Almanacs was measured along the ecliptic rather than the equinoctial.

In this problem:

Right Ascension Sun	=GHAγ - GHA sun
$18^h\ 25^m\ 0^s$	= 293°27′ 30″ - 99° 22′ 12″
	= 194° 05′ 18″
	= $12^h\ 56^m\ 21^s$

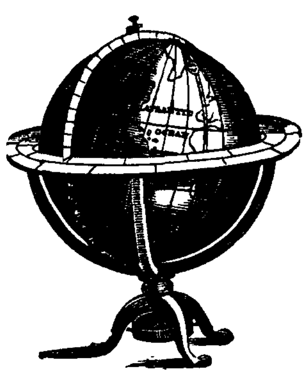
Reduced Sidereal Time

It is obvious that the old explorers and mariners needed a more sophisticated understanding of time than we possess including knowledge of Apparent Time, Sidereal time, Local Mean Time and Greenwich Mean Time. The key was to calculate Local Mean Time so it could be compared to Greenwich Mean Time. In addition, the concepts of a civil, nautical and astronomic day had to be considered when undertaking a timed sight.

I will not go into each of these systems here as it has already been covered in this Journal. (See *Nautical Astronomy in Lewis and Clark's Day.* Bruce Stark, Issue 67, Spring 2000). Mr. Kapp's problem requires the conversion of Local Apparent Time (LAT) to Local Mean Time (LMT). To achieve this, Reduced Sidereal Time is calculated as shown below. In the 18th century, this was done using tables known as the Mean and Apparent Suns in the *Nautical Almanac.* Today these are not published, however we can work them out using changes in the GHAγ derived from a modern *Almanac* as follows:

Let Δ GHA = Change in GHA

8 October 2002	GHA γ @ 1200^h GMT	196° 56.7′
9 October 2002	GHA γ @ 1200^h GMT	197° 55.9′
	Δ GHAγ	0° 59.2′



Δ GHA γ 1200^h to $18^h\ 25^m\ 0^s$ on Oct. 8, 2002 6h 25m/24h x 59.2 = 15.8′

\+ 196° 56.7′

RST Reduced Sidereal Time 197° 12.5′

= $13^h 08^m 50^s$

The Solution

h alt	39° 01′ 12″		
L lat N	33° 01′ 06″	log sec	0.076499
p pd	96° 01′ 24″	log cosec	0.002404
Sum	168° 03′ 42″		
Half sum s	84°01′51″	log sec	9.017005
Remainder s-h	45°00′39″	log sin	9.849567
			18.945475
			-10
log haversine t =			8.945475
LAT horary angle t =		34°33′12″	$2^h\ 18^m\ 12.8^s$
+ right ascension			$12^h\ 56^m\ 21.2^s$
LST local sidereal time			$15^h\ 14^m\ 34.0^s$
RST less reduced sidereal time			$13^h\ 08^m\ 50.0^s$
LMT local mean time			**$2^h\ 05^m\ 44.0^s$**

GMT	$18^h\ 25^m\ 0.00^s$
LMT	$02^h\ 05^m\ 44.0^s$
	$16^h\ 19^m\ 16.0^s$
Less	12^h
Longitude	$4^h\ 19^m\ 16.0^s$ 64° 49′ 00″ W

~~This varies from~~ Mr. Kapp~~'s answer of 64°49′23.5″W~~ as there appears to be a slight error in his calculation of GHA. He makes GHA sun 1825 hours on October 8, 2002 as 99°22.6′. I make it 99°22.2′. If this figure is inserted in Mr. Kapp's workings he also obtains a longitude of **64°49′00″ W.**

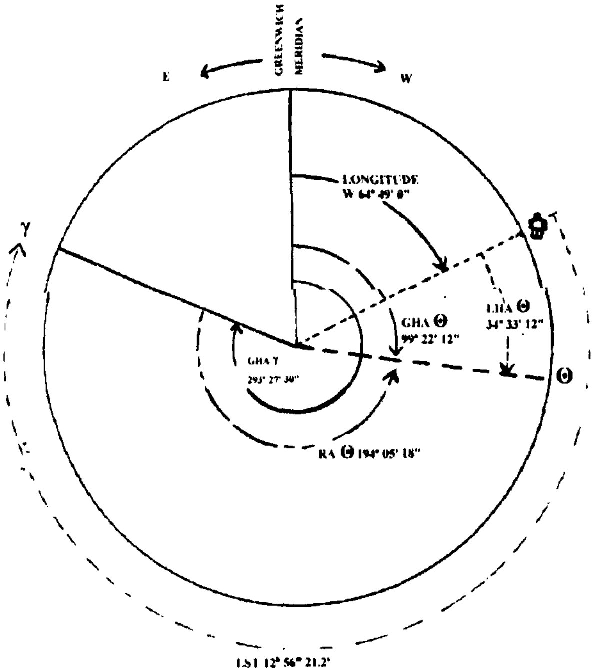
A further wrinkle

The assumption Mr. Kapp made was that the navigator knew GMT. In the period referred to, the navigator often did not. In Gregory's case, he was out exploring for two years. The chronometers went in numerous rivers, were bucked off packhorses and subjected to tropical heat and moisture. They were stripped several times and so GMT had to be re-established using a lunar.

The sequence Gregory used was

1) Sight of culminating star or sun for latitude
2) Timed sight to give LMT and longitude based on unadjusted chronometer GMT
3) Lunar to correct chronometer and adjust to reflect correct GMT. Longitude then adjusted accordingly

A timed sight showing the various relationships in this problem is attached. The use of a timed sight for Longitude using logs was covered in the standard texts and may be found in Henry Raper's *Practice of Navigation and Practical Astronomy,* London 3rd ed 1849, or *Norie's Navigation,* 15th ed 1852.



The author acknowledges the assistance of member George G. Bennett for the time spent on this project, in particular the analysis of a timed sight using logs, including formulae involved and the calculation of reduced sidereal time.

Member Bruce Stark comments:

<u>Haversine tables</u>

Haversine tables weren't needed. They were just handy. Instead of dropping the 10 from the sum of the logarithms and looking up 8.945475 in Raper's "log. sine square" table, divide 18.945475 by two, look up the result, 9.472738 in the log sin column, extract the angle and double it. That's the way it was done in Moore, Bowditch, and some others. Bowditch shortened the procedure slightly by making the time headings in his table of log sins twice what the angle headings were. "Bowditch" didn't give haversines until about World War 1.

<u>Right ascension</u>

Time sights were normally taken of the sun, and in that case there was no need of RA. In fact, navigators at sea were generally able to avoid dealing with RA. They seldom had to use a star or planet for time, and were generally able to measure the altitudes of the stars and planets they took their lunars from. Perhaps A.C. Gregory used star altitudes because he already had too much to get done when the sun was up, and didn't want to use daylight to do what he could do after dark.

Kieran Kelly thanks Bruce Stark for his comments on this paper and notes that Gregory indeed did not shoot the sun as he believed that star sights were more accurate and the noon halt for navigation left his party vulnerable to aboriginal attack.

BOOK ANNOUNCEMENTS

The Complete on-Board Celestial Navigator 2003-2007 Edition

By George G. Bennett

The first edition of this book covered the period 1999-2003, so there is an overlap of one year between editions. The format of the new edition is essentially the same as that of the first with the following improvements,

1. To facilitate quick entry into the data sections, highlighted side tab markers have been provided.
2. In the Prediction and Identification Section three stars for each list of 58 stars have a distinguishing mark against them. These stars have been chosen to give an optimum fix, taking into account their altitude, magnitude and azimuth distribution.
3. A stiff back cover holds the book in better shape than the first edition.

In Issue 64 Summer 1999, a detailed description of the first edition was given. This covers all the essential details of both editions. You may conveniently down-load and print this from the web page <u>http://www.netspace.net.au/~gbennett/.</u> Publisher: International Marine/McGraw-Hill, Camden, Maine, ISBN 0-07-139657-8

For more information and ordering go to <u>www.internationalmarine.com</u> or <u>www.amazon.com</u> 176 pages. RRP $27.95, Amazon $19.57 (Save $8.38)

Tracks in the Sea: *Matthew Fontaine Maury and the Mapping of the Oceans*

By George G. Hearn
International Marine/McGraw-Hill, Camden, Maine, USA.
ISBN 0-07-136826-4
278 pages, $24.95 USA, $39.95 Canada, first edition 2002.
From the Publisher:

"In eighteen years of sustained and inspired labor, drawing on the logbooks of sailing ships from around the world. Matthew Fontaine Maury transformed the oceans from trackless hazards into a network of highways marked by dependable winds and currents. No less than the invention of the chronometer, the pilot charts and wind and current maps of this self-taught genius from a Tennessee farm revolutionized ocean travels."

Line of Position Navigation: Sumner and Saint-Hilaire: The two Pillars of Modern Celestial Navigation

By Michel Vanvaerenbergh and Peter Ifland

Unlimited Publishing LLC is pleased to announce the release of *Line of Position Navigation:*

Anyone who has ever used a sextant will find this book helpful and interesting. It gives a clear and simple description of the evolution of the Line of Position method that navigators still use today. It includes a reprint of the entire first edition of the 1843 book that Captain Thomas H. Sumner wrote to describe his methods, and translations of two articles by Marcq Saint-Hilaire about establishing position. The book is easy to read for the beginner yet technical enough to satisfy the most mathematically minded professional.

NAVIGATION PERSONALITIES

William O. Land

By Roger H. Jones

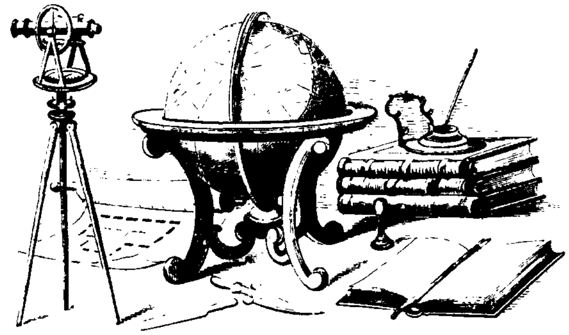
Bill Land, a director of the Navigation Foundation, and long time contributor to its activities and to The Navigator's Newsletter, is also a highly respected and very popular teacher of celestial navigation. He has furnished us with a fascinating account of how it is that he became involved in the teaching of the subject and the highly successful instructional program which he presented for more than eleven years in the Philadelphia, Pennsylvania area.

Bill retired early from business in the early 1970's, and responding to the call of the salt water, he started a sailing vessel delivery service which he operated for just over three years. He was well into his 60's during this time, and came to realize that the rigors of storms at sea and their effects upon thirty and forty foot boats were just not so much "fun" as they may have been at an earlier age, so in the late 1970's he decided to open his own Celestial Navigation School. This was, however, a "second wind" for him in regard to the celestial art. He graduated with a Bachelor or Science Degree in Mechanical Engineering from Lafayette College, which he acknowledges was "almost a math major." He subsequently received his Professional Engineer's License. Having been a sailor of small boats almost all of his life, with extensive experience in the Great Lakes, his inquisitive mind propelled him not only to seek and receive certification as SCUBA instructor and as a U.S. Coast Guard "Six Pack" licensed captain, but also as a licensed airplane pilot (the latter while he was still an undergraduate in the late 1930's). His love of the sea, however, was always in the foreground, and complementing all of these other activities was his interest in learning the celestial art.

He fulfilled this interest early on by reading and studying on his own, but he realized that many of the then-available texts left a great deal to be desired, and that a knowledgeable instructor would be of great benefit to him. Thus it was that in the late 1950's and early 1960's while living in Suburban Chicago, Bill saw advertisement in the Chicago Tribune for a celestial navigation course to be given at the Adler Planetarium. The Planetarium's Director, Joseph Chamberlain, was a retired naval officer who had spent many years in the arctic establishing facilities for the so-called "Dew Line," which required very accurate latitude and longitude position figures. Chamberlain's course used the now-out-of-print H.O. 214 Sight Reduction Tables, and while Bill Land passed the course with flying colors, he then left his new skill un-used for the next ten years or so. Retiring in his mid 60's, Bill then decided to seek out a home base nearer the salt water he loved so well, and he moved back to Suburban Philadelphia. It was here that he launched his sailing vessel delivery service, and it took him on fifteen voyages in the Atlantic, the Pacific, and many coastal waters as well. Navigation was mainly by dead reckoning, radar, RDF and Loran, but the call of the sextant was not to be ignored, and he then started his own celestial school in the late 1970's.

Starting with a small ad in the Philadelphia Inquirer, the school was launched very informally after Bill had re-acquainted himself with the subject and after he acquired the more modern volumes of H.O. 249 and H.O. 229. He enrolled four students. His skill as a teacher and as one who could anticipate the learning "sticking points" and present them in simpler, layman's language, soon became known. His classes grew, and at their height numbered 92 students at one time. On the average they probably numbered about thirty students, however. Almost invariably they entailed ten distinct subject matter lessons, and Bill used forms and simplified procedures which he devised himself. Expanding from card tables in his own living-room, Bill Land eventually had to move to a public school cafeteria (after hours) setting. Meanwhile, an article about the course in the Philadelphia newspaper had stimulated wider interest, and over the course of the eleven years of its existence the students came from nearby Pennsylvania areas, the Chesapeake environs, and other East Coast locations. Eventually, some of his students became licensed delivery skippers, including one young lady who successfully used her celestial skills on a delivery from the East Coast to Mediterranean waters.

By 1990 the advent of GPS had, sadly, cut into the otherwise natural reservoir of interest in the celestial art, and also Bill Land, then in his late 70's, had developed a medical condition which required that he withdraw form the scene he loved so well. He is now 88 and still



spry and articulate on the telephone. The author of this brief profile recently talked with him, and they compared notes on their mutual celestial teaching methods and experiences, sailing experiences, and even flying, as they both have been sailors, flyers, scuba divers, and celestial advocates for many years.

We wish Bill Land the best, and we thank him for his many contributions to the preservation of the Celestial Navigation Art in this day and age of black boxes and electronic wizardry. Bravo, Bill!

NAVIGATION BASICS — REVIEW

The following is adapted from the presentation of amplitudes in the 1958, 1977, 1981 (Vol. II) and 1984 editions of Bowditch:

Amplitudes

For checking the compass, an azimuth observation of a celestial body at low altitude is desirable because it can be measured easiest and most accurately. If the body is observed when its center is on the *celestial* horizon, the amplitude (A) which is the arc of the horizon between the prime vertical and the body, can be taken directly from a table providing solutions of the equation sin A=sec L sin d.

The amplitude is given the prefix E (east) if the body is rising and W (west) if setting. It is given the suffix N if the body rises or sets north of the prime vertical (which is does if it has northerly declination) and S if it rises or sets south of the prime vertical (having southerly declination). The suffix is given to agree with the declination of the body. Interconversion of amplitude and aximuth is similar to that of aximuth angle and azimuth. Thus, if A=E15°S, the body is 15° south of east or 90°+15°=105°. For any given body, the numerical value of amplitude would be the same at rising and setting if the declination did not change.

When the center of the sun is on the celestial horizon, its *lower limb* is a little more than its semidiameter above the visible horizon. When the center of the moon is on the celestial horizon, its *upper limb* is on the visible horizon. When planets and stars are on the celestial horizon, they are a little more than one sun diameter above the visible horizon. In high latitudes, amplitudes should be observed on the visible horizon.

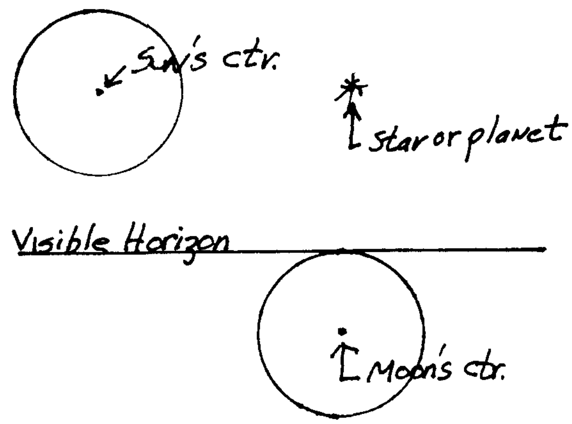


Figure 1. Positions of bodies relative to visible horizon when centers are on celestial horizon.

Computation of Amplitude

In the diagram on the plane of the celestial meridian shown in figure 2, a celestial body of declination same name as latitude is on the celestial horizon at M; a celestial body having declination of contrary name is on the celestial horizon at M'; Triangles PnNM and PnNM. are right spherical triangles, PnNM and PnNM. being right angles.

Side NM of triangle PnNM is the coamplitude (90°-A); side PnN is the latitude; and side PnM is the codeclination (90°-d)

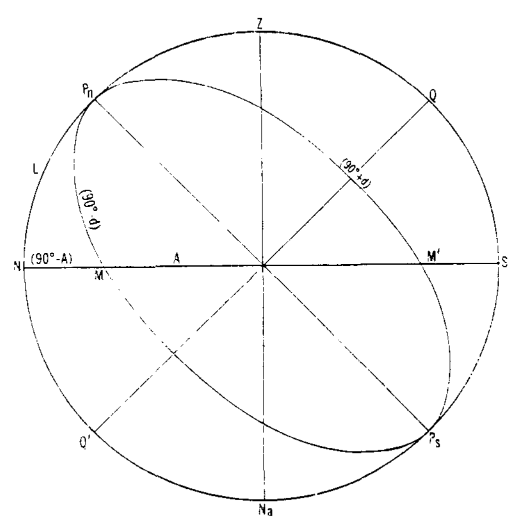


Figure 2. Diagram on plane of the celestial meridian

The formula for amplitude is derived by Napier's rules:

The five sectors of the diagram for right spherical triangle PnNM are completed as in figure 3. Applying Napier's rules:

sin d = cos L cos (90°-A)
sin d = cos L sin A
Sin A = sec L sin d

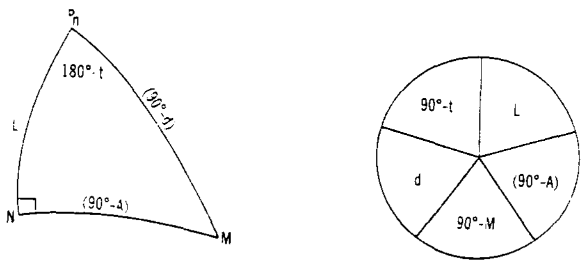


Figure 3. Circular parts diagram for spherical triangle PnNM.

For the contrary name case, side NM′ is (90°+A); side PnN is the latitude; and side PnM′ is (90°+d). The five sectors of the diagram for right spherical triangle PnNM′ are completed in figure 4. Applying Napier's rules:

-sin d = cos L cos (90°+ A)
cos (90°+A) = -sec L sin d
sin A = sec L sin d,

in which A is the amplitude, L is the latitude of the observer, and d is the declination of the celestial body. The Bowditch amplitude table was computed by means of this formula.

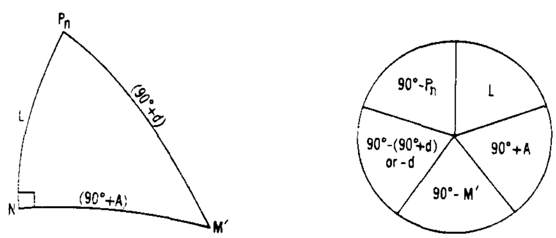


Figure 4. Circular parts diagram for spherical triangle PnM′.

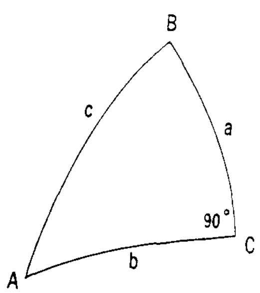


Figure 5. Parts of a right spherical triangle as used in Napier's rules

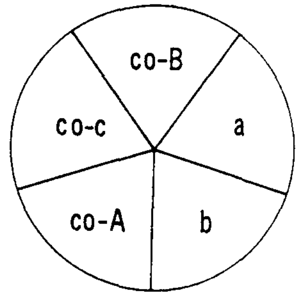


Figure 6. Diagram for Napier's Rules of Circular Parts.

Napier's Rules of Circular Parts

Right spherical triangles can be solved with the aid of Napier's Rules of Circular Parts, devised by John Napier. If the right angle is omitted, the triangle has five parts: two angles and three sides, as shown in figure 5. The triangle can be solved if any two parts are known. If the two sides forming the right angle, and the *complements* of the other three parts are used, these elements (called "parts" in the rules) can be arranged in five sectors of a circle in the same order in which they occur in the triangle, as shown in figure 6. Considering *any* part as the *middle* part, the two parts nearest it in the diagram are considered the *adjacent* parts, and the two farthest from it the *opposite* parts. The rules are:

The sine of a middle part equals the product of (1) the tangents of the *adjacent parts or (2) the cosines of the opposite parts.*

In the use of these rules, the cofunction of a complement can be given as the function of the element. Thus, the cosine of co-A is the same as the sine of A. From these rules the following formulas can be derived:

sin *a* = tan *b* cot *B* =sin *c* sin *A*
sin *b* = tan *a* cot *A* = sin *c* sin *B*
cos *c* = cot *A* cot *B* = cos *a* cos *b*
cos *A* = tan *b* cot *c* = cos *a* sin *B*
Cos *B* = tan *a* cot *c* = cos *b* sin A.

The following rules apply:

1. An oblique angle and the side opposite are in the same quadrant.
2. Side *c* (the hypotenuse) is less than 90° when *a* and *b* are in the same quadrant, and more than 90° when *a* and *b* are in different quadrants.

If the known parts are an angle and its opposite side, two solutions are possible.

Correction of Amplitude as Observed on the Visible Horizon

A correction must be applied to the amplitude observed when the center of a celestial body is on the visible horizon, to obtain the corresponding amplitude when the center of the body is on the celestial horizon. For the sun, a planet, or a star, apply the correction in the direction *away* from the elevated pole, thus *increasing* the *azimuth* *angle.* For the moon apply *half* the correction *toward* the elevated pole. ***This correction can be applied in the opposite direction to a value taken from the Bowditch amplitude table to find the corresponding amplitude when the center of a celestial body is on the visible horizon.*** The correction table was computed for a height of eye of 41 feet. For other heights normally encountered, the error is too small to be of practical significance in ordinary navigation.

The values in the table were determined by computing the azimuth angle when the center of the celestial body is on the visible horizon, converting this to amplitude, and determining the difference between this value and the corresponding value from the amplitude table. Computation of azimuth angle was made for an altitude of (-)0°42.'0, determined as follows:

Dip at 41 feet height of eye	(-)6.'2
Refraction at (-)6'. alt.	(-)35.'3
Irradiation of horizon	(-) 0.'6
Parallax (value for sun)	(+) 0.'1
	(-) 42.'0.

Azimuth angle was computed by means of the formula:

$$\cos Z = \frac{\sin d - \sin h \sin L}{\cos h \cos L}$$

in which Z is the azimuth angle, d is the declination **of the celestial body, h is the altitude (-0°42.'0), and** L is **the latitude of the observer.**

Amplitude tables

Bowditch has two amplitude tables. Table 22 (1995 and 2002) provides solutions of the amplitude formula sin A = sec L sin d, the center of the observed celestial body being on the *celestial* horizon. Table 23 of the same editions provides corrections to those amplitude observations of celestial bodies made on the *visible* horizon. As a correction table, table 23 is used to convert an amplitude observation on the *visible* horizon to an amplitude observation on the *celestial* horizon. The rule given at the bottom of the table is for the above conversion:

> For the **sun**, a **planet** or a **star**, apply the correction to the observed amplitude in the direction ***away*** from the elevated pole. For the **moon** apply **half** the correction **toward** the elevated pole.

It is often convenient to reverse the above rule and apply the table 23 correction to the Table 22 extracted value to adjust the calculated amplitude on the *celestial* horizon to the corresponding amplitude on the *visible* horizon. If there is no compass error, the amplitude on the visible horizon as observed by compass should be the same as the adjusted amplitude.

NIMA's Marine Navigation Calculator

http://pollux.nss.nima.mil

The **Celestial Navigation Calculator,** a part of the above web site, is expected to be revised soon to provide in lieu of the current tables 22 and 23 solutions two new solutions: Compass Error by Amplitudes Observed on the Celestial Horizon and Compass Error by Amplitudes Observed on the Visible Horizon.

Due to faulty programming, one should not use the current Correction of Amplitudes Observed on the Visible Horizon at this web site.

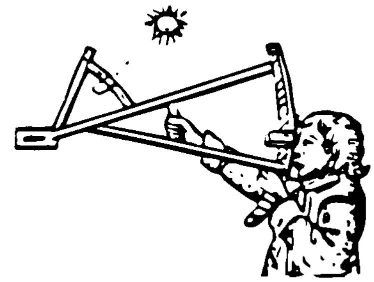
ANSWER TO DO YOU KNOW . . .?

(from page 1)

When the center of the sun, star or planet is approximately one sun diameter above the visible horizon, its center is on the celestial horizon. When the upper limb of the moon is on the visible horizon, the moon's center is on the celestial horizon and at approximately one-half sun diameter below the visible horizon. Thus, the adjustment of the moon's center to the visible horizon is one-half and in the opposite direction to the adjustment of the center of the sun, star or planet to the visible horizon. The same is true for any adjustment from the visible horizon to the celestial horizon.

The approximations are compatible with the accuracy requirements.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE SEVENTY-NINE, SPRING 2003

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

Spring is here and boaters fancies turn to being on the water and experiencing exciting new places. Winter lay-ups are being floated and the ravages of the winter are being corrected. We are all looking forward to weekend trips and voyages to distance ports.

When you are planning your trips and voyages, remember The Navigation Foundation for your charts, Almanacs, Sight Reduction Tables and books about almost everything nautical. You get good discounts, rapid service and most of all help keep The Navigation Foundation viable as well. For us to continue to be a dealer for many U.S. Government and other nautical publishing organizations we must sell 500 charts a year from the Government to continue to get a discount and to retain our dealership for many other organizations. So please order your charts, books and publications from your Foundation.

Always trust a woman's intuition. For years my wife and I had been planning a trip to China and Tibet. In February my wife asked me over coffee one morning if I would mind putting off our trip until later. When I inquired as to why she recommended putting off the trip for another year, she replied, "for some reason I do not want to go just yet." I agreed and now we are very thankful that we did not go. We would have been in the area where SARS started as well as staying in Hong Kong for several more days just as SARS began there.

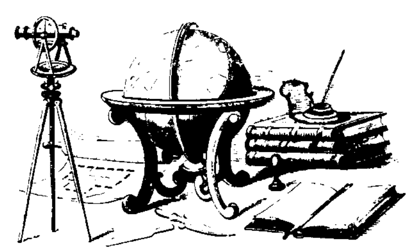
As many of our members know, our son was severely burned in a plane crash in Claxton, Georgia. I am happy to report he is doing just fine, working at his profession and enjoying life. Because he cannot currently pass a flight physical because of the amount of medication he has to take because of his skin grafts, he has now qualified as a "Race Car Driver."

I apologize for details about my family life but over the years I have served as a "foredeck' sailor handling jibs, spinnakers and such for my son when we raced. I have flown with him in acrobatic aircraft and been with him when we flew Russian jet planes in Crimea. For now I am very content and excited to just sail to distant places and enjoy the leisure of boating.

The Foundation for the Promotion of the Art of Navigation is pleased to announce the presenting of the following awards:

The Benjamin Dutton Award, for Excellence in Navigation, to MIDN 3/C Timothy Smiley at the United States Naval Academy, Annapolis Maryland, a plaque, a check for $100.00 and a one year membership in The Navigation Foundation.

The RADM Thomas D. Davies, United States Navy Award, for Excellence in Navigation, to Alex C. Lanstein at The Tabor Academy, Marion Massachusetts, a plaque, a check for $100.00 and a one year membership in The Navigation Foundation.



DO YOU KNOW . . . ?

By Ernest Brown

Why the correction for the effect of irradiation which was included in the Nautical Almanac data for the upper limb of the sun from 1958-1970 was discontinued?

(Answer at back of this issue)

READERS FORUM

Edited by Ernest Brown

YACHT FIONA

ROUND THE WORLD THE WAY OF THE CLIPPER SHIPS, 2002-2003

Newsletter 2

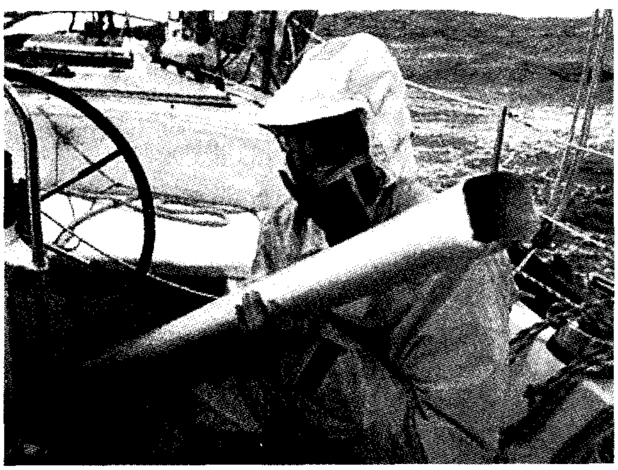
Eric B. Forsyth, Master

FILED FROM: Hobart, Tasmania, December, 2002

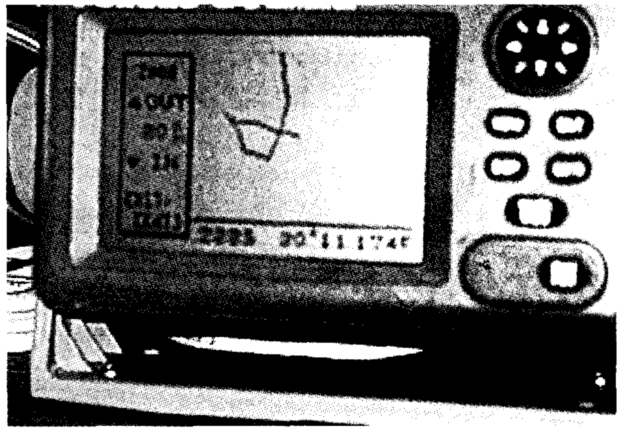
"On this leg I fly to New York, we dip our toes in the Southern Ocean and retreat, sail to remote Kerguelen Island and wind up in Hobart instead of Wellington.

"The flight from Cape Town to New York took a little over 24 hours. First I flew to Johannesburg for the international connection. When I got there I had never seen such chaos in my life. The departure lounge was a mass of humanity, pushing carts, trying to clear security, trying to get a boarding pass. Obviously I was not going to make it. I appealed to a porter; I told him I had an hour to make the New York plane. "You won't make it, mon," he said. I looked desperate. "I can help, it will cost," he proffered. I took his bait. "How much?" "$20 U.S." I replied, "Okay, let's go." He led me to a point and told me to wait. After a few minutes a South African Airways rep appeared and led me to a ticket agent. Within minutes I had the boarding pass and passed through security. Then the rep intercepted me, he wanted $20 as well. Clearly the people at Johannesburg International Airport have worked out a solution to the endemic unemployment of the area. Twenty minutes after strapping myself in, we taxied away. Once airborne I had a double rum and felt much better.

"The plane landed in the Cape Verde Islands to refuel and change crew. Twenty-four hours after leaving Cape Town, Don's limo picked me up at JFK in New York and within an hour or so I was in tranquil Brookhaven.



Bob inspects the breaks in the whisker pole.



GPS plot of the boat's position while hove-to for about 36 hours near 41° S, 30° E, The horizontal scale is 80 nm.

I had brought the SSB radio for repair and shipped it UPS overnight that morning. A couple of weeks later I flew back. I had put away the pool furniture, shut off the outside faucets and closed the shutters. The house was ready for winter.

"Back in Cape Town, the crew and I did the reprovisioning. Bob's partner, Sue, had inventoried the boat supplies while I was away so that we could stock up for the leg to New Zealand. We found time to squeeze in a tour of the South African wine making region at Stellenbosch. A full day tour cost $24, including lunch, such is the ludicrously favorable exchange rate for the Yankee dollar. While I was away, David had visited relatives in Botswana and had a fabulous time.

"We left Cape Town on 15th October with a fair wind and sailed south to clear Cape Agulhas, which is the southernmost cape of the continent, not the Cape of Good Hope. Once clear of the Cape, the weather deteriorated and almost before we knew it, we were dealing with heavy seas and winds up to 60 knots. After a couple days, the whisker pole broke into two pieces and a little later the staysail halyard block disintegrated; this allowed the sail to flog itself to bits before we could furl it. I surveyed the damage and decided to return to Cape Town, which lay 400 miles astern. Just a week after leaving we pulled into our old slip at the Royal Cape Yacht Club.

"The riggers and sailmakers were wonderful and we left again shipshape after only four days. This time we had a hard beat to weather to clear Cape Agulhas. Once clear we had to decide on the route to New Zealand. The world is a globe, and the shortest path is to sail south of east, but it gets windy and cold and Antarctica is in the way. Sailing Directions issued by the British Admiralty recommend sailing east at latitude of 40° S., claiming the weather is better than further south. But by sailing at 50° the distance shrinks by about a thousand miles, and we would pass close to the mysterious island of Kerguelen, one of the most remote in the world. Naturally, we opted for the higher latitude; the weather was indeed grungy. A little over a week after clearing the Cape, the wind swung to the east and increased to 60 knots. We set the double reefed mainsail, reefed staysail and hove to. In 36 hours we drifted backwards by over 25 miles, very frustrating. David managed to get his head in the way of the staysail boom and got a good knock, fortunately with no serious damage (to the boom, that is).

"As we approached the Crozet Islands, the bot was overwhelmed by a huge wave that literally buried the vessel. The cabin darkened for a moment and seawater poured in through every crack. Some equipment on deck was broken or washed away, but for the time being the ocean had spent itself and after that the weather improved. Three weeks after leaving Cape Town for the second time, we approached Kerguelen; the coast was covered by a thick fog. We got good radar contact and headed down the coast for the French research station at Port aux Francais. As the long sub-Antarctic twilight faded, the fog lifted to expose the stark, snow-covered mountains of Kerguelen. By morning we were near the base. The weather turned sunny and a call on the VHF radio brought out an inflatable to guide us to anchorage that was free of kelp.

"The station is home to about 100 people, all scientists and support personnel. They were very hospitable, and we were assigned a guide, a Scottish scientist based in Australia. We were told only one or two yachts sail to Kerguelen every year. We had a shower, did some laundry and met the station chief, who extracted a stiff fee for our visit. In return, we ate wonderfully in the base canteen. We found the post office, which is apparently famous throughout the world to collectors, who mail envelopes so that they can be returned with the rare Kerguelen stamp and frank. To my surprise they wanted to borrow *Fiona's* stamp, so some lucky collectors will get a bonus, as all the envelopes awaiting the next supply ship will carry our stamp as well as the Kerguelen frank. We bummed some fresh veggies off the chef, got our jerry jugs refilled with diesel and prepared to leave.

"We took a walk along the beach to inspect the many elephant seals and king penguins and let them inspect us. By late afternoon we weighed anchor so that we would be clear of the coast by nightfall. The met office gave us a five-page forecast of westerly winds, but we had easterly winds for 12 hours. We stayed near 49° latitude for over 1,000 miles, a region of the 'Roaring Forties' characterized in a recent book as 'Godforsaken.' In fact, the weather wasn't too bad — better than the stretch of ocean near South Africa. We had our share of gear failures, of course, mostly chafed lines and a few stainless fittings that cracked. Each day we checked in with ham operators in South Africa or Australia and each week we called Brenda and Sue on the Iridium satellite phone. Watch succeeded watch; on average we spent a couple of hours each day on deck, reefing or shifting sails. We cooked and baked bread, and every few days we opened a fresh *Manchester Guardian* from the stack my daughter Brenda had accumulated. The time passed quickly. Once a week, when the weather wasn't too bad, we had a

The author framed by the south coast of Kerguelen.

movie show, either black and white on my old 5" TV or a DVD on Bob's laptop. We are trying to educate young David to appreciate the classic movies, such as: *Lawrence of Arabia, Casablanca* and *The Maltese Falcon.*

"Nearly two weeks after leaving Kerguelen we were 800 miles south of Cape Leeuwin, one of the famous capes rounded by the square riggers. They were usually closer than us, as they favored latitude 40° S. We saw the solar eclipse on December 4th. A few days later, in the middle of the night, the Aries self-steerer failed, due to a structural collapse of the support assembly. We had to steer by hand most of the time, a tedious and chilly experience. As Hobart was a thousand miles closer than Wellington, we decided to switch our destination to Tasmania. We only had a one-in-a-million chart of Tasmania but we managed to contact the Royal Yacht club of Tasmania on the radio and got a promise of help as we got close. Our last night at sea produced the heaviest weather we had experienced since leaving Kerguelen — full gale conditions. We sailed up the Derwent River in the morning and a member of the club, John, guided us on the VHF radio to a slip he had arranged right in down-town Hobart.

"Two days after we arrived, Bob's partner, Sue, flew in, via New Zealand. She brought with her some new DVDs for our weekly movie show and spare parts sent by Red, our 'ship's wife' back in Bellport. A couple of days later, David's sister, Lindsay, flew into Hobart. We got our repairs organized and Helen Franklin in England shipped in spare parts for the Aries via DHL. At the moment everything seems to be under control for a departure for Stanley in the Falkland Islands in the week after Christmas. We should be able to witness the finish of the famous Sydney to Hobart Race before we leave. For the statistically minded, the leg from Cape Town (second departure) took 47 days and we logged 6.113 nautical miles. Total miles logged for the trip so far is 16,910. Hopefully, my next newsletter will be written from Brazil or the Caribbean, with Cape Horn and the chilly weather behind us."

—Best wishes until next time, Eric

NAVIGATION NOTES

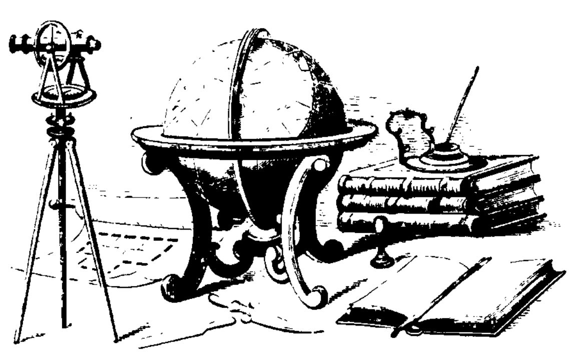
Lunar Distances - A Simple and Concise Solution

By G. G. Bennett

One of the most acerbic and humorous writers on navigation was Squire Thornton Stratford Lecky, Master Mariner. *His Wrinkles in Practical Navigation*, beginning with a first edition in 1881 was, for nearly half a century, the manual used by every aspiring and practicing navigator in the British Royal and Merchant Navies. I am fortunate to own a copy of the twentieth edition of his book published in 1917. Among the gems in this book, which is more than 800 pages long, is the following:

> "Whether Lunars are worth cultivating is not deserving of consideration. They are in fact, as dead as Julius Caesar; and, without being endowed with the mantle of prophesy, it is correct to say that they will never be resurrectionised (sic), for the best of reasons — they are no longer required".

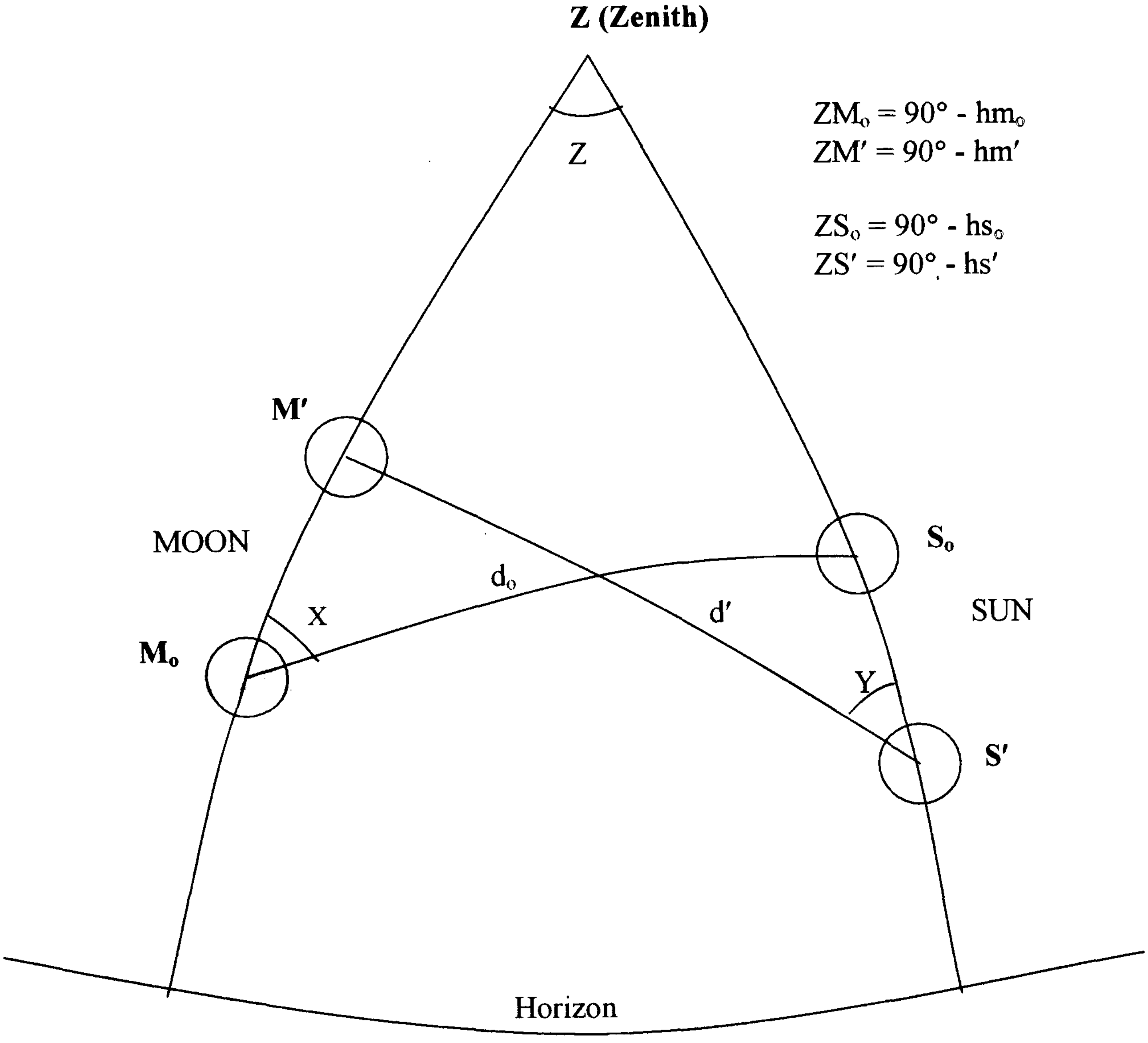
Well, the "Squire" was wrong because it seems that many old and new navigators still want to get a handle on the subject. The long list of writers, discoursing on practical observation techniques and reduction methods, including tables, goes back to Neville Maskelyne the fifth Astronomer Royal, who was responsible for the publication of the first edition of the Nautical Almanac and Astronomical Ephemeris. There are earlier writings but they are only of historical interest. The definitive theoretical exposition of Lunars is to be found in Volume I of William Chauvenet's monumental *A Manual of Spherical and Practical Astronomy*", 1863[1] The Dover editions of his books are probably still available. I paid $5.50 for both volumes from the Hayden Planetarium in New York in 1965. I note in my copy of the 1977 edition of the *American Practical Navigator* that "In 1802 Nathaniel Bowditch simplified the method and its explanation, thus eliminating much of the mystery surrounding it and making it understandable to the average mariner". This explanation and accompanying tables were discontinued in 1914. It should be noted that tables of calculated lunar distances for selected stars at three-hour intervals was included in the Nautical Almanac up to 1906. A broader approach to the method may be found in an article entitled "A Modern View of Lunar Distances".[2] This was prepared by the staff of H.M. Nautical Almanac Office in 1966 to mark the bicentenary of the publication of the first Nautical Almanac.



An interesting question is why has there been a renewed interest in method of lunars? I can only think that it presents a challenge to navigators, by testing their observational and calculating skills. The method has little practical value these days and it would be repetitive to discourse on such aspects as the practicalities of the timing and measurement of a lunar distance, which have been described in a number of publications. However, if we are going to use it then we should also use simple and concise calculation methods to achieve our goal, using, where possible, existing navigation tables etc. The reduction processes are not as complicated as some authors would have us believe and the first stage of correcting observations in preparation for the solution of some spherical triangles is quite simple and can be performed using the permanent tables in the NA together with three Critical Tables given later. The remaining geometrical problem to be solved is a pair of overlapping triangles with a common apex at the zenith. Adjacent sides consist of the observed and reduced co-altitudes of the Moon and another body, with one of the remaining sides being the reduced observed lunar distance. Finally, the computed value of the observed geocentric lunar distance **d'**, is compared with that derived from data taken from the NA, which enables us to calculate the watch error. All of this is illustrated in the diagram below and the example given later, which was my first venture into lunar distances. The subject is treated in two parts; Altitude Reductions and Distance Reductions.

Part 1 Altitude Reductions

The fundamental observations comprise timed sextant altitudes to the Moon and Sun (planet or star) and a timed sextant angle measurement between the two bodies. All observations must be referred to a common epoch. If the times of the observed sextant altitudes do not coincide exactly with those of the distance observations the altitudes may be corrected using a table of the time rate of change of altitude which will be found in many navigation tables. A simple nomogram for this rate is given in the Complete On-Board Celestial Navigator[3]. The observed sextant altitude observations must be corrected for index error and, if the observations have been made at sea, for dip using the critical table in the NA.



Critical Tables have the advantage that the maximum error can only be half the value of the unit in the last figure quoted and on the average only a quarter of a unit.

Before beginning the reduction process these corrected altitudes must, if applicable, be corrected for Semi-Diameter (SD). Add or subtract the SD, depending on which limb has been observed. The resulting altitudes are for the centers of the bodies and may be rounded off to the nearest minute. Result $\mathbf{hs_0}$ and $\mathbf{hm_0}$.

Step 1. Correct $\mathbf{hs_0}$ for refraction and, where appropriate, parallax. For the Sun it would seem logical to find the value of the combined correction for refraction and parallax from the NA tables. These [for the year 1958-70] should not be used because they include a correction for irradiation. Instead, use the refraction tables for stars and planets. For the Sun apply a correction for parallax of 0.1' for altitudes up to 70°, above 70° ignore the correction. For planets use the same refraction tables and then the Additional Corrections given on the inside cover of the NA. Result **hs'**. Note. The celestial coordinates for the navigational planets in the NA refer to the 'center of light' and not to the center of the body. It is therefore presumed that observations are made to the 'center of light' and no reference need be made to the SD of the planet.

Step 2. For the Moon, correct **hm**$_0$ for refraction, parallax and the oblateness of the earth. The first two corrections are straightforward but some authors have incorrectly used

-0.10'cosAltitude for the calculation of the effect of oblateness. This formula is given in Sight Reduction Procedures in the NA, beginning in 1989, and is an approximation to a correction which allows for the combined effects of oblateness on altitude and declination in S/R. The separate corrections are to be found in my paper "The Effect of Neglecting the Shape of the Earth on the Accuracy of Sight Reduction"[4], 1985. The simplest way of combining all three corrections is to make use of the permanent Moon tables which may be found inside the back cover of the NA, a technique which should be very familiar to navigators. The difference between the models is as follows. Ignoring the corrections for refraction and SD, which are common to both models, we have,

Cos hm$_0$ (P + 0.19'sin^2 (Latitude)	Bennett
Cos hm$_0$ (P - 0.10')	Nautical Almanac

where P is the parallax taken from the NA.

Therefore, if we add (0.10' + 0.19'sin^2 Latitude) to the tabulated parallax in the NA before using the Moon tables we can combine all three corrections into one, which is in accord with the Bennett model. This correction to parallax can be evaluated using Critical Table (1) given at the end. The L and U corrections may require interpolation. Result **hm'**.

Example:

Date: Wednesday 10th August 1966
Position: Latitude S33°55', Longitude E151°14'.
Sextant Index Correction: 0.4' (off the arc).
Watch: Keeping approximately GMT.
Height of Eye: Zero.
Observations at Watch Time 23h 25m,
Observed Sextant Altitudes,
Sun(UL)28°34.5', Moon(UL)22°07.8'.
Observed Lunar Distance 73°02.0'
Almanac Data: Sun SD 15.8', Moon SD 15.5', HP 56.8'.

Altitude Reductions:

		Sun		Moon
Observed sextant altitude		28°34.5'		2°07.8'
Index correction		+0.4		+0.4
Dip (H of E zero)		0.0		0.0
Semi-Diameter		-15.8		-15.5
	hs$_0$	28 19.1	**hm**$_0$	21°52.7'

Round off **hs**$_0$ and **hm**$_0$ to the nearest minute.

	Sun		Moon
hs$_0$	28°19'	**hm**$_0$	21°53'
Refraction	-1.8*	Corrn.	+50.4***
Parallax	+0.1**	**hm'**	22°43.4'
hs.	28°17.3'		

**Use refraction tables for stars or planets in NA.*
***For Sun altitudes below 70° add 0.1', otherwise ignore.*
****For planets use the Additional Corrections in the NA.*

Parallax (P)	56.8'	From NA.
Parallax Corrn.	+0.2	See Critical Table (1). Lat.34°
Corrected Parallax (P.)	57.0	
Main Corrn.	61.8'	Altitude 21°53' From NA.
Limb Corrn. (Use P.)	+3.6	$\frac{L+U}{2} = \frac{4.2'+3.1'}{2}$ = 3.6'
	-15.0	
Total Moon Corrn.	+50.4	

Part 2. Reduction and Calculation of Distances.

Phase 1. Distance Reduction

Step 1. Correct the observed lunar distance for sextant index error and, where appropriate, for the SDs of the Sun and Moon. The SD of the Moon needs to be increased because the observer is normally closer to the Moon than the center of the Earth, the point from which celestial coordinates are referred. This correction, called augmentation (+0.27'sin Altitude), can be conveniently applied using Critical Table (2) given later.

Step 2. If the observations have been taken at low altitudes, it will be noticed that the Moon and the Sun appear to have an elliptical shape (major axis horizontal). This phenomenon is due to the change in refraction between the upper and lower limbs of the body. A correction for this effect on the measured distance depends on the altitude of the body and the position angle between the vertical and the direction to the other body. Rather than calculate this angle, which would introduce an unwarranted complication, it may be estimated to the nearest 10° or so from the appearance of the two bodies in the sky. These angles are shown as X and Y on the diagram. The corrections can be evaluated using Critical Table (3) given at the end of the example. The table only treats altitudes above 5° because at lower altitudes there is poor definition at the point of contact and the refraction is large and uncertain. This correction is often neglected. Result **d**$_0$

Lunar Distance Reduction:

Measured Lunar Distance	73°01.6'
Index Correction	+0.4
Sun SD	+15.8
Moon SD	+15.5
Augmentation	+0.1*
Contraction of SDs	0.0**
$\mathbf{d_o}$	73 33.4

* *Critical Table (2) Altitude 28°*

***Critical Table (3) Moon Altitude 22°, Estimated X 60°,.*
Sun Altitude 28°, Estimated Y 70°.

Phase 2. Distance Calculations.

Navigators who have made celestial observations are usually familiar with the Nautical Almanac (NA) and Sight Reduction (S/R) procedures and may be disappointed and discouraged by a statement by The Nautical Almanac Office [2] that "...sight reduction tables and methods provide almost no assistance to the main problem of the reduction of lunar distances". Another author also claims that, in general, pre-computed altitude tables do not work with sufficient accuracy and only cover distances up to 90°. These criticisms are valid where the S/R tables employ chosen values for some of the principle variables. It will be seen later that suitable S/R tables can be used to advantage for the complete solution.

The geometrical problem to be solved is a pair of overlapping triangles with a common apex at the zenith. Adjacent sides consist of the observed and reduced co-altitudes of the Moon, 90° $\mathbf{hm_o}$ and 90° - **hm'**, and another body, 90° - $\mathbf{hs_o}$ and 90° - **hs'**, with one of the remaining sides being the reduced observed lunar distance, $\mathbf{d_o}$. Finally the computed value of the observed geocentric lunar distance, **d'**, is compared with that derived from data taken from the NA, which enables us to calculate the watch error. See diagram for details. All of this is set out in the example given later.

Step 3. The next stage requires the solution of the overlapping triangles referred to previously. There has been an inordinately large number of methods suggested for their solution, the Nautical Almanac Office [2] estimating that 50 or 60 schemes of solution have been used at some time or another, some of which include special tables. If you have a calculator, four applications of the cosine formula will give a simple, speedy, and accurate answer to the problem. If however, you spurn the use of electronics, it is then a matter of personal preference. The choice is not easy. Personally, I have no wish to use log tables, having used them for so many years before the advent of the calculating machine etc. S/R tables would seem to afford a solution with an interchange of variables, but tables that use chosen values for latitude and local hour angle will require laborious triple interpolation [2]. Tables which make use of DR positions can be used with an appropriate interchange of variables (Altitude becomes distance, LHA becomes (Z) etc). The S/R tables in the Complete On-Board Celestial Navigator [3], which are quite short (20 pages), can used for this purpose. They are intended for S/R without any interpolation (95% of errors of solution do not exceed one minute of arc). However, if interpolated, 95% of errors do not exceed a few tenths of a minute of arc which may be acceptable. I have constructed a new set of tables, also 20 pages long, in which the tabulations have been increased by one digit and the accuracy substantially increased so that no error (11,389 trials) exceeds one tenth of a minute of arc. The original S/R Tables have been used in the example given later. In both sets of tables there are no decimal places, no negative numbers, no problems of characteristic and mantissa, and only one rule to understand i.e. finding the algebraic difference between latitude and declination. There are no 'dead spots' in the tables, which can occur with some other S/R Tables. The headings of the three quantities given in the tables correspond to the variables used in the S/R solution i.e. LAT/DEC, LHA/SUM and L~D/RES, where SUM and RES are intermediate stages. A full discussion of these tables is given at http://www.netspace.net.au/~gbennett/

A short extract from the tables is given at the end of this article.

The distance calculations are set out in four stages in a systematic way as will be seen in the example, labeled **A, B, C** and **D**. The first column shows the heading in the table used for the variable, the second column the symbol for the variable and the third column the numerical values of the variables. All the tabular entries and values extracted by the user are printed in italics. It will be seen that many of the variables are similar in size, and a considerable saving in time can be made by looking up and extracting tabular entries at the same opening of the tables.

At first, see **A**, the tables are used in reverse starting with $\mathbf{d_o}$, and ending with a tabular entry for the apex angle (Z), the specific value of which is not required. The tables are now used in the normal order, see **B**, to solve for the observed geocentric distance, **d'**.

Step 4. Because geocentric Lunar Distances are now no longer published, they need to be calculated from the ephemeral data in the NA. Select two epochs which will straddle the estimated GMT of observation by, say, one hour and extract the GHAs and Declinations for each body. Find the differences in GHA and together with the Declinations calculate the distances $\mathbf{d_1}$ and $\mathbf{d_2}$ in the normal way, using the tables, see **C** and **D**.

Calculation of Lunar Distance **d'**

A L~D $\mathbf{d_o}$	*73° 33.4'*		*71692*		
L~D $\mathbf{hm_o \sim hs_o}$	*6° 26'*		*- 630*		
		RES	*71062*	*SUM*	*5855*
LAT $\mathbf{hm_o}$	*21° 53'*				*-423*
LAT $\mathbf{hs_o}$	*28° 19'*				*-721*
(Z)					*4711*

B (Z)	See above		*4711*	
LAT	**hm'**	*22° 43.4'*	*457*	
LAT	**hs'**	*28° 17.3'*	*719*	
		SUM	*5887*	RES *70665*
L~D	**hm'~hs'**	*5° 33.9'*		*472*
L~D	**d'**	*73° 13.5'*		*71137*

Calculation of Lunar Distances d_1 and d_2

At 23h GMT 10th August

Sun Dec.	**decs**$_1$	*N15°29.3'*	Sun	**GHA s**$_1$	*163°40.9'*
Moon Dec.	**decm**$_1$	*N22°11.4'*	Moon	**GHA m**$_1$	*241°40.8'*
			Difference	**AGHA**$_1$	*77°59.9'**

* 360° - 77°59.9 = 282°00.1' may also be used.

C LHA	**ΔGHA**$_1$	*77°59.9'*	*5241*		
LAT	**decs**$_1$	*N15°29.3'*	*209*		
LAT	**decm**$_1$	*N22°11.4'*	*435*		
		SUM	*5885*	RES	*70692*
L~D	**decs**$_1$**~decm**$_1$	*6° 42.1'*			*683*
L~D	**d**$_1$	*73° 22.0'*			*71375*

At Oh GMT 11th August

Sun Dec.	**decs**$_2$	*N15°28.5'*	Sun	**GHAs**$_2$	*178°41.0'*
Moon Dec.	**Decm**$_2$	*N22°20.1'*	Moon	**GHAm**$_2$	*256°09.3'*
			Difference	**ΔGHA**$_2$	*77°28.3'*

D LHA	**ΔGHA**$_2$	***77°28.3'***	*5306*		
LAT	**decs**$_2$	*N15°28.5'*	*209*		
LAT	**decm**$_2$	*N22°20.1'*	*441*		
		SUM	*5956*	RES	*69809*
L~D	**decs**$_2$**~decm**$_2$	*6°51.6'*			*716*
L~D	**d**$_2$	*72°51.5'*			*70525*

Calculation of Watch Error

At 23h GMT	d_1	73°22.0'	
		Difference 8.5'	
At Watch Time 23h 25m	d'	73°13.5'	
At Oh GMT	d_2	72°51.5'	
Difference		29.5'	

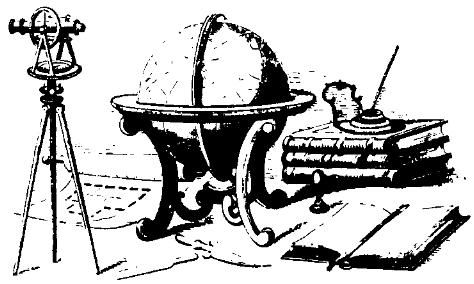
GMT of Observation: 23h + $\frac{8.5}{29.5}$ x 60m = 23h 17m

Watch Time of Observation 23h 25m

Therefore the Watch was 8m Fast on GMT.

Distances Greater than 90°

If there is a choice of bodies when measuring lunar distances, those bodies that are very distant from the Moon should be avoided. The accuracy of measurement is superior when distances are kept preferably well be-



low 90°. If there is a restricted choice and the distance is in excess of 90° a variation in calculation is required because conventional S/R tables only cover the following range of variables,

Local Hour Angle	0°- 180° (E or W)
Latitude	0°- 90° (N and S)
Declination	0°- 90° (N and S)
Altitude	0° - 90°

In the current application, the lunar distance is substituted for altitude, which would normally not exceed 90°. However, because of the cyclic nature of trigonometric functions, the problem may be overcome by some small variations in procedure as follows,

(1) When moving between SUM and RES, look up the angle corresponding to the value for SUM under the LHA/SUM heading, form its supplement and find the corresponding value for RES under the L~D/RES heading.

(2) **Look up the angle corresponding to L~D and then form its supplement, resulting distance d. The following example illustrates the technique.**

LHA	**ΔGHA**	*69°33.2'*	*2227*		
LAT	**ds**	*S21°09.9'*	*395*		
LAT	**dm**	*N2°56.2'*	*7*		
		SUM	*2629* *	RES	*74314*
L~D	**ds ~ dm**	*24°06.1'*			*-8717*
L~D	**d**	*110°07.3'* ←		*69° 52.7'*	*65597*

* *2629* LHA *104°53.0'* → *75°07.0'* RES *74314*

CRITICAL TABLES

Critical Table (1) Moon Parallax Correction.

Latitude:	0°	31°	63°	90°
Correction :	+0.1'	+0.2'	+0.3'	

Critical Table (2) Augmentation of Moon's Semi-Diameter.

Altitude:	0°	10°	33°	67°	90°
Correction:	+0.0'	+0.1'	+0.2'	+0.3'	

Critical Table (3) Contraction of the Inclined Semi-Diameter of the Sun or Moon.

POSITION ANGLE						
0°	10°	20°	30°	40°	50°	60°
Alt. Corrn.	Alt. Corrn.	Alt. Corrn.	Alt. Corrn.	Alt. Corrn.	Alt. Corrn.	Alt. Corrn.
-0.4'	-0.4'	-0.4'	-0.3'	-0.2'	-0.2'	-0.1'
5°20'	5°20'	5°00'	5°40'	6°40'	5°20'	7°40'
-0.3'	-0.3'	-0.3'	-0.2'	-0.1'	-0.1'	-0.0'
6°40'	6°40'	6°10'	7°40'	12°40'	10°20'	
0.2'	-0.2'	-0.2'	-0.1'	-0.0'	-0.0'	
9°10'	9°00'	8°30'	14°30'			
-0.1'	-0.1'	-0.1'	-0.0'			
17°00'	16°40'	15°50'				
-0.0'	-0.0'	-0.0'				

Extract from Sight Reduction Tables

	36°		
	LAT DEC	LHA SUM	L~D RES
00'	1199	13291	19098
01	1200	13286	19115
02	1202	13281	19132
03	1203	13276	19149
04	1204	13271	19167
05	1205	13266	19184

Conclusion

The measurement and calculation of lunar distances is a fascinating subject which requires a close and careful study to appreciate its complexities. For today's navigator, the obvious answer to the calculations would be to write a short computer program, but of course there is no challenge in this approach. What has been described is a practical alternative to some alternative lengthy and complicated solutions but is within the accuracy bounds of marine navigation. This is particularly pertinent for the occasional user who can use reference material which is readily at hand. Except for a sextant and a timepiece all that is required for this work are a Nautical Almanac and a set of suitable Sight Reduction Tables. If the use of a simple calculator is scorned, I use a table of proportional parts, which doubles as a book mark

References

1 Chauvenet, W. (1891). *A Manual of Spherical and Practical Astronomy* Vol. 1. Dover Publications, Inc., New York, USA.

2 Nautical Almanac Office. (1966). *A Modern View of Lunar Distances.* Journal of the Institution of Navigation (UK), Vol. 19, No. 2.

3 Bennett, G. G. *The Complete On-Board Celestial Navigator (2003-2007 Edition).* International Marine. A Company of McGraw-Hill, Camden, ME, USA.

4 Bennett, G. G. (1985). *The Effect of Neglecting the Shape of the Earth on the Accuracy of Sight Reduction.* Journal of the Institution of Navigation (UK), Vol. 38, No. 1.

NIMA'S MARINE NAVIGATION CALCULATOR

http://pollux.nss.nima.mil

CONTENTS:

Log and Trig Calculator
Celestial Navigation Calculator
Conversions Calculator
Distance Calculator
Time Measurements and Conversions Calculator
Weather Data Conversion Calculator
Sailings Calculator

Log and Trig Calculator

Logarithmic and Trigonometric Functions

Comment: (Table references are to the 1995 and 2002 editions of Bowditch). This calculator provides like:Table

Table 1 Logarithms of Numbers
Table 2 Natural Trigonometric Functions
Table 3 Common Logarithms of Trigonometric Functions

Unlike Bowditch and common practice, the logarithms of trigonometric functions are not presented in the +10 format. For example, table 3 gives log sin 30° as 9.69897[-10] whereas the calculator gives log sin 30° as -0.3010299956639812.

The +10 format was considered more convenient when adding figures in a column. The five decimal places of tables 2 and 3 do not insure getting answers to the problems to the nearest 0.1' of arc.

Celestial Navigation Calculator

Altitude Correction for Air Temperature
Altitude Correction for Atmospheric Pressure
Altitude Factors & Change of Altitude
Amplitude
Correction of Amplitudes Observed on the Visible Horizon

Comment:

Correction of Amplitudes Observed on the Visible Horizon should not be used because of faulty programming. This item is expected to be replaced by a calculation titled Campass Error from Amplitudes Observed on the Visible Horizon. The amplitude calculation is to be replaced by Compass Error from Amplitude Observed on the Celestial Horizon.

Latitude and Longitude Factors

Meridian Angle and Altitude of a Body on the

Prime Vertical Circle
Pub 229
Pub 249
Table of Offsets

Comment:

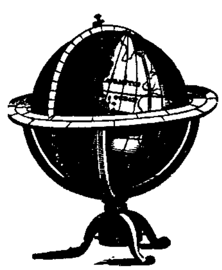
The Pub 229 calculator above is perhaps mislabeled in that it does not reproduce Pub 229 in its entirety. Part of the whole table is the visual presentation which enables one to see how respondents change with incremental changes in the entering arguments. Unfortunately, the design of Pub 229 does not permit convenient inspection of changes with time as did the replaced H.O. 214.

The Pub 229 calculator provides solutions for altitude and azimuth given the latitude, declination, and LHA. It also provides solutions of the spherical triangle given two sides and the included angle.

The Pub 249 calculator is not operative, awaiting development of the software.

Conversions Calculator

Chart Scales and Conversion for Nautical and Statute Miles
Conversions for Meters, Feet and Fathoms



Distance Calculator

Dip of Sea Short of the Horizon
Distance by Vertical Angle Measured Between Sea Horizon and Top of Object Beyond Sea Horizon
Distance by Vertical Angle Measured Between Waterline at Object and Top of Object
Distance by Vertical Angle Measured Between Waterline at Object and Sea Horizon Beyond Object
Distance of an Object by Two Bearings
Geographic Range
Distance of the Horizon
Length of a Degree of Latitude and Longitude
Meridional Parts
Speed for Measured Mile and Speed, Time and Distance
Traverse Table

Time Measurements and Conversions Calculator

Time Zones, Zone Descriptions, and Suffixes

Weather Data Conversion Calculator

Correction of Barometer Reading for Gravity
Correction of Barometer Reading for Height Above Sea Level
Correction of Barometer Reading for Temperature
Barometer Measurement Conversions
Temperature Conversions
Direction and Speed of True Wind
Relative Humidity and Dew Point

Sailings Calculator

Great Circle Sailing
Mercator Sailing

Compass Error from Amplitudes Observed on the Celestial Horizon

Latitude of the Observer	45	(degrees)	North	N/S	
Declination of the Celestial Body	14	(degrees)	North	Rising	Rising/Setting
Compass Bearing	068	(degrees)			
Compute Reset					
Amplitude	East 20.01	(degrees)	North		
Azimuth (Zn)	69.99	(degrees)			
Compass Error	2	(degrees)	East		

Expected change to Celestial Navigation Calculator: http://pollux.nss.nima.mil

Compass Error from Amplitudes Observed on the Visible Horizon

Latitude of the Observer	45	(degrees)	South	N/S	
Declination of the Celestial Body	14	(degrees)	South	Setting	Rising/Setting
Compass Bearing	248.75	(degrees)			
Compute Reset					
Adjusted Amplitude	West 20.76	(degrees)	South		
Azimuth	249.24	(degrees)			
Compass Error	.5	(degrees)	East		

Expected change to Celestial Navigation Calculator: http://pollux.nss.nima.mil
NIMA has scheduled this change for June 19, 2003.

ANSWER TO DO YOU KNOW . . .?

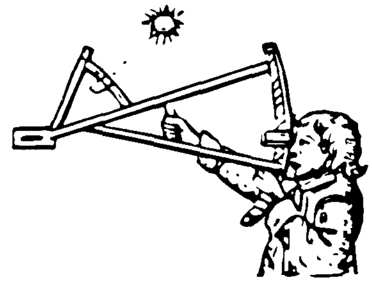
(from page 1)

From article 809 of volume II of the 1981 edition of Bowditch:

When a bright surface is observed adjacent to a darker one, a physiological effect in the eye causes the brighter area to appear to be larger than is actually the case; conversely, the darker area appears smaller. This is called **irradiation**. Thus, since the sun is considerably brighter than the sky background, the sun appears larger than it really is; and when the sky is considerably brighter than the water, the horizon appears slightly depressed. The effects on the horizon and lower limb of the sun are in the same direction and tend to cancel each other while the effect on the upper limb of the sun is in the opposite direction to that on the horizon and tends to magnify the effect.

From 1958-1970 a correction of 1.2' was included in the *Nautical Almanac* data for the upper limb of the sun as an average correction for the effect of irradiation. Recent investigations have not supported that average value and have revealed that the magnitude of the effect depends on the individual observer, the size of the ocular, the altitude of the sun, and other variables. In summary, the accuracy of observations of the limb of the sun at low altitudes may be affected systematically by irradiation, but the size of the correction is so dependent upon the variables enumerated above that it is not feasible to include an average correction in the tables.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY, SUMMER 2003

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

It has been a busy summer. As you know, The Navigation Foundation leases a 56-ft ketch. The reason was originally to allow members to go into the Chesapeake Bay and practice taking celestial sights. We found that the haze and light along the east coast prevented one from seeing all except a few stars directly overhead. We have kept the boat to take prospective members out for a "day on the bay." As you all know, having a boat is work, work, work. With a summer of radiation for cancer, a summer where my son was recovering in the hospital from a plane crash, and a summer of catching up on all the necessary things left over from the previous 2 years, the boat suffered.

This summer, my wife and I have spent almost every weekend caulking cabin windows, cleaning mildew, scrubbing the dark spots on the deck caused by the sugar refinery just a few hundred yards away and sanding the teak deck plates and oiling them. We have not taken the boat out this year because of all the work. Maybe it will be ready with new batteries and other necessary items by the late fall to take it out for a while.

Please remember to order all of your charts from The Foundation and get your discount. The Government has set up a new system of ordering. The last charts I ordered came in a day and a half, re-mailed the same day. Members should have their charts in 3 to 4 days from the time they order via the Internet at navigate1@comcast.net or a telephone call or FAX to 301-622-6448. If you call, please speak plainly and leave me a telephone number where you can be reached to verify your order. The same goes for publications, but they may take a few days longer unless they are shipped from the publisher. Do not pay any invoice on orders to The Foundation unless the invoice comes from us. That is the only way to get your discount. Keep ordering, as that is the only way we can keep our book dealer status and continue to give member discounts.

NAUTICAL CHART UPDATES: The National Ocean Service (NOS) has moved and expanded the function of its "critcorr" website. The new "Nautical Chart Updates" website allows the mariner to update their nautical charts from one database that includes information from NOS, NIMA, Notice to Mariners, the Coast Guard Local Notice to Mariners, and the Canadian Coast Guard Notice to Mariners. To access the website and for more information go to http://chartmaker.ncd.noaa.gov/ and click on "Chart Updates."

READERS FORUM

Edited by Ernest Brown

James N. Wilson wrote on May 16, 2003:

"I agree that navigators need a periodic reminder that vessel motion affects determination of longitude from a series of observations around meridian passage. Admiral Davies did publish an abstract of my paper many years ago, shortly after it was published in *Navigation,* and it was discussed in 1990 in the Royal Institute of Navigation *Journal of Navigation.* After its initial publication, I was made aware by a British sailor that I hadn't discovered anything new. The basics are in the Admiralty Manual of Navigation, Volume III, last published over a half century ago. Forrest Gibson managed to find a 1938 copy, and graciously loaned it to me, and I copied the

DO YOU KNOW . . . ?

By Ernest Brown

The communities which could be impacted by changes in the UTC Timescale by approaches to reduce or eliminate the operational impact of the leap second?

(Answer at back of this issue)

relevant pages. It comes up with the same basic equation, but is limited to only the sun. It's fun reading, since it was written back in the days when celestial objects were 'heavenly bodies.' My graphical approach is new, but I'm not sure that I would have happened upon it without the suggestion of Ham Wright. Alas, Ham passed away many years ago, and I've lost contact with Forrest.

"I sympathize with your editorial woes expressed by Terry Carraway, in that I was editor (and publisher) of the Maserati Owners Club Quarterly magazine for ten years. I finally quit when the material dried up. I refused to write the magazine myself, and once prolific writers gradually stopped writing. It was sad, in that my resignation led to the demise of the club, in that the Quarterly was their main offering to members. We still get together socially, and have as much fun as ever, but we no longer offer a service. Really, the Internet allowed Maserati owners all over the world to compare problems and offer solutions more rapidly, and maybe better, than we could. Actually, my last few issues were mostly copies of Internet correspondence.

"I'm sorry that I can't offer you any more articles, but I'll keep my thinking cap at the ready. Teaching my class has kept me on my toes, and it looks like I'll have another one next year. Amazing! After a ten year drought, to have back-to-back celestial navigation classes is a total surprise. This year's comprised ten students, an almost astronomical number nowadays, but next year's will probably be half of that. That will still be enough to get them involved and interacting, and that's where the real learning comes from. And maybe they will provide me with an idea."

—*Jim Wilson*

Member Timothy J. Smiley wrote:

"Thank you for honoring me with the Benjamin Dutton award. The study of Navigation and its practical application has been an interesting and valuable experience. I believe that it will become even more important as I get closer to joining the fleet. Thank you for your support of the study of Navigation and for recognizing my dedication to it.

—*Very respectfully, Timothy J. Smiley, MIDN, USN*

Member Frederic C. Kapp wrote:

"I was pleased to read the responses from George Bennett and Kieran Kelley to my article on Time Sights.

"Mr. Bennett is quite correct in his statement 'latitude errors should be heeded only if the *time sight* is taken in a position away from the Prime vertical.'

"I neglected in my article to state that should the navigator be concerned about the accuracy of his DR, he could work the time sight from two separate latitudes - one to the north of and one to the south of the DR. A line through the two longitudes so obtained would produced a Sumner Line.

"Mr. Kelley is correct regarding my figure for GHA. And this accounts for my 24s error in the longitude found. His article on solving for longitude by hand was most impressive. I disagree, however, with his use of t interchangeably with LHA. 't was also known as the horary angle and we know it today as the meridian angle.' Meridian angle t is the angle at the pole between the local meridian and the body, measured through 180 east or 180 west and labeled as such. LHA is measured 360 westward from the local meridian. Those remembering HO 211 or HO 214 will remember having to find t as an entering argument. As a matter of interest, HO 211 refers to LHA, but the number to be entered is really meridian angle (t).

"New subject. I read with interest Mr. Kelley's experience sailing on *Endeavor.* I had the good fortune to sail on her on a voyage form Bermuda to Tortola, BWI in 1998. I wrote an article about this passage, which was published by The Foundation. I occupied Sir Joseph Banks' cabin, which was on the starboard side of the Great Cabin. Doing my celestial work up at the great cabin table was a pleasant change from doing the same on a racing yacht where I was subjected to wet sails and spray coming down the companion. It was on that trip that I first learned of Celestial calculators. The first officer saw me working up my first set of sights with the almanac and HO 229. He kindly offered me the use of his Merlin Calculator, and it became love at first sight. (No pun intended). My article in *The Navigator's Newsletter* was about using the amazing device. I subsequently purchased a Celestecomp and used it in the Marion Bermuda Race in 1999.

"I did not have the difficulties faced by Mr. Kelley. After a nasty day or two caused by the remnants of Hurricane Mitch, Captain Blake steered west into and through a cold front behind which was a wonderful Northwester. We kept this breeze all the way to Tortola as it slowly veered and became the NE trades. During our eight day voyage I would do AM/PM stars on the poop where the exec would record my data for me. Being in those latitudes I had plenty of twilight to do my work. As Mr. Kelley will remember, the *Endeavor* has a great amount of sheer and since our course was southerly, I never could get a shot of Polaris due to the immense height of the stern rail, but Alkaid was available off the port quarter and the clear skies allowed me a large selection of stars, planets, and the daytime moon. I took my sun sights form the waist which I could do all by myself. Being on a starboard reach, *Endeavor* was quite steady and did not roll much. However, the seas were dead ahead and we did pitch quite a bit. I was able to take the sun standing in the waist unsupported and with practice could have the sun kiss the horizon at the top of the seas with excellent results. Once again, our course prevented me from taking a meridian altitude, the course, main topsail and foretopsail always being in the way. However, the sun would eventually be visible to starboard and a good running fix could then be obtained.

"I was fascinated with Mr. Kelley's description of the travails of land celestial navigation and my hat is off to him.

"I am most grateful to Mr. Bennett and Mr. Kelley for their interest and comments on the 'time sights', and for Mr. Kelley's wonderful solution for the same. My thanks also to the comments of Bruce Stark."

Member Jack R. Tyler wrote on May 16, 2003:

"I have misplaced my copy of newsletter number 74, so please send another one to me (at the above address). A check for $3.00 is enclosed.

"I am still very active in celestial navigation. I pack a sextant in my tote bag and have very little difficulty getting it through airport security. An inspector at the San Antonio International Airport did complain about too much metal in my hand luggage! A few other inspectors have simply stared at my Aries 40 (Astra IIIB) or the Brass Box Sextant for a few moments and then say nothing. (I have developed the habit of not volunteering any information while going through inspections, thus avoiding time consuming discussions).

"I take six to eight trips per year, one or two 3-4 masted sailing schooners, 1-2 passenger freighters (1600 tons) and the rest on 12-deck cruise liners. And I kept to this schedule during the last 3 years. The areas covered included the South Pacific (Bora Bora to Valparaiso, Chile and up the coast to Panama), the Caribbean (all areas), transAtlantic crossings (Miami to Gibralter), and western Mediterranean (Morocco, Spain, France, Italy). Most of the weather was not particularly good. A few things that became apparent to me during this time:

a. While we cherish the _ nautical mile intercept, very good results can be had with less accurate data (e.g. 15 to 20 nm). Often I have plotted fixes 3-5 nm off of gps plots from very large triangles obtained through averaging series of shots in rough seas and obscure skies and horizons.
b. Angle of intersection between sun lines is far more important than close-in intercepts. A second series of shots should average about 30 degrees azimuth from the first. Care must be taken to avoid comparing or plotting shots that are approaching a difference of 180 degrees azimuth!!
c. Dead reckoning is the heart of navigation, celestial work is used to confirm it.
d. I interpreted the phrase 'a well running rated watch' to mean a scuba diver's 200 meter, shock-resistant watch. I have one and it doesn't respond to changes of temperature and has a constant error. I leave it permanently on GMT. I am able to calculate the correct time to the second even after several months (An error of a few seconds doesn't seriously affect the accuracy of the fix, anyway).

"I still enjoy the challenge of celestial navigation and will continue to do so. I do most of my work with Celesticomp V hand computer, occasionally taking up pencil, paper and almanac to determine position. I still think the spherical trigonometry is magic! --- *Sincerely, Jack R. Tyler*

YACHT FIONA
ROUND THE WORLD THE WAY OF THE CLIPPER SHIPS, 2002-2003
Newsletter 3

Eric B. Forsyth, Master

FILED FROM: Barbados, May 2003

"On this leg the Fiona's crew deals with bureaucracy, completes the circumnavigation, and meets old friends.

"I last visited Santos eleven years ago when I was sailing home on *Fiona* from Tahiti after Edith had passed away. I have two strong recollections of the place. First is the memory of the luxurious yacht club, at which, as a foreign yacht, we got to stay for eight days free. Second, I still remember the bureaucratic nightmare I got involved in because my American crew did not have Brazilian visas. To sort out the mess I had to hire an agent. I was hauled up before an administrative judge and fined $30 for illegally bringing aliens into Brazil. I pleaded that failure of the ship's transmitter had forced me into Santos for repairs. The judge asked to see a letter from a repair shop before I could leave. The agent connived with a technician to get the letter, which cost me $200 and he did not even bother to fix the radio. This time I was ready. Bob and David had got their visas from the consulate in New York before we left. After we had tied up at the yacht club, which seemed little changed, I took a bus into the center of Santos to start the dreary round of official approvals needed to enter the country by boat. At Customs, after a couple hours, I was told that the only man who knew the correct procedures was away that day and I should return in the morning. I still had time to make it to Immigration before dark. I took a taxi

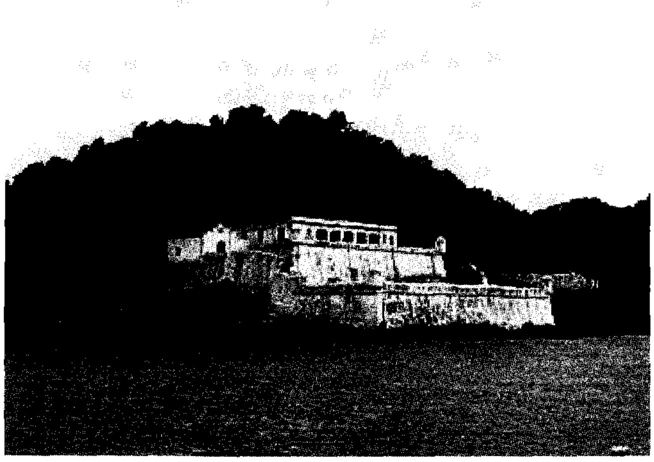
The circumnavigators raise a toast at Elda's restaurant, Fernando de Noronha.

along the miles of decaying waterfront warehouses to the station of the Federal Police, which deal with matters of immigration. It was a dingy office. Three or four fellows in black uniforms with side arms were lounging about, mostly watching a very loud TV set. I gave my little pile of papers to a balding man with a mustache at a desk. He riffled through them and seized the passports. 'Visas?' he asked. I pointed to the large stamps in the passports.

"He shook his head and scowled. He said something I didn't catch over the noise of the TV and put a beefy finger on the date - May 2002; just before we left. I finally got the message that they were only good for 90 days. I explained we had been in the South Ocean and Antarctica for the past few months, areas notably deficient in Brazilian consulates, and that we had got them when we could, we had paid the $45 fee, wasn't that the important thing? By this time the other fellows had smelled some fun and gathered round the desk. There was a long conversation in incomprehensible Portuguese. Finally a woman was produced from a back room who spoke a little English. She told me the visas were no good, and Bob and David would have to leave Brazil immediately. I put my case again that they had visas. But she was adamant. 'Go to Argentina,' she said. Visas can only be issued outside the country.' That didn't seem like a good idea. Argentina lay well to our south. I was shown the door and told to come back in the morning. In the meanwhile, Bob and David must not leave the boat.

"I returned to the Yacht Club feeling disgusted. A few weeks earlier I had been battling 'bergs, now I was battling bureaucrats. I think I preferred the 'bergs'. When I got to the boat I found that Sue had flown in from New York and that she and Bob had booked themselves into a nice hotel on the beach. It didn't seem like a good time to tell him to stay on the boat. I poured a stiff Mount Gay instead. Later, one of the club security guards came by to say they had a fax from the Feds and I was to meet them at 8 am the next morning. The next day I also discovered the fax instructed the club not to let Bob and David off of the premises, but fortunately nobody paid any attention. I guess the Brazilians are used to their overblown officialdom. Before Bob and Sue retired to the beach we discussed strategy. Just in case we were forced out we decided that the three of them would go to the supermarket in the morning and restock the boat while I was at Gestapo headquarters. I got up bright and early, as I had no idea how bad the morning rush would be. In fact it was light at that hour and I arrived back at the same dingy office by 7:20 am. The night shift as just getting ready to clock out. The captain spoke a little English. I explained that I had just arrived from Antarctica on a yacht and that yesterday I had been told to come back because the visas were dated. 'Antarctica,' he mused, 'Show me the papers.' He looked at the clearance manifest from South Georgia to Santos. 'It's no problem,' he said and promptly made out and stamped the form I needed for the Port Captain's office. I grabbed it, thanked him and scooted away before my nemesis showed up at 8 am. But they got me in the end, as you will learn.

"I completed the clearing-in procedures, got my beard trimmed and returned to the club. David, Bob and Sue had done the shopping and loaded the food aboard *Fiona*. One of the uncooperative policemen from the dingy office was standing on the dock watching, but he said nothing. For the next couple of days we did boat maintenance in the mornings and explored the region in the afternoons. I was lucky enough to run into a Brazilian yachtsman who spoke good English, called Dancini. He helped me get repairs done that required local experts. He took the jib furler to a rigger and came back a few days later with it rebuilt. David took the bus for a long weekend in Rio de Janeiro. One evening on the way to the boat from supper I noticed a circus had pitched its tent in a large lot. The show was due to start in twenty minutes so I treated myself to a night at the Circus Stangowich, which had one ring, two clowns, some dancing horses and a rather moth-eaten camel. The children loved it. On Sunday afternoon I walked over to the beautiful beach on the seaward side of Santos in a very upmarket area called Gonzaga. The seafront consisted of a park behind the beach and then a wide boulevard in front of tall apartment blocks. In the park local artists exhibited their pictures. One showed an Arabian scene with camels. I bought it as a reminder of my night at the circus. Soon it was time to go. David returned from Rio, suitably exhausted and Sue flew home. On our last evening, Dancini took us to a small factory belonging to a friend of his that made surfboards. David knew a bargain when he saw one and bought a nine-foot plus board on the spot. I steeled myself and went into Santos to repeat the clearance procedure so that we could leave. Unfortunately, my cooperative captain was not on duty at the Federal Police office and my documents were heavily annotated to state the crew must not leave the boat in Brazil, thus making sure I had problems in the future at other ports.



The old Portuguese fort guards the entrance to Santos harbor. It was once attacked by Francis Drake.

"Our first stop was the beautiful cruising area near Ihla Grande. It took us a little over a day to get there under power. We anchored in a pretty bay with a bar on the beach and cooked some Brazilian sausages after a few beers at the bar. Dancini had given me a cruising guide to the Brazilian coast that mentioned another anchorage not far away with access to beach on the seaward side with good surfing. Naturally, David had to try his new toy and so the next day that is where we went. We took a jungle path over a hill and emerged on the beach that had huge waves rolling in. After a while Bob and I walked back to a small restaurant and had a few beers while we absorbed the local color. Rio was only about 60 miles away, and several ferries had disgorged a bevy of Bikini-clad beauties who frolicked in the water. It was all quite a change from our ocean cruising regimen. During the night it poured, the first rain we had seen in a while The next morning we powered over to a charming fishing village and anchored. There were no vehicles in the village. We tried to do e-mail without much success and after lunch left for the long haul north. Dancini's guide mentioned that the coast in this region is notoriously windless, as we found out. After using the engine for two days, I decided to refuel at a city a couple of hundred miles up the coast from Rio called Vitoria. The guide mentioned that the fuel dock at the local yacht club was quite shallow. I wanted to sneak in and refuel without attracting the attention of the Port Captain who might look askance at our clearance papers from Santos. Fortunately, as we got close we found a Swedish cruising yacht anchored near the club who was also refueling by using his dinghy to transport jerry jugs. The captain very kindly offered to take me in, and while Bob and David circled outside I went in with the Swede and sounded out the depths. We could just fit. I went back to the boat and we cautiously crept up to the fuel dock with only one minor bump from the keel on a launching ramp, and tied up.

"Within 20 minutes we had a full load of diesel and we were away. It took us eight days from Vitoria to make the leg of slightly over a thousand miles to Cabedelo, located at Cabo Branco, the easternmost tip of the South American continent. Although we were well inside the region of southeast trade winds, they did not materialize and we sailed with light winds or powered in the calm spells. On the way we celebrated my 39th birthday, again!

"We arrived a couple of hours after nightfall on Good Friday. Our guide recommended anchoring just south of the main wharf if arriving at night and proceeding up the Paraiba River to the yachtie hangout in Jacare in daylight. We anchored in the designated spot and were just enjoying a well-earned rum and apple juice when a huge car ferry emerged out of the gloom and passed us with a few feet to spare, the captain hooting his displeasure as he left us rocking in his wake. It seemed like a good idea to move a half-mile further down the river. Later we discovered the ferry service had been instituted since the guide was published. In the morning we negotiated the river sandbars and dropped anchor near several other yachts at a marina run by an expat Englishman called Brian that is famous in cruising circles. One reason it is famous is that the local officials are fairly relaxed. Considering it was a holiday weekend I decided it would be unkind to burden them with extra paperwork so we did not check in at all. The day after Easter Monday we quietly glided down the river and left for the offshore island of Fernando de Noronha. Talk about a small world; while were at Jacare we had a cup of coffee on an American yacht belonging to a single-hander called Alec. He mulled over the name *Fiona* and said it rang a bell. Finally we discovered he had known Barbara and John Knight in St. Johns for years. You may recall Edith and I made our first transatlantic crossing as crew for John aboard *Arvin Court II*. Just south of Brian's marina are a number of bars and restaurants that are very popular with the locals. This holiday weekend they were very busy; the whole area throbbed with Brazilian music. One evening there was a dance with live bands that changed every hour as they exhausted themselves, such as the energy they put into it. On the way to the dance floor you are frisked for weapons. Ah, Brazil!

"Fernando de Noronha had a special significance for us. We left this island on August 13th, 2002 for Cape Town, thus we completed a circumnavigation, albeit in the southern hemisphere, when we returned on April 24th, 2003. There were two other yachts at anchor. We invited the crews over for a party to celebrate the evening after we arrived. The captain of one boat, a Swiss, brought over an imaginatively decorated bottle of champagne titled 'The Jules Verne Trophy - Round the World in Eight Months.' Later we all adjourned to Elda's restaurant overlooking the harbor for supper. Most of the die-hards then went on to a dance in the village, but I must confess I took the dinghy back to *Fiona* and fell fast asleep. We did a little maintenance and boat clean-up, and on two afternoons David surfed with his new board. We left after three days for the final leg with the original crew across the equator to Barbados. Bob has been poring over the logbook and come up with some interesting statistics of the 'mini' circumnavigation. A complete circumnavigation will not be officially completed until we cross the equator again a couple of hundred miles north of Fernando de Noronha. Here are a few facts:

Days at sea: 184
Days in port: 72
Total days: 256
Total mileage logged: 21,828
Average: 119 nm/day
Number of times mainsail was reefed: 54
Number of staysail was reefed: 4
Number of times spitfire jib rigged: 4
Total time under power: 492 hr (20.5 days). max continuous run: 62 hr.

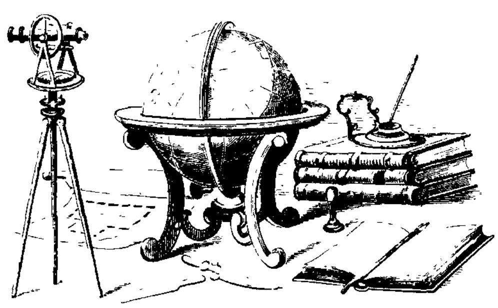
Total fuel added, Diesel: 495 gal.
Propane: 86 lbs
Lowest pressure recorded: 981 mbar. (Feb. 7th, 2003)
Number of times we replaced steering lines on the Aries: 15
Number of ships logged: approx 78
Number of icebergs logged: 127
Number of icebergs hit: 1

"I should make a comment on the total miles logged. This is only an approximation to the true distance. Errors arise because of the calibration of the instrument itself and because we often did not sail the direct course due to tacking or bearing away on a reach. Motion due to ocean currents, towards or against the boat's course does not record on the log. For the comparison, our track for the circumnavigation measure on a chart is 21,030 nm in length.

"The leg to Barbados had two distinct parts. The first, from Fernando de Noronha to about 3 degrees N, was across the equator in a region known as the Doldroms. The wind was fickle and light, the current was often against us and there were frequent squalls, some with strong wind gusts and heavy rain. This was frustrating sailing. Then we ran into the northeast trade winds; they were steady and strong. We tied two reefs in the mainsail and flew. Victor the Vane handled the steering as we made tremendous time to the island. The speed over the bottom shown on the GPS was often over 8 knots due to the boost from the Brazilian Equatorial Current. We sailed the last thousand miles in six days; great sailing for an old cruising boat. We arrived at 11 pm local time and anchored in Carlisle Bay, Bridgetown. We cleared customs and immigration in the morning, hassle-free compared to Brazil. As we stepped ashore, David spotted his father, who had flown in the day before. Bob and David are leaving *Fiona* in Barbados after completing their southern ocean circumnavigation. I plan to fly home for a couple of weeks and then have a leisurely cruise in the Caribbean with a new crew. Since leaving New York last June we have logged 29,549 nautical miles."

—*Best wishes until next time, Eric*

Editor's Note; Newsletter 4 is expected to be posted on the web in late September, 2003. (www.yachtfiona.com).



NAVIGATION NOTES

Position from Observation of a Single Body

By James N. Wilson

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ABSTRACT

A fundamental method of calculating the time difference between meridian transit and when a body is at its highest altitude allows direct correction for the effects of vessel velocity and rate of declination change. A novel graphical procedure for determining the time of highest altitude results in a simple way to obtain a fix from observations near meridian passage. Calculators or computers are not needed in the method. An example demonstrates the practical merit of the approach. Derivation of the equations is presented, and observational error sensitivity is discussed.

INTRODUCTION

To determine longitude from observations of a single body near meridian transit, the double altitude approach has been proposed, where the times for equal altitudes before and after meridian passage are averaged.[1] Several years ago, this author tried this method on trips to Catalina. From a known mid-channel position, longitudes were consistently calculated on the opposite side of the island! Analysis showed that boat speed was responsible — Reference 1 notes, "For a stationary observer . . . ," and "If there has been no change in declination . . . ." Further, on finding the time of meridian transit,[2] "This method is not reliable if there is a large northerly or southerly component of the vessel's motion, because the altitude at meridian transit changes slowly, particularly at low altitudes. At this time the change due to the vessel's motion may be considerably greater than that due to apparent motion of the body (rotation of the earth), so that the highest altitude occurs several minutes before or after meridian transit."

Figure 1 is a plot of altitude vs time, illustrating that north-south vessel motion produces a time of highest altitude different from that of a fixed observer. Declination rate of change has a similar effect on time of highest altitude, and may be dominant for the moon. East-west motion of the vessel has a much smaller effect, since vessel speed is significantly slower than the rate of change of Greenwich Hour Angle (GHA). Since the body is not on the observer's meridian at the time of highest altitude, and the latitude then is different from that at meridian passage, an error in altitude (Δh) results, but this is negligible for usual boat speeds and common latitudes.

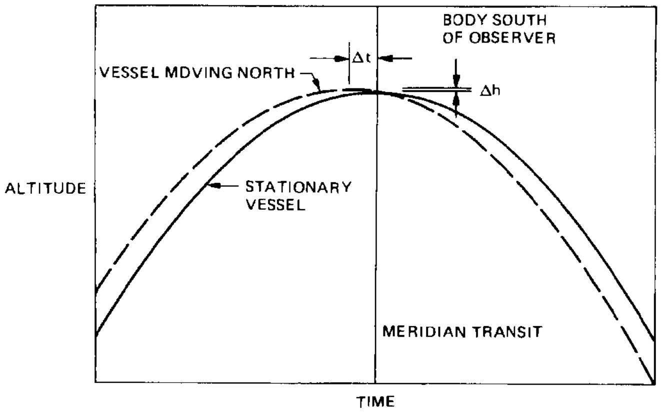


Fig. 1 — Altitude vs Time

AN APPROACH

Thus, the time of highest altitude is different from the time of meridian transit. In using the double altitude method, this difference is independent of how long before meridian passage the initial altitude is measured, because it is due solely to vessel velocity and rate of declination change. A correction can be applied to the calculated time of meridian transit, or to the time average of equal altitudes. Presuming constant speed and course, a quite accurate calculation for the sun can be made by using the following equations (derivation of the equations and application to other bodies is explained in Appendix I):

LAN = time of highest altitude + Δt

$$\Delta t = \frac{48}{\pi}\ (Sn - d)\ \ (\tan Lat - \tan Dec)$$

Where: LAN = Local Apparent Noon
Δt = correction, seconds
Sn = northward component of vessel motion, knots
d = hourly change of declination, '(+ if Dec is changing northerly)
Dec = declination (+ if north)
Lat = latitude (+ if north)

The Catalina example at a dead reckoning (DR) Latitude of 34°N, Dec 10°S, *d* = 0.9', Sn =-5.2 knots corresponds to a Δt of -1m19s. This translates into a longitude error of 20'W, or a 17 mile westerly error — quite close to that observed. Appendix II shows examples of Δts and Δhs for various conditions.

The equation for the calculation of the correction Δt has been plotted in Figure 2. Entering with Lat and Dec, paying attention to whether they are in the same hemisphere or the opposite one, a value of K can be selected. Read K only to the nearest whole unit; interpolation isn't warranted for usual small boat speeds. Multiply K by (Sn - *d*), keeping track of signs, and Δt results. Add it algebraically to the time of highest altitude to obtain LAN. Note that *d* may have a different sign from that used for declination calculation. For latitudes in the southern hemisphere, reverse the sign of K.

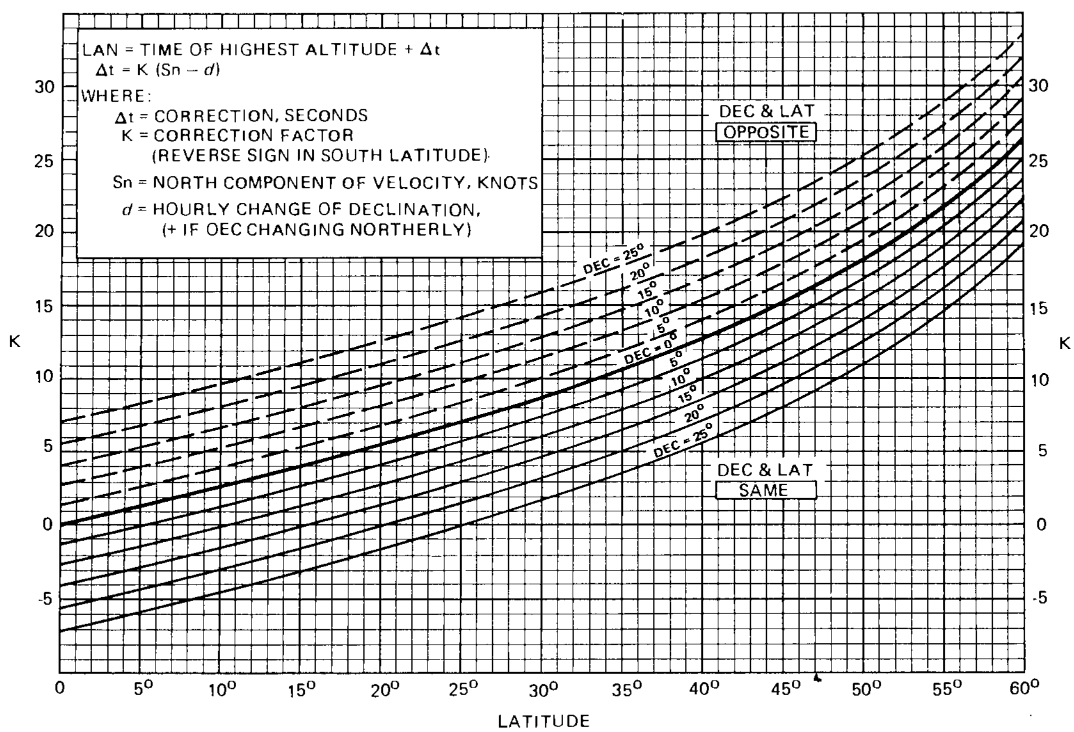


Figure 2 — Correction Factor for Time of Sun's Meridian Passage

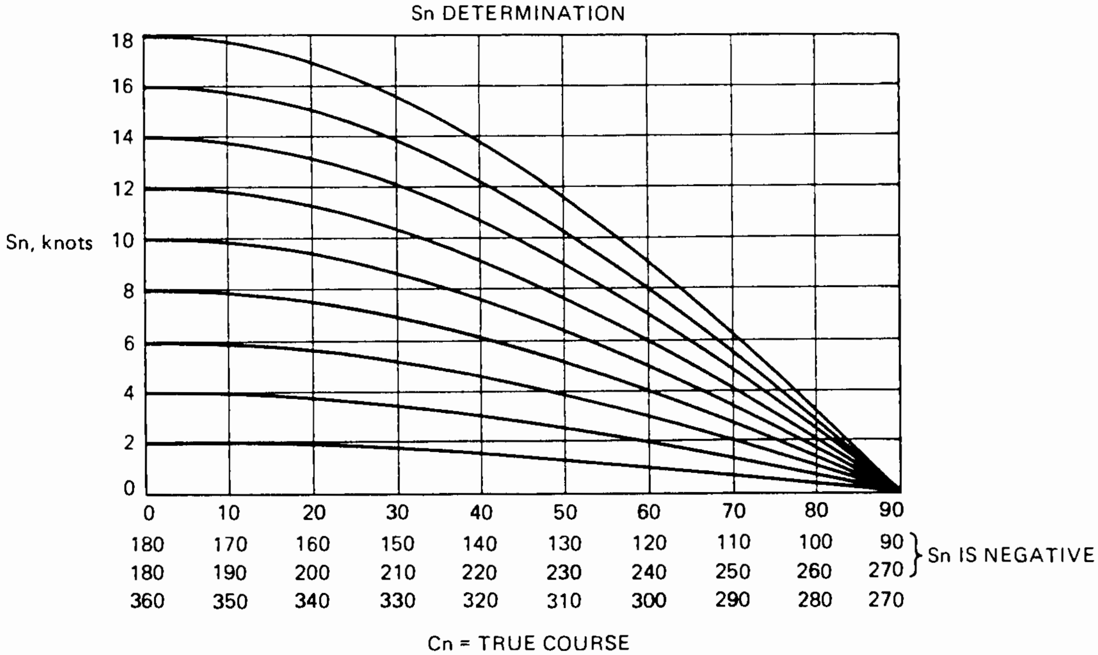


Fig. 3 — Sn Determination

Figure 3 is a plot to aid in the calculation of Sn. Enter with S and true course (Cn), and read Sn. Note that Sn is negative for Cn between 90° and 270°.

ERROR SENSITIVITY

For normal sights, an observational error translates directly into a position error, so a 1' error in sextant altitude (hs) results in a 1 mile error in the line of position. However, in attempting to determine longitude by double altitudes, any observer error is significantly magnified. Appendix III shows examples of Δt errors for a 1. hs error ranging from 11 seconds to more than 3 minutes.

One way to minimize this error is to take the first sights 20 or 30 minutes before meridian transit, but longitude errors are still 2 to 10 times the hs error. Another way is to plot hs vs watch time (WT) and fair a straight line between the plotted points, to select the best hs. A further advantage of plotting hs is that the initial hs reading does not have to be exactly duplicated after meridian passage. A significant compensation for the work involved in plotting is that systematic errors or biases cancel.

THE METHOD

The following method was derived to obtain a reasonably accurate fix from a series of sights near meridian transit, presuming course and speed are constant.

1. About 20 or 30 minutes before meridian passage, record a run of five or more sights. Plot hs vs WT while waiting for the body to approach maximum altitude; Figure 4 shows such plot.
2. Record enough sights near meridian transit to be sure that the body has attained and passed maximum altitude, and that meridian transit has occurred. Plot these on a compressed WT scale, so that the body's altitude arc can be faired through the normal hs scatter. This is used for latitude determination.
3. When hs has decreased to the highest value of the first run, record another run of at least five sights.

Now, a helpful trick — on the same plot, create a second WT scale directly under the first one. To facilitate averaging, start it an even number of minutes later than the first scale. Plot the last run of sights using this scale (Use a different symbol for plotting this run, to avoid confusion with points from the first run.) Straight lines faired through each of the two sets of points will intersect at a pair of times when altitudes before and after meridian transit are equal. The average time from the two scales is the time of highest altitude. Another trick — average only the hours and minutes just before the time of the intersection, then read the seconds directly underneath it.

Then determine the Δt correction from the equation, or obtain K from Figure 2 and multiple by (Sn - *d*), paying proper attention to signs. Apply this correction to the time of highest altitude to obtain the time of meridian transit, after which latitude and longitude can be calculated.

AN EXAMPLE

The following example illustrates the procedure for obtaining both latitude and longitude from a series of sun sights near LAN.

December 30, 1982

Known position at LAN Lat 33°40.0'N

Lo 118°16.6'W

LAN computation:

Lo	118°16.6'W	
GHA sun at 1900 GMT	104°21.0'	
	13°55.6'	= 55m42s
GMT	19-55-42	
ZD	+8	(rev)
ZT	11-55-42	LAN

The following data was recorded, Sun LL:
Course 210° Speed 6.0 Knots WE = 0-00
IC = +1.5' Dip = -2.4'

WT	hs	WT	hs	WT	hs
11-28-21	32°34-0'	11-50-39	32°55.1'	12-19-54	32°42.6'
28-59	35.5'	51-41	56.1'	21-10	41.2'
30-00	34.0'	52-21	56.2'	22-51	37.6'
30-44	36.9'	53-31	58.5'	23-47	36.6'
31-24	38.5'	54-30	56.9'	24-50	35.0'
32-06	37.5'	55-04	57.5'	26-01	33.9'
32-42	40.3'	56-16	57.5'		
33-12	40.3'	56-52	57.6'		
		57-42	57.6'		
		58-42	59.9'		
		59-20	57.5'		
		12-00-58	55.1'		

After the first run of sights, plot hs vs WT. (Suggested scale: WT; ¼" = 10 sec, hs; ¼" = 1'.) Start plot at 11-28-00; fair a straight line through the points (see Figure 4, line 1).

After the second run, plot hs, compressing the WT scale to ¼" = 1 min. The hs scale may have to be broken (as in Figure 4) to get this run on the page. Fair a curve through these points (see curve 2).

After the third run of sights, establish the second WT scale, starting at 12-20-00 (an even number of minutes after 11-28). Plot the third run, again fairing a straight line through the points (see line 3). Average 11-31 and 12-23 to get 11-57, and read the time of equal hs below the intersection of the two lines as 11-57-09. This is the time of highest altitude.

Finally, perform the calculations: *(See Figure 4 at botom page.)*

1. Determination of time correction
   Lat ≅ 33°40'N
   Dec ≅ 23°10'S (Lat and Dec OPPOSITE)

From Figure 2:
K = 17. From Figure 3: for S = 6.0 and C_n = 210°
Sn = -5.2 knots
d = +0.2' (Dec changing northerly)
Sn - d = -5.2 - 0.2 = -5.4'/hr
Correction = K (Sn - d) = 17 (-5.4) = -92s
= - 1m32s (-87 seconds from t equation)

2. Longitude determination
   From Figure 4:

Time of highest altitude =	11-57-09	
WE =	0-00	
Correction =	(-) 1-32	
ZT =	11-55-37	
ZD =	+8	
GMT =	19-55-37	LAN

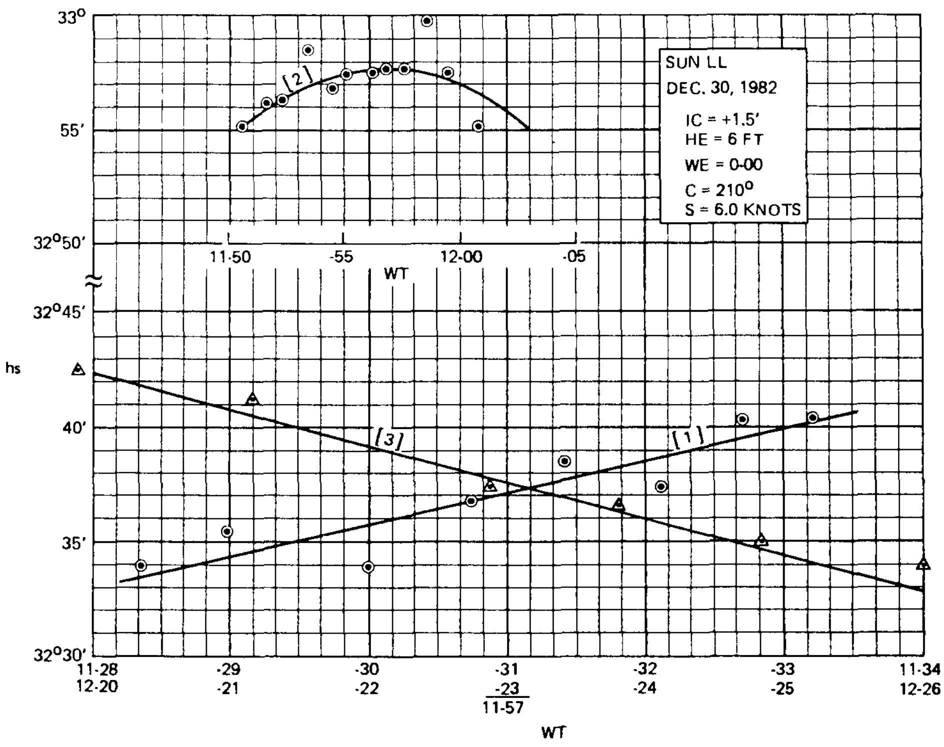


Fig. 4—Plot of Illustrative Example

GHA sun at 1900 GMT =	104°21.0'
55-37	13°54.3'
Longitude =	118°15.3'W
DR Longitude =	118°16.6'W
Difference =	1.3'

3. Latitude determination

Dec at 1900 GMT =		23°09.1'S
d = -0.2'	55m	-0.2'
Dec =		23°08.9'S

From figure 4:

hs at LAN =	32°57.5'
IC =	+1.5'
Dip =	-2.4
ha =	32°56.6'
Correction =	+14.8'
Ho =	33°11.4'
90 - Ho =	56°48.6'
Dec =	23°08.9'S
Lat =	33°39.7'N
DR Lat =	33°40.0'N
Difference =	0.3'

DISCUSSION

The data for the example were taken while singlehanding a 31' ketch on a clear day with a sharp horizon and a calm sea. The sun's altitude was low, and its rate of change was slow. These observations were the first taken by the author in over two years, adding to the data scatter. Subsequent use of the method under significantly worse observation conditions has resulted in longitude errors of less than 5'.

The time correction equation was derived assuming constant heading and speed throughout the sight taking period. Maintaining constant heading is usually achievable, but where maintaining constant speed is not possible, using the average speed introduces only very small errors. For example, where Sn decreases linearly from 9.0 knots to 3.0 knots in 40 minutes, using the average speed of 6.0 knots introduces only a 2 second error in time of meridian transit.

While the practicality has been demonstrated, there are some drawbacks. The method requires that the sights be taken at a specific time, and this is not always convenient or possible. If overcast conditions threaten to restrict continual visibility of the body during the sight taking period, the first run of sights should be started earlier, to insure that they will encompass some portion of the last run. In extreme cases, the faired line from one of the runs can be extended as necessary to determine the time of highest altitude. Useful celestial bodies are probably limited to the sun and the moon, since twilight duration restricts the time before the after meridian passage when observations of stars and planets can be made. As noted in Appendix I, 7% should be added to the K value from Figure 2 for the moon.

To better predict the time of highest altitude, the time correction can be computed prior to taking sights. Sights should not be taken too rapidly, since several minutes should elapse dring each run to enhance the ability to plot the altitudes. Note that the hs value used for latitude determination is that at the time of meridian transit, and not at the time of highest altitude. This results in a true fix, in that both latitude and longitude are determined at the same time, and also eliminates the small latitude error.

CONCLUSION

This example (and others) are evidence that the method is an effective way to obtain a fix from observations of the sun near meridian transit. Since plotting runs of sights is always recommended, no extra work is involved there, and the few computations are significantly less than reducing a pair of sights and plotting them to get a fix. (Some form of regression or least squares method could be used to determine the time of highest altitude,[3] but this places reliance on a calculator, thus disqualifying the method as a backup navigation system.)

Thus, if the satellite navigation receiver is out, the calculator is a carcass, and the sight reduction tables are moldy from disuse, this method will still allow the navigator to do his job. And for those who don't own any sophisticated equipment, it is simple enough to be used as a primary method.

REFERENCES

1. Bowditch, N., *American Practical Navigator*, Vol. 1, 1977 Edition, Defense Mapping Agency Hydrographic Center, Article 2114, "Double Altitudes," page 589.
2. Bowditch, N,. *American Practical Navigator*, Vol. 2, 1981 Edition, Defense Mapping Agency Hydrographic Center, Article 733, "Finding Time of Meridian Transit," page 540.
3. Rogoff, M., *Calculator Navigation*, W. W. Norton & Co., 1979, pages 243-250.

APPENDIX I

DERIVATION OF THE EQUATIONS

Differentiating the basic altitude equation,

sin Hc = sin Lat sin Dec + cos Lat cos Dec cos LHA

yields,

$$\text{Cos Hc}\,\frac{dHc}{dt} = \text{sin Lat cos Dec}\,\frac{dDec}{dt} + \text{cos Lat sin Dec}\,\frac{dLat}{dt} - \text{cos Lat cos Dec sin LHA}\,\frac{dLHA}{dt} - \text{cos Lat sin Dec cos LHA}\,\frac{dDec}{dt} - \text{sin Lat cos Dec cos LHA}\,\frac{dLAT}{dt}$$

For small LHA, cos LHA = 1 and sin LHA = $\pi\,\frac{LHA}{180}$

Substituting and combining:

$$\cos Hc \frac{dHc}{dt} = \left[\left(\frac{dDec}{dt} - \frac{dLat}{dt}\right)(\tan Lat - \tan Dec) - \pi \frac{LHA}{180}\frac{dLHA}{dt}\right] \cos Lat \cos Dec$$

At maximum altitude, $\frac{dHc}{dt} = 0$

$$\text{So: } LHA = \frac{180}{\pi}\left(\frac{dDec}{dt} - \frac{dLat}{dt}\right)\frac{(\tan Lat - \tan Dec)}{dLHA/dt}$$

If Meridian Transit = Time of highest altitude + Δt

Then: Δt = correction in seconds,

And: $\frac{dLHA}{dt}\frac{\Delta t}{3600} = -LHA$

$$\text{So: } \Delta t = \frac{648{,}000}{\pi}\left(\frac{dLat}{dt} - \frac{dDec}{dt}\right)\frac{(\tan Lat - \tan Dec)}{(dLHA/dt)^2}$$

Let: $\frac{dLat}{dt}$ = north component of velocity = $\frac{Sn}{60}$
(Sn = north speed in Knots)

$\frac{dDec}{dt}$ = hourly change in declination = $\frac{d}{60}$
(d in', + if Dec is changing northerly)

$\frac{dLHA}{dt}$ = hourly change in LHA = ΔLHA

$\Delta LHA = \Delta GHA - \Delta Lo$

Δ GHA = hourly change in GHA, degrees

Δ Lo = hourly change in longitude, degrees
(+ if vessel is moving west)

$$\text{Then: } \Delta t = \frac{10{,}800}{\pi(\Delta LHA)^2}(Sn - d)(\tan Lat - \tan Dec)$$

Some examples for various bodies, assuming $\Delta Lo = 0$:

BODY	ΔGHA	$\frac{10{,}800}{(\Delta LHA)^2}$	Δ%	
Sun	15°	48		
Planets	15° + v	47.89	-0.3	(v = 1.0')
Stars	15°02.5'	47.73	-0.6	
Moon	14°19' + v	52.07	+8.5	(v = 5.1')
		50.74	+5.7	(v = 16.4')

Considering observational errors, the sun's value of K from Figure 2 can be used for all but the moon. For the moon, adding 7% to the sun's K value results in errors of only a few seconds.

APPENDIX II

SOME EXAMPLES OF Δt AND Δh FOR VARIOUS CONDITIONS:

1. Sun

			Sn = 0		Sn = 6 knots		Sn = 20 knots	
Lat	Dec	d	Δt	Δh	Δt	Δh	Δt	Δh
34°N	23°S	0	0	0	1m41s	+5"	5m36s	+56"
34°N	0	-1.0'	10s	0	1m12s	+4"	3m36s	+38"
34°N	23°N	0	0	0	23s	+1"	1m16s	+12"
52°N	0	-1.0'	20s	0	2m17s	+8"	6m51s	+1.12"
52°N	23°S	0	0	0	2m36s	+8"	8m41s	+1.27"
82°N	7°N	-0.9'	1m36s	+1"	12m17s	+42"	37m13s	+6'19"

2. Moon

Sn = 0

Lat	Dec	d	Δt	Δh
34°N	7°S	-14.8'	3m13s	+24"

APPENDIX III

Δt ERRORS RESULTING FROM A 1'. ERROR IN hs

Lat 34°N	Sn = 0		
Time of first sight, minutes before meridian transit	Declination		
	23°S	0	23°N
		d = 1.0'	
5	3m20s	2m	46s
10	1m40s	1m	23s
15	1m07s	41s	15s
20	50s	31s	11s

JOHN M. LUYKX

It goes without saying that we are still reeling in shock from the unexpected and most untimely passing of John Luykx, who was Gladys Siegel's dearest friend, coworker and business partner for over thirty years. All who knew John had a deep respect for his manifold talents, extensive language skills, broad literary knowledge and exceptional navigational expertise. Throughout his Navy and business careers he was a well respected teacher, writer and lecturer. But even more importantly, John was a gentleman in the fullest meaning and honor of the word. He was a true Renaissance man.

His influence went far beyond St. Mary's County and those that knew him professionally will be working with Gladys to set up a Living Legacy in John's name and honoring him with an area in The Houston Maritime Museum. The area within the navigational museum will both bear his name and display his extensive navigational collection. A memorial fund is being established in John's name for both the navigational display within the museum, as well as a fund to provide classes for future students to learn more about seamanship, navigation and the nautical instruments that were such a love in John's life.

In lieu of flowers or contributions to non-profit organizations, anyone wishing to honor John's memory may make a donation to: The John M. Luykx Memorial Fund–The Houston Maritime Museum, 23204 Dorrington, Houston, TX 77030.

For those wishing to send a card to Gladys, her address is: Gladys Siegel, P.O. Box 95, St. Mary's City, MD 20686.

John was buried in Arlington National Cemetery September 9th.

From the obituary for Navigation Foundation Director John M. Luykx which was written by the owner of the Maryland Antiques Center on behalf of Gladys Siegel.

CORRECTION

Lunar Distances - A Simple and Concise Solution

By G. G. Bennett

Errors in the printing of the above article in issue seventy-nine (Spring 2003) of *The Navigator's Newsletter* are as follows:

Page 4

LH Column	
From top, line 3	His, not italics
From bottom, line 7	New para after "interest"
Last line	New para after "1965"
RH Column	
From top, line 25	New para after "etc"

Page 6

LH Column	
From top, line 6	New para after hs'
From top, line 14	No break after "used"
RH Column	
From * top, line 3	Not 2° but 22° etc
From * top, line 16	The three asterisks should be on the next line. They are a reference to Parallax etc
From top*, lines 19 & 21	P' not P in both cases

Page 7

LH Column	
From * top, line 29	missing minus sign after 90°
Last line	missing "be" after "can"

Page 8

LH Column	
From top, line 11	For $AGHA_1$ put ΔGHA_1
From top, line 16	The value for SUM is displaced

Page 8

LH Column	Paragraph headed by "Calculation of Watch Error" Vertical registration is erratic
From * bottom, lines * 8 & 10	For 29.5 read 30.5 (Author's mistake)
RH Column	
From bottom, line 17	For resulting put result
* Middle of Column	For 68°33.2' put 110.°26.8'

*The errors above marked with an asterisk might have caused a problem to the reader.

Editor's note: The author asked me to apologize to the readers on his behalf as to the quality of the data that was used to illustrate the corrections and lunar distance calculations. The source of the data was from a student exercise.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

As reported by the Institute of Navigation:

The following communities could be impacted by changes to the UTC Timescale by approaches to reduce or eliminate the operational impact of the leap second:

International Timekeeping,
Navigation, Earth Rotation,
Telecommunications and
Internet Timing

// THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY-ONE, FALL 2003

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

In Issue #78, Winter 2002-2003 of The Navigator's Newsletter, there is an incomplete E-mail address for the Online Almanac. The entire E-mail address is:

http://www.tecepe.com.br/nav/almanac.htm. This site does the celestial navigation solution for you.

Another good site is the U.S. Naval Observatory at: http://aa.usno.navy.mil. There is a little bit of everything but one of particular interest is "Data."

An expanded site is the National Ocean Service's "Nautical Charts Updates." The new "Nautical Charts Updates' website allows the mariner to update their nautical charts from one database that includes information from NOS, the NIMA Notice to mariners, the Coast Guard Local Notice to Mariners and the Canadian Coast Guard Notice to Mariners. To access this website go to: http://chartmaker.ncd.noaa.gov and click on Chart Updates." Chart Corrections can be also found on the site. An alternate site for Chart Corrections is http://www.maptech.com.

More Navigation Internet Sites:

Light List Corrections: http://pollux.nss.nima.mil/pubs/USCGLL/pubs

Coast Pilot Corrections: HTTP://CRITCORR.NCD.NOAA.GOV

Weather: http://intellicast.com/

Hurricane Isabel did considerable damage to the Washington, D.C. area. Electrical power was lost to almost everyone in the area and it took the local electric companies over 5 days to restore the power. Personally, my family was fortunate. Last winter we installed an automatic, natural gas powered electric generator. We travel in the winter and feared ice storms breaking the large tree limbs close to the power lines. Frozen and broken water lines was a scene when we returned.

I checked some of the marinas in the Baltimore area. The ones with floating dock slips had no problems and no damage. Those with fixed piers had some boats damaged. Our marina docks floated up over 8 feet. Three more feet and the docks would have been over the pilings.

The United States Naval Academy at Annapolis, Maryland suffered about $50 million in damages from flooding. The previous flooding was in 1933.

READERS FORUM

Edited by Ernest Brown

Member Wesley Jones wrote on September 29, 2003:

"I'm trying to decide between finding a used sextant and buying a new Astra IIIB. I don't want to pay more than a IIIB would cost since at this point shooting sights will be for fun instead of necessity — since I can buy several GPS's for the cost of a IIIB — but I wonder about the quality of the IIIB. I used a David White navy issue sextant while in the service and as far as I could tell it was a good instrument. I'm sure that I could get a much better used sextant than the IIIB for about the same money if I knew where to go. I don't want to buy one that I'm going to have to turn around and spend a lot of money on to get the mirrors re-silvered and to correct alignment problems from rough handling, so it seems that it would be ideal to buy one from an instrument shop that would

DO YOU KNOW . . . ?

By Ernest Brown

The pending name change for N.I.M.A.?

(Answer at back of this issue)

have already re-conditioned the instrument and would stand behind the sale for a while. (Bacon's in Annapolis has a number of sextants but they've just been turned in on consignment). Do you have any suggestions/advice in this regard? What's your impression of the IIIB quality? I plan to do some offshore sailing beginning next spring." — *Thank you. Wesley Jones*

Director Roger Jones responded:

"Terry Carraway has forwarded your e-mail message to me regarding your interest in acquiring a sextant. I am not up to date on the cost of the Astra IIIB, so I cannot offer much in the way of guidance in the dollars arena. However, I would offer the following observations to you:

"1. You comment that you plan to do some offshore sailing next spring. Bravo! As one who has many thousands of ocean miles in his wake, and as one who has, of course, used GPS and practically every other electronic means of navigation (in both boats and airplanes), I would still urge you and all sailors not to go offshore relying solely on electronics. I still carry a sextant (Tamaya Spica that is 30+ years old), and I still insist on having paper charts to back up any electronic charts aboard. Electronic devices can and do fail, especially in a constant environment of high humidity and salt air. If your vessel is going to be constantly air-conditioned, as would be the case of a navy vessel, that is another matter. So I urge you to adopt a mindset that your well-being and that of your vessel should never depend solely on one means of navigation, and certainly not only on electronic means. There is no substitute for excellent dead reckoning skill, and one of the problems of the GPS age is that so many people relay on it without the essential skill in 'time, speed and distance' coupled with a good compass, and coupled with the ability to do a vector diagram based upon known set and drift values. So I APPLAUD YOUR DESIRE TO GET A SEXTANT.

"2. You are quite right to be interested in the quality of the sextant and especially in the size, alignment, and reflective condition of the mirrors. Some general comments here. If your budget can afford it, get the best metal sextant you can find. I have used plastic and composite material sextants, but the problem is that they are notoriously susceptible to temperature and other atmospheric changes, and these changes affect the alignment and adjustment of the mirrors. A good quality metal sextant is made up of metal components with varying coefficients of expansion and contraction, that are designed to minimize the effect of atmospheric changes on mirror adjustment. I haven't adjusted the mirrors on my sextant in over 15 years, and I've had it in the tropics as well as the more temperate zones and even on occasion in colder climates.

"3. I have at times in the past visited Bacon's, but not in quite some time. My impression was that it was a respectable firm. I am sure they have some very good used sextants. What may be very hard to determine, however, is whether any particular one has ever been dropped or otherwise subjected to hard 'knocks.' A good sextant will absorb a lot of abuse, and dropping one on a sand beach is a far cry from dropping it on a hard deck. And, initial impact upon its arc is different from initial impact upon its mirror frames or micrometer drum. I would be interested to know what if any guarantee they offer on any sextant they have reconditioned. If they have simply re-silvered the mirrors, that is a matter that should be of minimal concern. If they have worked on straightening any rigid component, I'd be very skeptical.

"4. The size of the mirrors can be important. Try to avoid even a good metal one that has the smaller mirrors. Any good quality sextant made during the last thirty or forty years should have the larger mirrors. And by all means, get a micrometer drum sextant, not the older vernier type.

"5. Don't necessarily be put off by an older style sextant whose optics contain the split field of view. I actually prefer this to the newer totally open field of view, because that vertical boundary between the open field of view and the 'dark' area permits a very rapid means of determining if you are holding the sextant vertical to the horizon. I have worked with both types, and outstanding results can be obtained using both, however.

"6. As a general proposition, I'd suggest you seriously consider a new or newer sextant, and the Astra IIIB may be your logical choice in that regard. A sextant is something that you should approach with the mindset that you will give yourself the gift of the very best one you can afford. I would say this applies even more so in the matter of a sextant than it would in the case of a fine automobile or even a fine watch, because it is a very specialized piece of equipment that will last your lifetime and possibly that of your successors, unlike most other fine pieces of 'machinery.'

"7. You'll also want a very good means of determining accurate time — to the second. In this day and age that is simple: get a reliable atomic chronometer, and since you say you will also have GPS aboard, it will include an excellent internal chronometer. It is not 'cheating' to use the sextant in conjunction with the GPS's atomic clock. But you can also use a good wrist watch of this type. However, many of the ones on the market today are designed to be used only within about 2,000 miles of the time source in Colorado, so that may not be the answer if you are several thousand miles to the east or west of a U.S. coast line. I have also used a good spring wound chronometer with a known "rate" and you can get very good results for appreciable periods of time since the last 'rating' of the time piece. And, it is, of course, possible to 'recapture' usable time using your sextant and information as to your exact position in conjunction with the Almanac, etc.

"If you'll send to me any brochure you have on the Astra IIIB, I'll be happy to comment on it. Lastly, I don't know where you are in terms of your understanding of celestial theory and practice but I may be able to help you there. Some years ago, I wrote, in layman's terms, a 'text' on the celestial art which was published by the Navigation Foundation, and which is also available today from the Seven Seas Cruising Association (SSCA) of which I am also currently a board member. 'Celestial Navigation — An Armchair perspective,' is a 'boiling down' of the usual 250 or 300 pages of celestial text into just 21 pages of text proper, which are accompanied by about 29 additional page of illustration, step-by-step procedures, sample pages from the Almanac and the Sight Reduction Tables, and an illustrative problem. Those 21 pages of 'text' deal with the complete celestial theory, and I am told by people who have used this monograph that they found it very easy to understand. You can obtain a copy of this from the Navigation Foundation, but be sure to ask for the one that I revised in September of 2001. Or, if you like, I'd be happy to send a copy to you, and then communicate with you via e-mail or phone if you have questions.

"The bottom line: Get the best metal sextant you can afford. Obtain a good atomic clock means of determining time anywhere in the world. And in your choice of sight reduction methods: I'd earnestly suggest you consider using H.O. 249, the tables originally developed for air navigation, as opposed to H.O. 229, which are the 'modern' tables primarily for maritime use.

The aviation tables are easier to use, and for your purposes on a small boat will provide results that are really just as good as those you'd get using H.O. 229. You can, of course, get hand-held navigation computers to do all the sight reduction for you, but again, don't rely solely on electronics. And, once you understand what you are doing, the actual work to 'reduce' a sight to a useful line of position can consume as little as six or seven minutes of your time if you work with a logical work-form and a clear set of procedures. The result obtained from your own work-form is one that I have always found to be inherently more satisfying than one obtained from a computer, and it is far easier to go back and spot any informational input errors when you've got your paper trail in front of you.

"Please forgive the length of this message. I was responding to Terry Carraway's forwarded message, and was a bit 'blind' as to your informational needs.

"As was etched in glass aboard my former Hans Christian cutter, 'May Dolphins Dance Beneath Your Bows!'" — *Roger H. Jones*

Member Richard Gibson wrote on October 2, 2003:

"Having had no luck pulling up the Internet addresses for the Online Nautical Almanac given in issue 78, I poked around and finally succeeded in getting into a most interesting trove of navigation information. Enter www.usno.navy.mil/ and click on PRODUCTS. Go to Astronomical and Navigation Software and click on MICA. Go to Test Drive MICA Now and click on **here**. A form will come up which calls for entry to assumed position, sight information and a query how you want the sight reduction presented. Having access to this on board a vessel would make celestial nav a cinch, but it would kill all the fun of using tables and calculators. The site has many other interesting paths to pursue."

YACHT FIONA ROUND THE WORLD THE WAY OF THE CLIPPER SHIPS, 2002-2003

Newsletter 3

Eric B. Forsyth, Master

Hobart to Cape Horn, Stanley . . .

Editor's note: Newsletter 4 was inadvertently published in Issue 80 as Newsletter 3.

"This letter will cover the long leg from Hobart to Stanley around Cape Horn and our adventures at South Georgia Island. But before that I want to jot down a few memories of Hobart, which proved to be a great stopover. The city itself has a population of about 45,000. It was founded as a prison colony in the earth nineteenth century. There are many very fine examples of Victorian architecture still remaining. Several downtown blocks are now a pedestrian precinct with malls and outdoor restaurants. As we were there during the Christmas holiday season, we experienced many festive activities such as a food tasting fair on one of the harbor piers. Don't forget, summer started a week after we arrived. As I mentioned in my last letter, Bob's partner Sue and David's sister Lindsey joined us in Hobart. The five of us took a tour of the Tahune Forest, a surviving bit of original rain forest on the west coast of Tasmania. On the way there the countryside reminded me of England. The lower level of the forest is full of huge, impressive ferns. The upper level canopy can be viewed by means of an 'Air Walk", which in one spot is cantilevered out sixty feet over the trees. The sight of these massive, tall Huan pine trees with the wild river beyond is unforgettable. The tour ended with an ascent of the four-thousand foot Mount Wellington which overlooks Hobart and Storm Bay.

"I enjoyed pottering round the city. When I went for a beard trim, I found the barber was quite an accomplished amateur artist. I bought a painting of a cricket match right off the wall of his shop. I found several used book stores to browse and I visited the many museums and art galleries. The old prison church, built by convict labor, was fascinating. The bricks were hand-made by the prisoners. On many, their thumb-prints were still visible, left as the bricks were pressed from the mold. The tiny, dark cells for solitary confinement were built directly under the pews, presumably so the unfortunate inmate could hear the service in a muffled kind of way. It was an interesting aspect of the Victorian psyche, as by 1840 even the Governor said the cells were not fit for animals, let alone humans. The church was converted to a courthouse and used until the 1970's, which is why it survived. The original Victorian prison with cells, workshops and treadmill was knocked down as late as the 1960's, sadly enough. It was huge, the twenty-foot high wall covered two city blocks. It held 1,500 prisoners.

David and Lindsey rented a car for island sightseeing over Christmas. While they were away, Sue, Bob and myself took another organized tour of Field Mountain and a game farm. On the mountain we saw wallabies in the wild and at the game farm we inspected Tasmanian Devils, wombats, Koala bears and kangaroos, the latter two of which are not native to Tasmania. The other animals were mostly orphans of road-killed parents and would be released when older. The 'Devil' is so named because they are nocturnal and their howls at night convinced the original settlers, who could find no source, that the countryside was haunted by devils. They are scavengers and are not a danger to humans unless you stick your hand in their hole.

"Back in Hobart I had curry almost every night at one of the numerous Indian restaurants. I often ate lunch in a pub accompanied by a glass of good but inexpensive Australian Chardonnay. I saw a couple of movies and most days I spent an hour checking e-mail at a friendly Internet café. It all seemed very civilized after a few weeks in the Roaring Forties. On Christmas Day we moved the boat to the Royal Yacht Club of Tasmania, about a mile out of town, as our slip at the downtown pier was needed by early arrivals in the annual Sydney to Hobart Race. I usually picked a different route for the walk into town from the club each day throughout the suburbs of the city. Generally speaking, the houses were small, often with corrugated tin roofs. The ramble was great fun. One day Sue, Bob and I went on a massive shopping spree at the local supermarket and packed enough food in the boat to get us to Brazil, which will be our next chance to restock. An old cruising friend, Pauline Chapman, noticed while checking out the Fiona website that I had fetched up in Hobart and contacted a friend of hers that lived nearby. He arranged to pick up David and myself for lunch at his farm on New Year's Eve. He breeds Alpacas, a very superior-looking animal. We had a very interesting stay and a pleasant meal with him and his wife before he dropped us back at the boat in time for the evening's festivities. I also had a date that afternoon with the Australian Quarantine Service, who had sealed all our canned meat when we arrived. They checked the seals and gave us permission to leave the next day. When it dawned, Sue started her long trek to New York at 4 am and we cleared for Stanley in the Falkland Islands just before 10 am. The controller manning the harbor radio seemed mildly surprised at our destination.

"An enthusiastic member of the yacht club insisted that we visit Auckland Island, lying about 300 nm south of New Zealand at 51°S. He said it was on the way, it was unique and he even gave us Xerox copies of detailed charts. It is a World Heritage Site and prior permission is needed for a visit, so we decided to sail by without landing. It took us a week to get there. We arrived at the south coast just as dawn was breaking and were greeted by thousands of sea-birds that wheeled and screamed overhead. It appeared to be typical sub-Antarctica tundra, with no trees and no high mountains. Our friend had pressed us to visit a particularly scenic bay on the east side, but it was beset by turbulent winds and choppy seas. I was not keen to get too close to shore but we got within a quarter mile. The chart copy we had was dated 1883; things might have changed since then. We took the mandatory photos and hung a turn right. Ahead lay Cape Horn and Stanley, 5000 nm downwind in the 'Furious Fifties'.

"On the 12th of January we crossed the international date line. It was a Sunday, so we had two of them, the first when ship's time was 12 hours ahead of Greenwich, and the second when we were 12 hours behind. The next day the weather deteriorated and eventually we had to hove-to, just holding our position until the storm blew itself out. Unfortunately, a heavy wave broke onto the boat and burst the staysail, which was sheeted to windward. This is a very useful sail for windy conditions, so we carried it below to repair it with the old Read sewing machine. We suspended watches and all worked full time to stitch two patches on the 'T' shaped tear. One person was needed just to stop the machine from sliding about as *Fiona* rolled furiously in the storm. We had the job done in about five hours and we were able to set the sail again. A few days later we entered a region of very high humidity and the boat was plagued by heavy condensation. Water dripped copiously off the bulkheads and hatches. It played havoc with the electronics, most of which we were able to dry out, but the radar hasn't worked since then. Perhaps the condensation was associated with the presence of icebergs, which also appeared about this time. They were huge. They probably originated at the Ross Ice Shelf that lay a thousand miles to our south. Even though we kept a good lookout, it was a little scary at night without radar thrashing to the east, hoping one would not get in the way. After a few days we failed to see any more but then came a period of intense squalls with wind shifts and cold rain. At one time when Bob was on watch he counted six, scattered about from horizon to horizon. Even without the transient effect of the squalls, we were finding the weather down in the fifties was never constant for long, frequent shifts of wind direction and speed had us on deck several times a day reefing or jibing so that we could hold the course. While we were furling the jib on January 23rd, we noticed the Profurl was not working correctly. Inspection revealed that the lower drum mechanism had split into two pieces. The upper piece carried the drum, the lower the bearing, which was visible as the parts separated. I called the company on the Iridium satellite phone for advice, but they were pessimistic. The unit could only be repaired at the service center. We winched David to the masthead so he could relocate the stop and thus limit movement of the foils. This enabled us to use the jib in light winds. A day later the wind increased to gale force and we reached under reefed staysail and reefed main. At the height of the storm I was working in the cockpit when I noticed a pod of pilot whales surfing through the waves next to the boat. They seemed to be enjoying the storm, their shiny black skin glowed. It was still blowing hard when David reported the toilet in the forward head had blocked up. As we pitched and rolled, I pulled the plumbing to pieces looking for the stoppage. This is when you find out if you are really cut out to enjoy ocean cruising.

"January 26th was David's birthday, so I baked a cake to have with our Happy Hour rum. As it lay on the counter awaiting the addition of a few candles, a large wave dolloped on the main hatch and sea-water spurted under the slides, splashing part of the cake. We took this as a hint that Father Neptune wanted some, so we cut a soggy slice and tossed it over the side as a peace offering. Curiously enough, after that we had an unusual spell of very calm weather. For six days we never even reefed the mainsail. Can it be that there is something in the old sailor's superstitions? Our daily mileage dropped, we were frustrated, especially as we were below 54°S, where the wind is supposed to blow all the time. Eventually, near 100°W the wind came back and our daily rate pickup up dramatically. Cape Horn was now a little more than a thousand miles away. One day the pressure fell by 17 millibars in twelve hours and when it bottomed out we got a gale. About midnight a steering line on Victor chafed through and we all spent a couple of hours on deck repairing it. When we finally got back in the cabin out of the noise and spray, we had a stiff tot of rum. Two nights later we again had gale force winds and we spent two hours on deck reefing and shifting sails. More rum! We arrived in the vicinity of Cape Horn as dawn was breaking on a rainy, misty day. The wind was piping up to 30 knots from the north. Just as I cracked the old joke to David and Bob, 'There's Cape Stiff, if you're lucky you won't see it again,' things began to go wrong. We were working forward to clear a fouled halyard when I noticed Victor's vane seemed rather wobbly. Walking over to the stern for a look, I saw that the support strut had broken again. This is the same failure that forced us into Hobart, this time it was the starboard strut. I had replaced both struts the previous winter because they were worn; clearly the manufacturer has a QC problem. Unfortunately, we would have to hand steer until we got to Stanley, 400 nm away. Shortly after Victor's demise, the starboard jib sheet parted with a bang. We passed about three miles south of the Horn at ten-thirty and gave the Chilean navy people a call on the radio. After recording details of the boat and voyage, they wished us luck. The Cape was only intermittently visible in the driving rain and fog. I think they were being more than just polite. Later that day the wind picked up to about 50 knots. We furled the mainsail and as we adjusted the boom, the topping lift broke, permitting the boom to fall with a crash. David was lucky to escape being brained, as it was the force bent a stanchion. Despite all our problems there was one good thing: we picked up a three knot current that whisked *Fiona* past the Horn and Staten Island and ejected us into the Atlantic Ocean like a cork out of a champagne bottle. We made it to Stanley three days later, arriving in the late afternoon of Valentine's Day, 46 days after leaving Hobart. We had added 5,634 nm to the log. I estimate we also received a boost from the current of about 552 nm, making a total distance sailed of 6,186 nm at an average of 134 nm/day.

"You may recall from my first newsletter that one objective of the cruise was to duplicate a typical clipper ship voyage around the world. Putting into Stanley needing repairs after rounding the Horn was very typical. In fact, there are a number of hulks of old square-riggers still littering the harbor that made it to Stanley but were too battered ever to leave. That was not to be our fate. We soon got our repairs in hand, but other similarities are worth a comment. I cannot properly compare our experiences as sailors with those of the old salts that manned the clippers. Their was a brutal existence; manhandling heavy ropes and gear on a ship that weighed several thousand tons. Frequently, lives were lost on a rounding of the Horn, often by falling from the rigging as they worked as much as a hundred feet above the pitching deck.

"But every watch we had to don foul weather gear and sea boots, once you are soaked by a wave, or your boots are full of sea water you are just as wet and cold as they were. Below the boat was damp from leaks and condensation. I got a great appreciation of a remark often seen in the memoirs of old seamen, namely that they went to sleep 'all-standing', that is, in their wet clothes. The continuous exposure to salt water meant that the minor cuts on your hands never healed. You accepted the bruises and bangs gained as the boat rolled unexpectedly, as normal. Although we were not working a hundred feet in the air, it was often pitch dark and slippery as we worked on deck to reef or furl sail at the onset of a gale. And there was no let-up. We had to stand watch after watch, day after day, week after week. There were frequent gear failures that had to be dealt with immediately with all of us on deck, regardless of who was on watch. When you got the chance you slept and ate, and got through one day at a time. We had one advantage the seamen of old did not enjoy — we knew where we were. They depended on scuttlebutt, usually passed on by the cook. We plotted our position every day and watched it creep slowly across the chart of the featureless South Pacific Ocean. One question — how on earth did they manage without flashlights in the old days? We all worked at night with our small Maglights, often clenched between our teeth.

"Stanley had changed considerably since I was last there in 1992, a reflection of the affluence brought by selling licenses to fish their waters to foreign companies. Quite a modern looking suburbia is growing on the east side of the town. One development we really came to appreciate was a new Seamen's Centre built adjacent to the floating dock where we tied up the boat. It provided toilets, showers, laundry, e-mail, a snack bar and many home comforts for visiting fishermen. I was a little hesitant at first that dilettante yachtsmen would be able to use it, but they treated us as real seamen. It functions under the auspices of the UK-based Royal National Mission to Seamen. They describe themselves as Christians with their sleeves rolled up, and that seems apt. The social center of Stanley is still the Globe Tavern. David and Bob soon discovered it, and its attractive barmaids. We mostly ate our lunches at the Seamen's Centre, but we tried just about every eatery in the place for our suppers during our one-week stay, These ranged from the up-market 'Upland Goose' hotel to a fish and chip shop on wheels. It was a pleasant 30-minute walk along the shore into town, unless it was raining, which it did most days. I talked to the administrator of South Georgia, who is based in Stanley. He told me that plans are underway to remove most of the old whaling station at Grytviken because of asbestos contamination. I also talked to the Fisheries Department people about the ice conditions for our trip. They predicted plenty. For openers there was a thirty-five mile long berg aground off the northwest of South Georgia. For this reason, combined with our lack of radar, we decided to skip a visit to the South Orkney Islands, as originally planned, and go directly to South Georgia. We were a little pushed for time anyway. When I talked to the British Antarctic Survey about our trip, which has a summer base at King Edward Point, they suggested taking the mail, as few ships call there. The post office put together a twenty-pound bag of accumulated mail in a sack with the imposing label 'Royal Mail'. We refueled, restocked our fruit and veggies and we left a week after we arrived.

"At first the wind was fairly light, then it died altogether. For about a day we ran the engine. With the lack of wind the fog descended on us. It was a little scary, as the visibility dropped to a hundred yards or so, to peer ahead hoping an iceberg would not emerge out of the gloom. I had looked at our defunct radar when we were tied up in Stanley. The problem seemed to be a defective integrated circuit chip, which is impossible to fix without a direct replacement. When the wind came back the fog dispersed, and within a few hours we found ourselves surrounded by icebergs. We sailed through them for over a hundred miles. They came in all shapes and sizes, but many were flat, suggesting they had broken away from an ice-shelf. We maintained a constant cockpit lookout and at night we slowed the boat down by reefing the mainsail. The big 'bergs were easy to spot, at least in daylight. The real danger was the small pieces, called 'growlers', which had broken off the big ones, and although they weighed many tons, showed little surface above the sea. As we sailed past the 'bergs, seals popped their heads out of the water to get a look at us. Dolphins frequently gamboled across our bow. The vicinity of the ice must be rich in fish. The last night we sailed along the coast of South Georgia, invisible in the inky night. We set a double reefed main to both slow us down and to allow us to arrive off the land at daybreak. As the sky lightened, the fantastic jagged black and white outline of South Geogia appeared before our eyes. As the sun rose, the white mountain peaks were bathed in pink.

"We tied up temporarily at the government jetty at King Edward Point. The resident Fishery Department Officer, who is also customs, immigration, magistrate and wears many other hats, briefed us on the current conditions and the care we had to take to avoid damaging the environment. The old Norwegian whaling station at Grytviken, across the bay, is now in such dangerous shape that it is off limits. The museum, church and the whalers cemetery are still open. After a shower and a cup of tea at the resident's apartment, which, by the way, must have one of the most spectacular vistas in the world, we motored across to Grytviken and tied up to the rotting dock. This was the chance to meet my old friends, Pauline and Tim Carr, again. They run the museum. The next day we walked to the cemetery that holds the grave of Sir Ernest Shackleton. Numerous fur seals barked at us as we passed. Then we hiked a few miles to see the dammed lake above Grytviken, built by the whalers to get hydroelectricity. After that we walked on to the site of a helicopter wreck, a victim of the fighting when the Argentinians invaded in 1982. In the evening we staged a movie using a DVD in Bob's laptop, 'It's a Mad, Mad, Mad, Mad World.' The next day we trudged past hundreds more fur seals to King Edward Point and the Shackleton memorial, erected by his shipmates when he died in Grytviken in 1922. We were just in time to see the Royal Navy patrol boat, Leeds Castle, tie up, carrying the Governor of the Falkland Islands on an inspection tour. The next morning he stopped by the boat for a few minutes chat. I think he made the visit because almost any decision about future of the old whaling factories at Grytviken and other sites along the coast will cost big bucks. Another sailboat tied up next to us carrying a group of mountaineers planning to climb the formidable peaks for the next month. We had quite a party on board their boat that evening. We left the next morning and powered over to Stromness. This is where Shackleton wound up at the end of the epic journey over the mountains and glaciers of South Georgia after his whaleboat had made a landfall on the west side of the island in 1916. We did not land, as the dangerous condition of the dock and buildings has caused the authorities to put it off limits to visitors. We could see the manager's house where the three men first made contact with civilization again after two years and we saw the stream they splashed down on their way out of the mountains. After a brief look at the remains of the whaling station at Leith, we put out to sea. Our destination was tropical Brazil.

"Once clear of the coast, we again encountered the field of icebergs that had plagued us on the way down. As night fell we decided to lie a-hull for the night, that is, take the sails down and drift for the night. The wind was blowing up to gale force. Just after Bob came on watch at 10 pm he was horrified to see a growler close to the bow on the port side. Bob's growler was about the same size as Fiona but, of course, weighed much more, as most of its mass is under water. He gave me a call to start the engine. Just as I came on deck, we grazed the thing, but by then the engine was running and we backed away without damage. I shall not easily forget the sight of its tortured outline in the beam of our flashlights as the storm tossed spray over it and it faded from view into the darkness. When the sky lightened in the morning, we counted thirteen large icebergs in sight. We set sail and zigzagged through the field all that day and again lay a-hull the following night. By the next day the iceberg count had thinned. Although we still spotted a few, it seemed safe enough to sail through the night with a lookout in the cockpit. The starlight gave just enough visibility to see an obstruction ahead. The next day we were clear of the ice, but by then the clouds rolled in and the wind increased to strong gale force on the nose. As we got into the 'Roaring Forties' the wind strengthened to 50 knots, but that is an estimate based on the sea surface condition. The wind blew away our anemometer and its masthead mounting bracket. Mother Nature was making us fight to leave the Antarctic and get to the Tropics. We slowly worked our way north to the 'Horse Latitudes', a band of variable weather lying above 39°S, allegedly so named because the old clippers had to abandon their cargos of horses and dump them in the sea when they ran out of fresh water. 'Variable' is certainly the right word. On the 16th of March we enjoyed happy hour in the cockpit for the first time in months. A few hours later, just after midnight on the 17th, we had to fight to furl the reefed mainsail in a wind that increased to over 60 knots and was shrieking across a foaming sea. By late in the day we were jogging over a calm sea under a full moon, listening to President Bush on shortwave as he announced the attack on Iraq. The weather continued to be fluky with head winds, calms and occasionally a nice reach. But it was much warmer. On the 18th we saw some flying fish. The next day we dropped the mainsail in a calm period to make a minor repair and decided to take a swim while the boat was stationary. The water was wonderful. We slowly fought our way towards Santos, now also bucking the strong current that flows south from the equator. It took us three weeks to make good the 1860 nm distance from South Georgia. We logged 2,338 nm to do it."

— Happy sailing until the next time, Eric.

Editor's note: These illustrations can be viewed at www.yachtfiona.com.

IMGO225 The impressive Victorian edifice of the old gas company in Hobart. It now houses a shop for tourist items.

On the nature trail at Field Mountain, Tasmania.

A Tasmanian Devil at the game farm. When it is older it will be returned to the wild.

At the Alpaca farm near Hobart. The animals are bred for their fine wool.

Bob and Eric are repairing the staysail on the way to Cape Horn.

David and his birthday cake. We made sure to give Father Neptune a slice.

Rounding Cape Horn. This was Eric's third passage past the famous cape.

The plain exterior of the center of Stanley's social life. The interior is warm and cozy, like the barmaids.

The hulk of the square rigger CAPRICORN lying near the shore at Stanley. Other abandoned ships were converted into jetties.

Loading the Royal Mail for delivery by FIONA to South Georgia Island.

Iceberg encountered on the way to South Georgia. We passed about a hundred on the way in and as many when we left.

The spectacular coast of South Georgia. The sun was just coming up as this picture was taken.

The mountain behind Eric is called 'Sugartop'. It rises to over 6,000 feet.

Sir Ernest Shackleton's grave in the whaler's cemetery at Grytviken. He died in 1922 while leading an expedition to Antarctica

FIONA tied up to the old dock at Grytviken. Its decaying state is clearly evident..

L to R Pat Lurlock, Resident Officer, Eric, Howard Pierce, the Governor of the Falkland Islands, who was on an inspection tour.

Chinstrap penguins near Hope Point, South Georgia.

NAVIGATION NOTES

Some Dilemmas in Multiple Sight Position Solutions

By K. Herman Zevering

The least squares (LSQ) method and double sight method for resolving a position from two or more sights produce equivalent results in the case of simultaneous sights. As position solution methods they are both superior to a position solution based on position lines obtained for each sight with the intercept method. In the sight-run-sight situation, however, the LSQ method and the double sight method obtain significantly different position solutions with the same data. This creates both a dilemma and an interpretation problem. It ultimately raises the question whether the LSQ method as a mathematical technique can substantially and automatically correct the position solution obtained with more traditional methods with regard to both random and systematic observation errors.

Errors of observation

Traditional error theory, for instance found in the (British) Admiralty Navigation Manual (ANM) appears to distinguish between what may be called random error and what the ANM calls "systematic error" affecting all sights equally. Systematic error is associated with the instrumentation and is countered through corrections to sextant altitude and to deck watch error. With residual error the position line (PL) would lie in the middle of an error zone. With two intersecting PLs residual systematic error would thus according to the ANM give rise to an "error parallelogram" (see Fig. 1).

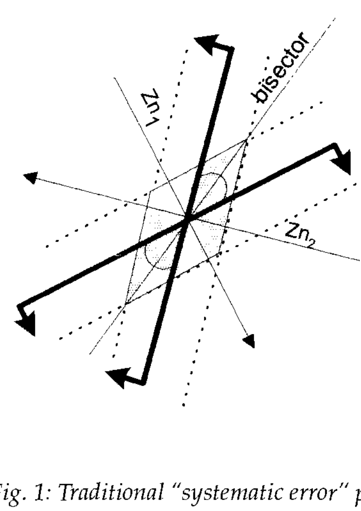


Fig. 1: Traditional "systematic error" parallelogram

With a systematic error assumed equal for all sights (sights have equal weight) this in turn supports the "bisector" approach: the "fix" would not lie at the intersection of two PLs but somewhere along the relevant bisector. Note that the marked sectors are the relevant ones, i.e. all PL arrows point in or all point out. A third sight will have a much better chance of forming a consistent cocked hat with the marked sectors.

With three or more consistent sights, again all PL arrows pointing in or all pointing out, traditional systematic error theory would expect the "fix" to lie inside the "cocked hat" formed by the PLs, but the bisector approach to my knowledge never became a formal means for determining the fix inside the cocked hat.

With two sights there is no method to evaluate the degree of observation error: the width of the error zone in which the PLs could lie cannot be determined. On the contrary, a small cocked hat area could indicate that the observation errors were relatively small.

As to random error one can only speculate as to its effect on the location of the PL intersection. Random error, which again is unknown, would perhaps cause some rotation as well as displacement of the PLs, thereby shifting the point of intersection.

In any case, with three or more consistent sights, traditional error theory would expect the "fix" to lie inside the cocked hat boundaries, not outside it. The location of the "fix" would need to be plotted on the chart, for instance, by shifting the boundary PLs at an equal distance inwards (see Fig. 2), or determined by an iterative algebraic procedure which is possible. There is some justification for the bisector approach if it is assumed that systematic error is equal for all sights and random error can be ignored.

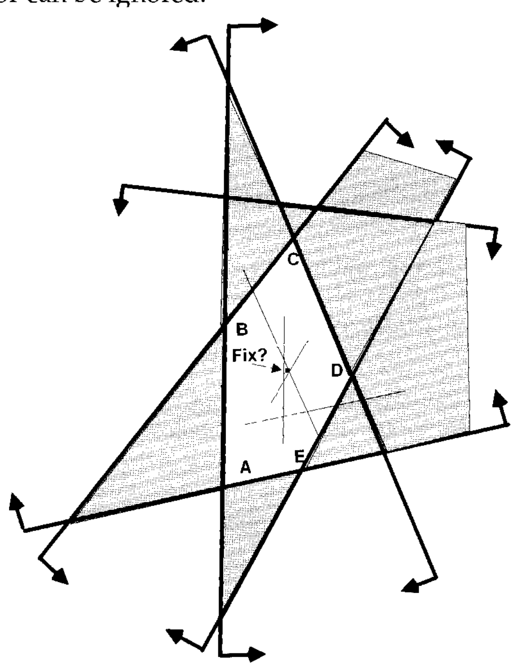


Fig. 2. Consistent and inconsistent pologons formed by multiple sights. Only area ABCDE forms a consistent polygon.

The LSQ method applied to three or more sights presumably captures total stochastic error as a mathematical byproduct of least squares regression, but to be effective in this respect it in fact requires that the sights are taken at different times from a moving vessel. Statistical error cannot be evaluated in the case of the single or double sight. Nevertheless, an (unknown) error zone surrounds the double sight position solution. Applied to three or more sights in the sight-run-sight situation, the LSQ method *not only* calculates a *statistical confidence* zone around the "fix" but also minimizes systematic error[1].

Interestingly, the LSQ method applied to three or more simultaneous sights can likewise produce a confidence zone around the "fix", reduce systematic error and positions a "fix" inside the cocked hat. This may be seen from the results plotted in Fig. 3. The LSQ method has reduced the systematic error zone roughly by the difference in area between cocked hat ABC and A'B'C'. Residual systematic error remains relatively large (area A.B.C.). The confidence ellipse in Fig. 3 may perhaps be seen as the aggregate of (residual) systematic error and random error. Nevertheless, positioning the "fix" inside the cocked hat ABC is consistent with the expectation of traditional systematic error theory.

The simultaneous double sight

The single sight Intercept Method (IM) requires an assumed position to solve the position circle equation. With more sights the position solution becomes in principle independent of assumed position.

A double sight solution derived from spherical geometry has been around for some time[2]. The double sight solution can also be derived algebraically by solving Lat and Long as the two unknowns from two position circle equations[3].

The LSQ method has already been mentioned[4]. A programmed version of it is used in packages like CelestNav[5] The LSQ method applied to two sights and the double sight methods give the same position solution provided the sights are simultaneous or taken from a stationary point. The solution yields the Lat-Long coordinates of the intersections of two position circles from which the most plausible position is chosen. This position may be visualized as the point of intersection of two position lines (PL), straight lines representing small segments of two position circles. The azimuth orientation (Zn) of the PLS are identical in both types of solution methods.

Table 1: Comparison of simultaneous double-sight position solutions*

Body	Data	Variables	Calculated from: DR position (1)	Special position (2)	LSQ method & double sight method (3)
Sun	GHA 284°.2467 Dec 18°.4050 N Alt_{obs} 20°.5150	$Lat_{special}$		50°.000 N	-
		$Long_{special}$		4°.247 W	-
		Zn	85°.180	85°.306	85°.452
		Interc. (n.m)	13.99	9.83	0.00
Moon	GHA 19°.3350 Dec 15°.4900 N Alt_{obs} 53°.4550	$Lat_{special}$		50°.000 N	-
		$Long_{special}$		4°.335 W	-
		Zn	204°.832	204°.735	205°.390
		Interc. (n.m)	-6.35	2.71	0.00
		Lat_{DR}	49°.833 N	-	-
		$Long_{DR}$	4°.333 W	-	-
		Lat_{fix}	49°.842 N	49°.870 N	49°.841 N
		$Long_{fix}$	4°.329 W	4°.243 W	3°.972 W

* The data are from M. Blewitt "Celestial Navigation for Yachtsmen", 6ty ed., Fig 26 and 27. The LSQ method results are from 3 iterations. The PL intersections for (1) and (2) are found with a program..

*Table 1: Comparison of simultaneous double-sight position solutions**

The traditional IM approach to the simultaneous double sight obtains the point of intersection by working each sight from an initial assumed (DR) position. With the same GHA, Dec and H_0 data, the IM approach will of course not arrive at the same position solution as the other methods. This is illustrated with Table 1 comparing "fixes" obtained with traditional IM and the LSQ/double sight methods. As is seen from Table 1, the IM position solutions differ a great deal in Long, both from each other and from the LSQ/double sight method. In this example, the adjustments the IM brings about in Zn to accommodate the different DR plots affect Long more than Lat. The double sight and the LSQ method are equivalent and clearly more dependable.

With the single sight or intercept-based double sight it is impossible to deduce the degree of position accuracy from the length of intercepts as is sometimes believed. For instance, the intercepts derived from the "special position" are smaller than those derived directly from the DR position. Nothing can be deduced about the relative dependability of method (1) and (2) in cases like this: change the DR position and the "fix" changes.

The intersection of two PLs obtained with the double sight or LSQ methods from simultaneous sights may be called a "fix", but due to errors of observation the actual position is unlikely to lie at the point of intersection. If the errors are relatively small the position may lie nearer the point of intersection but there is no means to evaluate the *confidence zone surrounding* the "fix". For instance, using the LSQ method with the double sight would show zero "Std dev" in the relevant CelestNav output screen.

More than two simultaneous sights

Two approaches are available. One is using the double sight method to determine the location of the vertices of the triangle or polygon (cocked hat) formed by the PLs. This approach does not really yield a calculated "fix". A "fix" can be constructed from the bisectors of the vertex angles, which assumes that all sights contribute an equal amount of systematic error and random error can be ignored.

The other approach is via the LSQ method. Fig. 3 shows the results of the LSQ method applied to three simultaneous sights. The triangle or cocked hat ABC derives from the intersections of the pairs (Sun-Vega (A), Moon-Vega (B) and Sun-Moon (C) obtained with the double sight method. The LSQ "fix" lies inside a smaller cocked hat A.B.C. within ABC with the following results:

	Sun	Moon	Vega
Zn	280°.5029	149°.1173	56°.8070
Intercept (n.m)	-7.7	-5.3	-5.8
Fix" (3 iterations)	32°.2157 N	14° 9746 W	

A.B.C. is constructed from the residual intercepts. Its sides are drawn perpendicular to the intercepts and are practically parallel to the sides of ABC.

Nevertheless notice that the azimuth orientation of respectively ABC and A.B.C. is slightly (but significantly) different. The "confidence ellipse", which is a by-product of the LSQ method, throws a total error zone around the "fix" of some 32 by 28 n.m at the 95% probability level. Needless to say, distance (and bearing) from the "fix" to a DR plot with two, three or more sights as one finds calculated in such packages as CelestNav and Astronavigation[6] is information that needs to be treated with caution, as with the LSQ method any initial Lat_{fix}~$long_{fix}$ position will give the same result, while the double sight method is independent of assumed position.

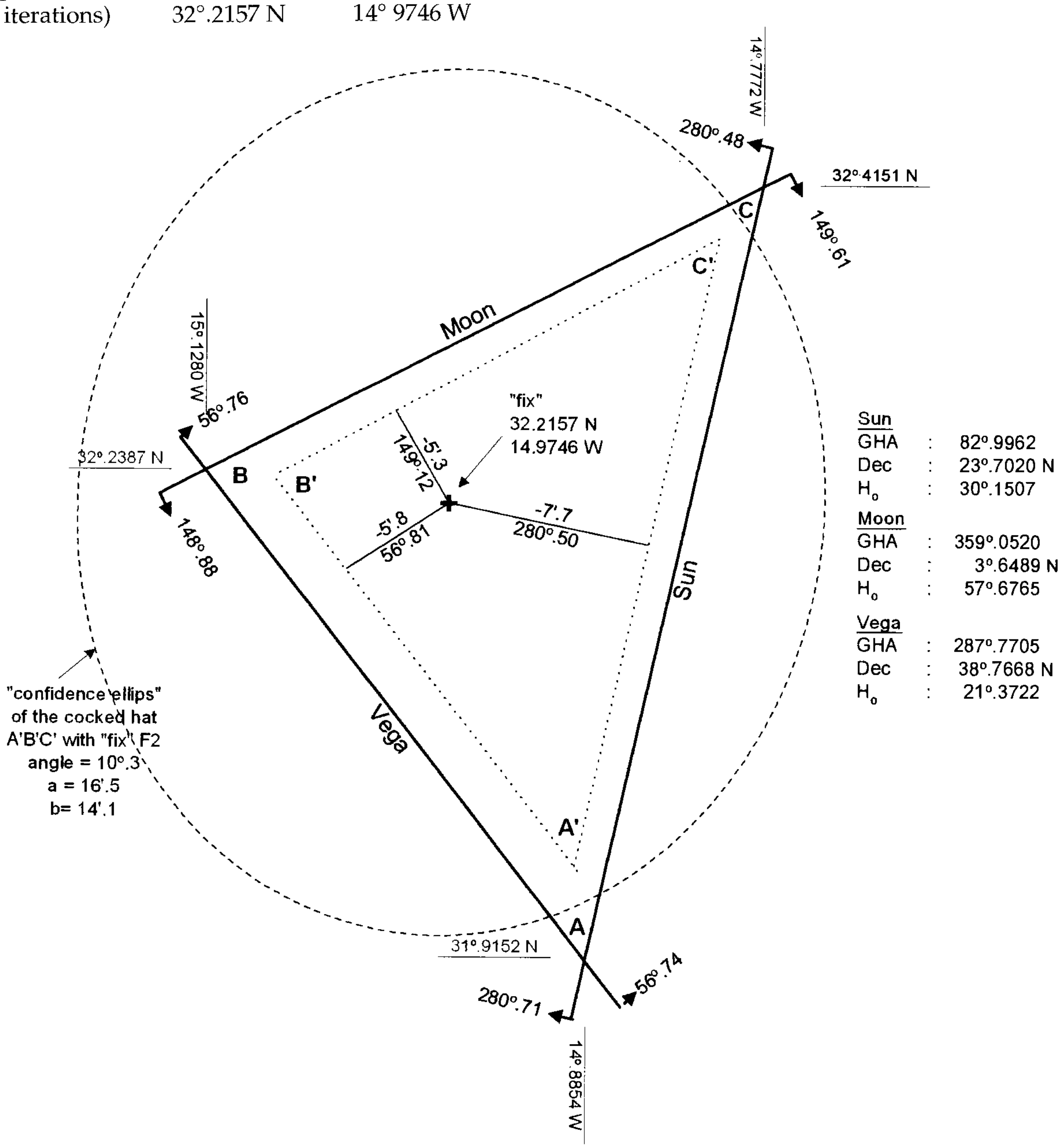
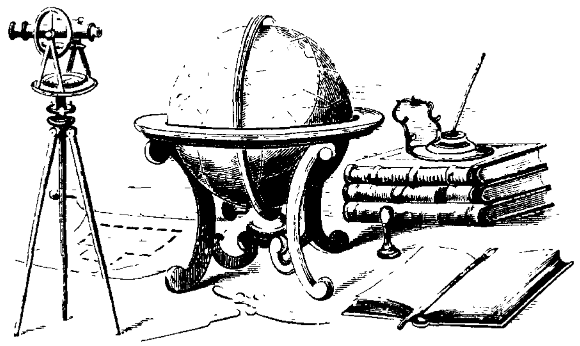


Fig. 3: Position solution for three simultaneous sights obtained with the LSQ method.



Run between sights with the double sight

In the sight-run-sight case, multiple sight solution programs must allow for run between sights. Such sights may include successive sights taken on the same celestial body, for example, taking successive sights during daylight on the sun.

There are to my knowledge three methods to account for run between sights, the DR method; updating the altitude of the earlier sight; and updating the GHA and Dec of the earlier sight.

The LSQ method uses a DR displacement method (see Box), but the choice of the initial Lat_{fix}~$Long_{fix,}$ is immaterial in obtaining the position solution with this iterative method.

In the Alt-updating method, H_o of the earlier sight is recalculated by means of the Lat_{old}~$Long_{old}$ of the DR position at the 1st sight and the Lat_{new}~$Long_{new}$ at the 2nd sight obtained with the run data. Th recalculated altitude is then used as "datum" in the double sight solution[7]. This method is adapted from the IM approach, thus dependent on assumed position and therefore less dependable.

Box

Accounting for Displacement

(DR method)

The data set consists of distances (**d** n.m) sailed at given true bearings (α^o) since the last DR position; d = ***tV***, where V is speed in knots and ***t*** is duration of run. The rhumb line equations to find the new Lat~Long are:

$$Lat_{new} = Lat_{old} + \Sigma d'Lat/60$$
$$Long_{new} = Long_{old} + (\Sigma Dep/60)/\cos(½Lat_{old} + ½Lat_{new}), \text{ where}$$

Σd'Lat, a displacement across latitude, is the sum of all the **d**cosα; Σdep, a displacement across longitude, is the sum of all the **d**sinα Easily accommodated in Σd'Lat and ΣDep is information on current sets or other drift. If α of the run is constant (=**T**), Σd'Lat = d'Lat = ***tV***cos**T** and ΣDep = Dep = ***tV***sin**T**

To operate the LSQ procedure, define ***t*** = **t**$_f$ - **t**, where **t**$_f$ is the time the "fix" is determined and t the time a particular sight was taken. It is immaterial whether the DR at the time of a particular sight is determined from an initial DR (1st sight), from the DR at the time of the last sight or from a DR determined after all sights have been taken, provided the time of the last DR is defined as **t**$_f$. The rhumb line equations are thus rewritten as:

$$Lat_{sight} = Lat_{fix} + [(t_f - t)V\cos(T-180)]/60 = \ldots[(t_f - t)V\cos T]$$
$$Long_{sight} = Long_{fix} + [(t_f - t)V\sin(T-180)]/\cos(½Lat_{sight} + ½Lat_{fix})/60 =$$
$$\ldots[(t_f - t)V\sin T] \ldots, \text{ where } Lat_{fix} \text{ may be substituted for } ½Lat_{sight} + ½Lat_{fix}$$

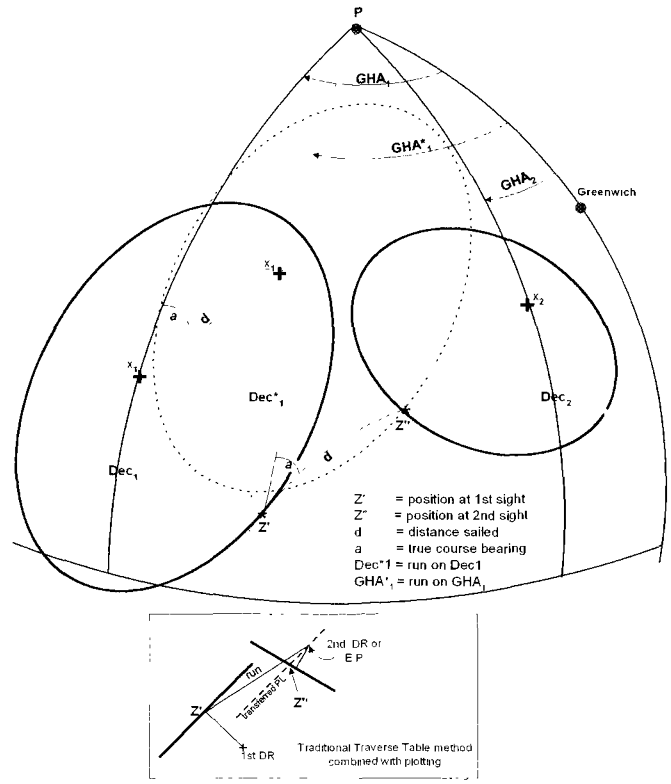


Fig. 4: GHA-Dec updating method with successive sights

The GHA-Dec-updating method eliminates the effect of an uncertain DR position. With this method the coordinates (GHA, Dec) of the transferred position circle of an earlier sight are updated from the run data:

$$Dec^* = Dec + \Sigma d'Lat/60 \text{ and}$$
$$GHA^* = GHA - (\Sigma dep/60/\cos(½Dec^* + ½Dec).$$

The negative sign in the GHA equation converts a westerly bearing from algebraic neg. to pos. and an easterly bearing from pos. to neg., with GHA measured positively in a westerly direction.

Only Σd.Lat and ΣDep, common to all methods, are influenced by factors that cause a vessel's estimated trajectory to deviate from its actual course and speed over the ground. The GHA~Dec-updating method is in fact the electronic version of the old traverse table cum plotting method but without using the intercept method (see Fig. 4).

With simultaneous sights, t_{fix}-t (see Box) for every sight is zero and in this case the LSQ method applied to two sights and double sight solution method give the same "fix" and Zn_1, Zn_2. With run between sights the "fix" and Zn_1, Zn_2 will be different for all methods (see Table 2).

Table 2: Sight-run-sight solutions with the LSQ method and double sight method*

	Data:	Sun (1st sight)	Vega (2nd sight)
1	Time of sight	$17^h30^m45^s$	$20^h12^m20^s$
2	GHA	82°.5829	287°.7705
3	Dec	23°.3211	38°.7668
4	H_o	30°.1507	21°.4135
5	Run time (hrs)	2.6931	0.0
6	Distance sailed	0°.5386	0°.0
	Σd'Lat	0°.3809	0°.0
	ΣDep	-0°.3809	0°.0
	DR plot	32°.0068 N 14°.6168 W	32°.3876 N 15°.0669 W

Results:	LSQ method (7 iterations) (1)		Double sight method: (GHA-Dec updating) (2)		Double sight method: (Alt-updating) (3)	
Position solution	32°.2334 N 15°.1239 W		31°.9252 N 14°.8854 W		31°.6955 N 14°.7081 W	
	Sun	Vega	Sun	Vega	Sun	Vega
GHA^*_1	-	-	82°.9982	-	-	-
Dec^*_1	-	-	23°.7020	-	-	-
Alt^*_1	-	-	-	-	28°.5592	-
Z	79°.7407	56°.7603	79°.2915	56°.7428	79°.66578	56°.7287
Zn	280°.2593	56°.7603	280°.7085	56°.7428	280°.3343	56°.7287
Intercepts (n.m)	→ +0.0	→ -0.0	not used	not used	not used	not used

* Data 1-6 taken from Yallop & Hohenkerk, op. cit; Σd'Lat and ΣDep calculated from data 5 and 6
GHA^*_1 , Dec^*_1 and Alt^*_1 are respectively the run on GHA_1 , Dec_1 and Alt_1
The DR plot is derived from Yallop & Hohenkerk"s 32°.50 N 15°.20 W at 21^h00, but is only relevant with the Alt-updating method.
Alt^*_1 is calculated with the DR plot.
→+-0.0 = approaching zero (intercept pos.) → -0.00 = approaching zero (intercept neg.)

*Table 2: Sight-run solutions with the LSQ method and double sight method**

As with the IM for single sights, method (3) in Table 2 is directly affected by the assumed initial position.

The different position solution obtained with the LSQ method (1) and the double sight method (2) raises an interpretation problem and dilemma to which we will return later.

The following analysis refers to three sights. A vessel moved at 315° (due NW) and 12 knots. Vega was the last sight, so that the Sun and Moon sights are run on to the time of the Vega sight. The data and results of the first step are in Table 3[8].

Run between sights with three or more sights

In this case a similar dilemma is encountered as with two sights: the LSQ method and the double sight method produce different solutions that are not easy to reconcile.

When submitting the data to the LSQ method or to a program like CelestNav, it is advisable to omit inconsistent sights first. With more than two sights, the intercepts calculated with the LSQ method should be all negative or all positive after the 1st iteration or so. If some intercepts are positive and some negative, an inconsistent sight should be suspected. The simplest way to find out is to sketch the Zn and PL of each sight, with the intercepts laid out from the "fix", not from some assumed position!

Table 3: LSQ method "fix" with 3 consistent sights

Data:	Sun	Moon	Vega
Time of sight	17:30:45	18:15:24	20:12:20
GHA	82°.5829	358°.7759	287°.7705
Dec	23°.3211 N	3°.3713 N	38°.7668 N
H_o	30°.1507	57°.6765	21°.4135
Time sailed to Vega sight (hrs)	2.6931	1.9489	0.0
Distance sailed (°)	0°.5386	0°.3898	0°.0
Σd'Lat (°)	0°.3809	0°.2756	0°.0
ΣDep(°)	-0°.3809	-0°.2756	0°.0
Results:	**Sun**	**Moon**	**Vega**
Z	79°.7496	148°.9697	56°.7631
Zn	280°.2504	148°.9697	56°.7631
LHA	67°.9 LHA < 180°	344°.0 LHA > 180°	272°.6 LHA > 180°
Intercepts (n.m)	-0.33	-0.23	-0.25
LSQ method "Fix" (6 iterations*)	F_1 = 32°.2459 N 15°.1278 W		

* At 4 digits behind the decimal point the "fix" stabilizes with the 2nd iteration.

Table 3: LSQ method "fix" with 3 consistent sights

A small cocked hat (triangle) is formed around "fix"

F_1, lying in an area of less than a square mile. A "confidence ellipse" at the 95% probability level of only 1.4 by 1.2 n.m. surrounds it. This plot would certainly inspire confidence. It lies within a slightly larger cocked hat, whose vertices are formed by the PL intersections of Sun-Vega (A"), Moon-Vega (B") and Sun-Mon (C") found with LSQ (or CelestNav), but using the DR displacement subroutine (see inset in Fig. 5):

	A"	B"	C"
	Sun-Vega	Moon-Vega	Sun-Moon
Lat	32°.2337 N	32°.2469 N	32 °2546 N
Long	15°.1239 W	15°.1344 W	15°.1195 W

We finally combine Fig. 3 with Fig. 5 and indicate the "fix" obtained in Fig. 3 as F_2. Noted here is that the GHA and Dec data for Sun and Moon in Fig. 1 were already run on with the same displacement information to the time of the Vega sight, while LSQ was run with all time differences set to zero. As is seen from Fig. 5, F_1 lies outside the big cocked hat ABC and so does most of its little cocked hat and A"B"C". A position F_1 completely eccentric to ABC will be found regardless of the Lat_{fix}~$Long_{fix}$ position assumed.

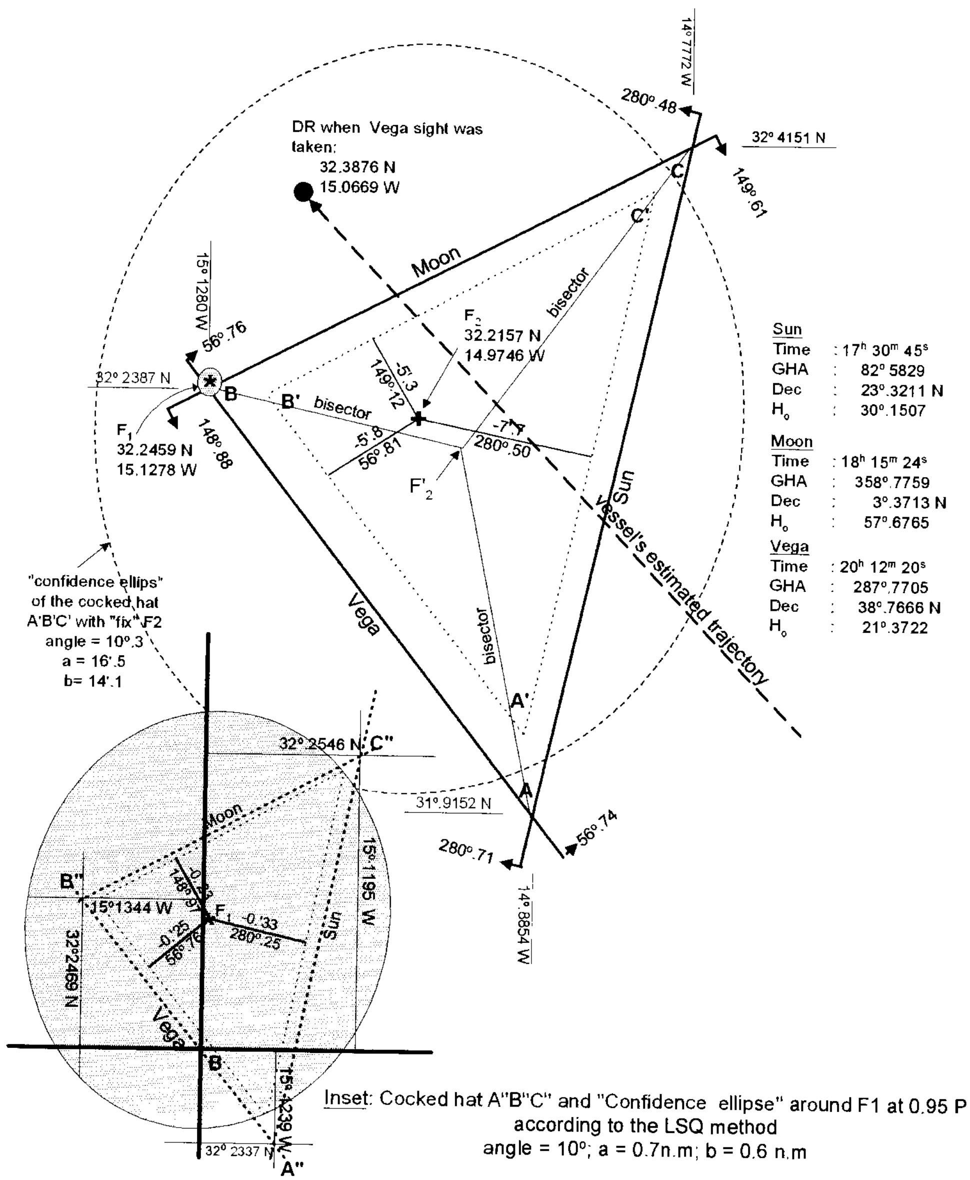
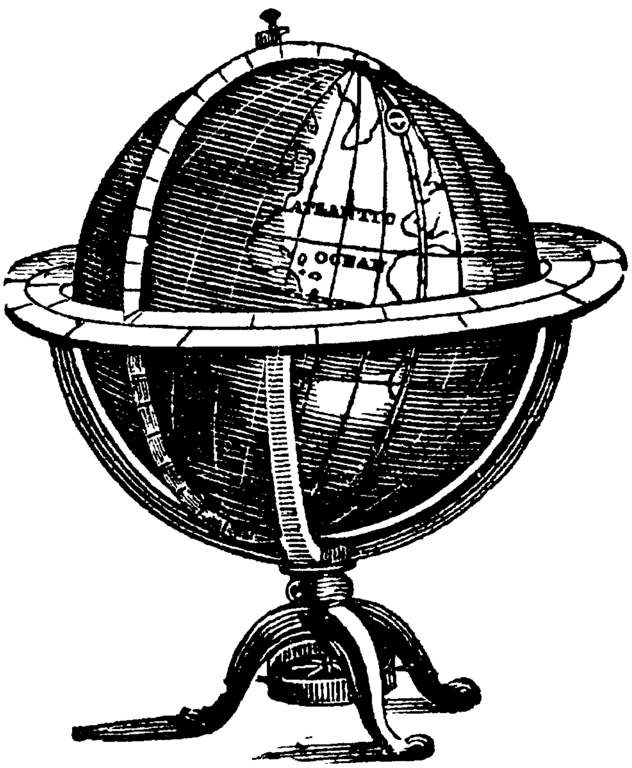


Fig. 5: Different position solutions F1 and F2 obtained with the LSQ method. A vessel sails at 315° and 12 knots. Successive sights are taken on Sun, Moon and Vega. The plot relates to the time of the Vega sight.

The interpretation of the different results raises questions. The LSQ and double sight methods use the same GHA, Dec, H_o, %d.Lat and %dep and are independent of assumed position. The initial Lat_{fix}~$Long_{fix}$ position assumption with the LSQ method, although arbitrary, nevertheless appears instrumental in causing the difference in the final position solution when sights are not simultaneous.

A cardinal question here is, whether the LSQ method in non-simultaneous multiple sights cases indeed automatically reduces the errors of observation by shifting the plot obtained with the traditional methods to a plot which is substantially corrected for both random and systematic observation errors. For example, is the position solution in Table 2 of 32°.2334 N 15°.1239 W obtained with the LSQ method a position corrected for some of the (hidden) observation errors compared to 31°.9252 N 14°.8854 obtained with the double sight method? Can the position solution at F_1 in Fig. 5 compared to a position somewhere centrally located in cocked hat ABC like F_2, F_2 be accepted as a more dependable one that is corrected for most of the observation errors?



Appendix 1: Accounting for Displacement between Two Sights with the Alt-updating method

$\cos(GHA_1 - Long_{old}) = \cos MA_1 = (\sin Alt_1 - \sin Lat_{old} \sin Dec_1) / (\cos Lat_{old} \cos Dec_1)$

$\cos(AZ_1) = (\sin Dec_1 - \sin Lat_{old} \sin Alt_1) / \cos Lat_{old} \cos Alt_1)$

$MA_1 = \cos^{-1} MA_1$

$Az_1 = Z_1 = \cos^{-1}(AZ_1)$

$LHA_1 = GHA_1 - Long_{old}$

Northern latitudes: LHA<180°→true Az = Zn = 180°-Z, otherwise Zn = Z

Southern latitudes: LHA<180° →true Az = Zn = 180°+Z, otherwise Zn = 180°-Z

$dlong = Long_{old} - Long_{new}$

$Zn_1 > 180° \rightarrow MA^*_1 = MA_1 + dLong$

$Zn_1 < 180° \rightarrow MA^*_1 = MA_1 - dLong$

$\sin(Alt^*_1) = \sin Lat_{new} \sin Dec_1 + \cos Lat_{new} \cos Dec_1 \cos MA^*_1$

$Alt^*_1 = \sin^{1} Alt^*_1$

Alt = H_o; MA = meridian angle; $Alt^*_1 = Alt_1$ updated for run between sights; Long E = + and Long W =-; Lat and Dec N = + and Lat and Dec S = -.

Appendix 2: Finding the coordinates of the intersection of the position lines of a double sight worked from an initial IM position

p = intercept; d = (unknown) distance from estimated position to intersection of the PLs

The displacement across latitude gives Eq.1: p1cosZn1-d1sinZn1=p2cosZn2+d2sinZn2

The displacement across longitude gives Eq.2:p1sinZn1 +d1cosZn1=p2sinZn2-d2cosZn2

Write Eq. 1 as Ad1+Bd2+C = 0

A=	sinZn1
B=	sinZn2
C	p2cosZn2-p1cosZn1

Write Eq. 2 as A*x1+B*x2+C* = 0

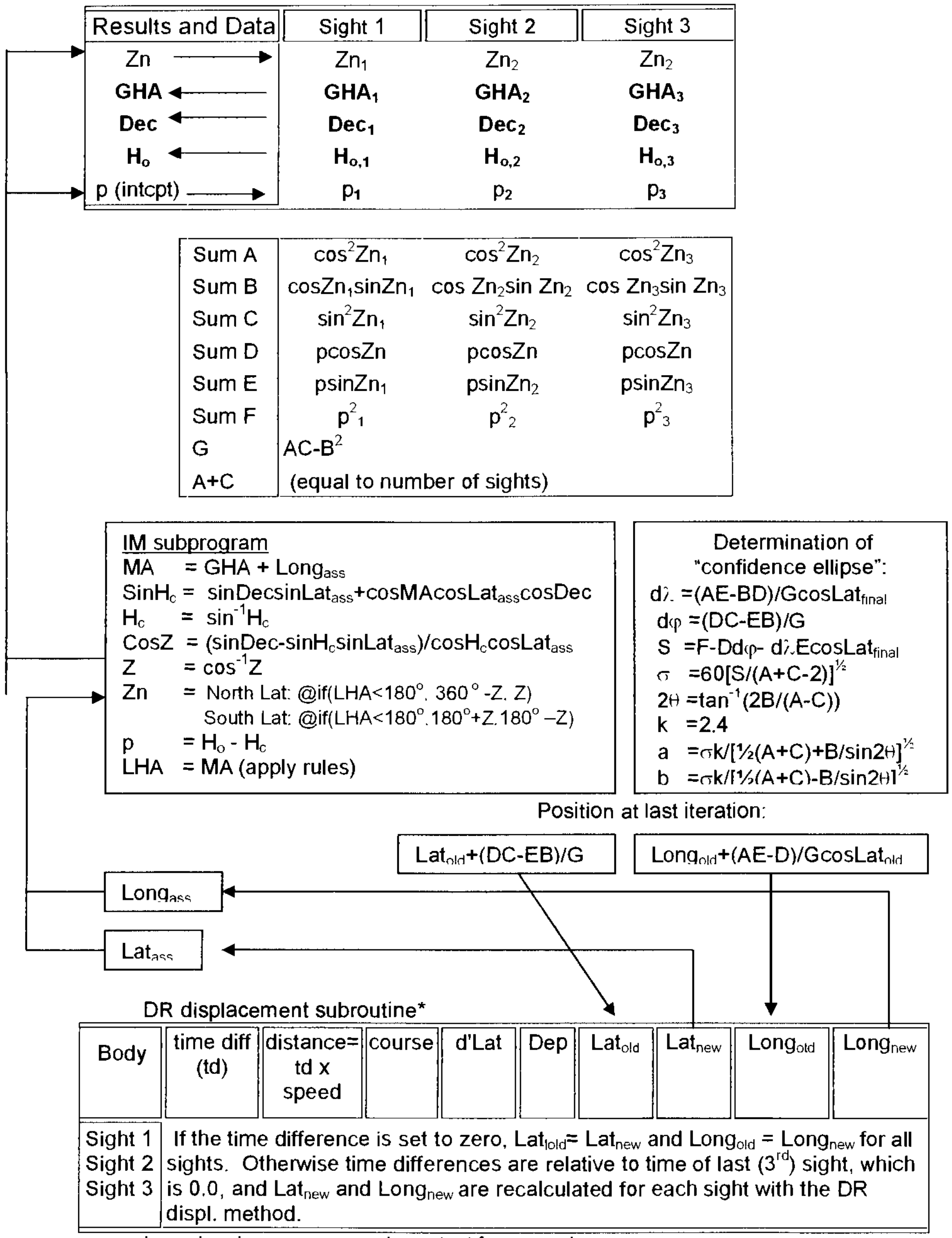
A*=	cosZn1
B*=	cosZn2
C*=	p1sinZn1-p2sinZn2

Solving with Cramer's rule:

d1 = (BC*-B*C)/AB*-A*B)

d2 = (AC*+A*C)/(AB*-A*B)

Appendix 3: Schema of Iterative LQS program



*speed and course assumed constant for convenience

(Endnotes)

1 The authors of the method for instance state: "...the size of the (confidence) ellipse...depends upon the errors of observation. The method assumes that the observations have equal weight. The best results will be obtained when the observations are equally spaced in azimuth. In such cases the effect of systematic errors on the final calculated position will be minimized" (Yallop & Hohenkerk. op. cit. pxxi).

2 For example, see G. G. Bennett, "General Conventions and Solutions - Their Use in Celestial Navigation". J of the Inst. of Navigation, USA Vol 26, issue 4, 1979, p 275-280; G. Keys, Practical Navigation by Calculator, 1982

3 For the algebraic solution method see the forthcoming issue of the Netherlands Institute of Navigation newsletter in which the author will publish this method.

4 The method was first published in B.D. Yallop and C.Y. Hohenkerk "Compact Data for Navigation and Astronomy" (H.M. Nautical Almanac Office - Royal Greenwich Observatory), 1986 and appeared in subsequent issues of the Nautical Almanac.

5 For more information on this package visit www.mobilegeographic.com. A general description of it is found in "Navigation help in a small package" by Larry McKenna, Ocean Navigator No. 128, March/April 2003.

6 See www.online-fischer.de

7 An application of a geometric solution method with the altitude-updating method is found in G. G. Bennett and G. Keats, op. cit.

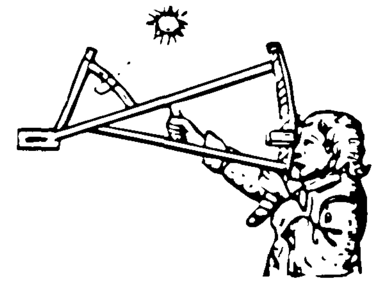
8 The data are from Yallop &Hohenkerk, op. cit. p xxiii.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

The National Geospatial-Intelligence Agency.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY-TWO, WINTER 2003-2004

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

I have the usual request that each member get a member. The interest in celestial navigation is rapidly eroding. If those of us who are dedicated to keep the art of celestial navigation from becoming extinct does not get new people interested in this ancient art it is doomed to extinction. By holding classes, educating sailors on the risk of going out to sea without a knowledge of celestial and extolling the joy of becoming proficient in this ancient art, you will help create interest in this ancient art. Keep hammering at every sailor you know to study celestial.

How many of you travel and take a PDA or a cell phone with a lithium ion battery inside. I do and even though I carry an electrical plug-in charger I have lost my total charge in countries which have electrical plugs for which I have no match. I found a Zink Air fuel cell that works just fine. I ordered one with the correct cable connection and when I need to recharge I open the fuel cell, plug it in and get a full charge. I get 3 charges from the fuel cell before it is exhausted. If you are interested, I can give you the location of the source of fuel cells.

We are now in the final stages of winter and time to start thinking about our navigational needs for our Spring and Summer cruising,. Your Foundation can provide you with Nautical Almanacs, Sight Reduction Tables, whether U.S. Government Publications or Commercial Editions. We can also supply you with nautical charts for any place in the world. Navigation books for many maritime publishers are also available. All are discounted for our members. On U.S. Government Publications there is 15% discount and on all commercial publications there is a 20% discount. The commercial versions cost a little more than half of the cost of the Government publications. On charts there is a 20% discount on all orders up to $100 and/or a 25% discount on all charts on orders over $100.00. All orders are plus postage. Order through your Foundation, save on your order and help the Foundation stay viable.

You can order by Fax or telephone at 301-622-6448, by e-mail at navigate1@comcast.net or by mail to either The Navigation Foundation, P.O. Box 1126, Rockville, Maryland 20850 or if you want to get your charts sooner write to: The Navigation Foundation, 12509 White Drive, Silver Spring, Maryland 20904.

For those who want the latest information on buoys, navaids, chart updates, Coast Pilot updates, Light List corrections, tides on line, Tides, Currents, Ports and Chart Corrections, check http://www.navcen.uscg.gov. There is a very long list of Internet sites available at this address.

Keep Celestial Navigation
From Becoming Extinct.
Sign Up A New Member!

DO YOU KNOW . . . ?

By Ernest Brown

Who was the chief architect of GPS throughout the system's concept, engineering, development, and implementation?

(Answer on page 19.)

READERS FORUM

Edited by Ernest Brown

Member J. E. Thompson wrote to the Executive Director on December 22, 2003:

"...Some of our members may enjoy my story of interest in celestial navigation. Kind of unique in that I am an Air Force fighter pilot. (F-4D/E/N). It all started in S.E.A. 1972 one night while escorting AC-130 gunships over Laos. My wso backseater was an 'old head' AF navigator, Major Phil Greenwood (now MIA, 1972). He was observing stars by eye (sic) as we went back and forth for air refueling requesting I 'mark' LAT/LONS via INS Computer and 'hacking' time GMT. Later after returning to base he used an almanac and compared our LAT/LONS from the INS to his estimates, and wow — he was within 3-5 nm each case. I was impressed and still am. Thus my interest in celestial continues. Our newsletters and articles from experts are a real pleasure and I look forward to each one — Thanks to all.

"Now retired from active duty, I am an instructor pilot for LSI contract teaching instrument flying to undergraduate pilot training at Columbus AFB, MS.

"A small world indeed — recently three grads from the Merchant Marine Academy, Long Island, NY, arrived for training as 2nd Lts in USAF. Guess what — assigned to me and wow what boon to my education of CelNav, they are super fine young folks — our members will be glad to learn — strong in moral values and very intelligent — young folks that do our system proud.

"For reader/member Wesley Jones, Issue Eighty-one Fall 2003 concerning sextants. I can offer that I purchased an Astra III B extant and find it very well constructed — I.C.0.4 with bubble horiz. Around $500.00 US with shipping. One just has to get over the fact it is made in China!! — ALAS — like so much else is! Also for what it's worth, I enrolled in David Burch's STARPATH CELESTIAL NAV course and find it excellent — recommend it to all novices like me.

"Some of our members may be disappointed to learn that the U.S.A.F Navigation Training School has stopped including Celestial Navigation in its formal course of training. Guess electronics has taken over -- hope the batteries hold up!"

— J. E. Thompson, "Land Locked Navigator"

Director Roger Jones responded to an inquiry about the teaching of celestial navigation:

"Terry Carraway, with whom I am associated in the Foundation for the Promotion of the Art of Navigation (The Navigation Foundation) has forwarded to me some of your e-mail correspondence. I was an early 'recruit' by Admiral Tom Davies and Capt. Carraway back in the 1980's when the Foundation was just getting started, and for a number of years was the editor of 'The Navigator's Newsletter,' as well as a contributor to that publication. One such contribution was a 'text' on celestial theory and practice, which was published in ten successive articles in the Newsletter. It has also been published in the Seven Seas Cruising Association Commodore's Bulletin, and I have used it to teach the subject in various venues both here in the East and also in California. (I am a Commodore of SSCA — actually a Rear Commodore now that I am no longer living aboard my sailing vessel, and a former Board member of SSCA.)

"In California I lived at 13900 Panay Way in Marina Del Rey from 1985 until early 1993 and then I lived aboard at the California Yacht Club during 1993. I left to go cruising on my Hand Christian cutter. I departed the CYC dock at midnight in early February of 1994 — bound for Panama.

"My 'text' is entitled *Celestial Navigation — An Armchair Perspective*, and I have had quite favorable feedback about it from mariners in far flung locations. It is addressed to celestial theory and practice using H.O. 249, which I think is understandably the preferred set of sight reduction tables for small boat mariners. It is a boil down of the usual 350 pages of 'stuff' that one finds in standard texts, and it presents both the theory and the step-by-step procedure and practice in 50 pages, including a universal sight reduction worksheet that I designed which can accommodate four sights on the front side, and a plotting sheet on the reverse side. Many students of mine have asked me for multiple copies of this worksheet, and I am happy to provide it to them. This monograph is in layman's terms and I have never had trouble teaching the subject to students who are complete novices. It is addressed mainly to the logical starting point. Sun sights, since it is those sights that most small boat navigators seem to favor because of their ease, the availability of the Sun throughout the day, and the ancillary procedures such as the LAN shot coupled with timed shots just before noon and at the same exact time interval after meridian passage to produce a very accurate longitude.

"If you would have any interest in examining *An Armchair Perspective*, I am sure Terry can provide you with a copy at a very, very modest cost. And if there is any way in which I can be of assistance or help to you in your endeavors out there in my old stomping grounds, please let me know. I salute your efforts, and welcome you as one of the brethren who seek to preserve the celestial art in this day and age of black boxes. There are not enough of us these days. But I do get 'recruits' from strange quarters. This morning I had a man fixing the air conditioning on my current boat (a Nordic Tug). Like me, he is both an airplane pilot and a sailor, and he wants to learn the celestial art, so I will teach it to him. He has a 45-foot sailing vessel. (Alas, my sailing vessel, '*Allidoro,*' was sold in 2000 after about 40,000 ocean miles, and after a very vexing case of serious bottom blisters.)

I am on the little tug now because of a need to stay out of the sun, but I've put 11,000 miles on her in about 3 years. I carry my sextant (a Tamaya Spica) aboard and all the tables, almanacs, etc.

"So — best wishes to you in your celestial classes. As was engraved in glass board *Allidoro,* 'May Dolphins Dance Beneath Your Bows!'"

— Roger H. Jones

Member George Huxtable sent on February 25, 2004:

"Shortcomings in "Some dilemmas in Multiple Sight Position Solutions" by K. Herman Zevering, in NN81, page 8:

1. Herman Zevering 's paper claims, in Table 1, to have discovered serious defects in using the intercept method to find a position, from the intersecting position lines that result from a pair of altitude observations. That would indeed be bad news for traditional navigators, who have confidently used that method for the last 150 years.

Although Zevering claims that his Table 1 shows such errors, he is mistaken. The large differences shown in Long(fix) between column 1,2, and 3 in that table can only be the result of arithmetic error in his program that computes them. Calculated properly, any difference between the various methods is navigationally insignificant.

As those presumed defects in the intercept method form the cornerstone of the whole paper, then much reassessment is now called for from the author. If that same fault program has been used to compute the various position solutions in Table 2 (for example), then it could explain why they, too, appear to show errors. It seems likely to me that a further recalculation is likely to remove all of the "dilemmas" that have so vexed the author.

2. There seems to be other problems with his Fig. 3. We are given no reason why the triangle A'B'C' (misstated in the text sometimes as A.B.C.) Should be smaller than triangle ABC. I can see no reason why the two should differ in any way. That diagram itself gives rise to confusion in that, as printed, it's not on a Mercator projection. The vertical scale, to judge by the North-South distance between A and C, is 6.75 miles per inch, whereas judging by the East-West distance B to C, it's 5.5 miles per inch, so distortion abounds.

3. It's often unclear where the paper refers to 'systematic' error, where to random error, and where to a combination of the two. There can be circumstances, such as a wrongly-measured index error, or a bad day for anomalous dip, in which a common error can affect all measured altitudes in the same way, by the same amount. If the observer KNOWS that this is the case and KNOWS that any random-errors are small in comparison, then there are steps he can take (given 3 or more such altitudes) to allow for those errors.

Zevering refers to those as "systematic" errors, although other types of error exist (such as timing inaccuracies, or taking the almanac predictions for the wrong day) which are equally systematic, but have quite a different effect. In this note, his restricted meaning for "systematic" will be followed.

In real life in a small vessel, random errors in measured altitude, varying unpredictably from one measurement to the next, caused mostly by the motion of the vessel and the unsteadiness of the horizon, are likely to be much larger than any systematic errors. The resulting data-set will be a tangled combination of both types of error, impossible to separate out. That's what gets fed to the sight-reduction procedure, for it to do its best with.

Zevering considers that "applied to three or more sights in the sight-run-sight situation, the LSQ [least squares] method not only calculates a statistical confidence zone around the "fix" but also minimises systematic error." To back this claim he quotes from the authors of that method -"The best results will be obtained when the observations are equally spaced in azimuth. In such cases the effect of systematic errors on the final calculated position will be minimised."

Here, Zevering appears to have misunderstood what was being said, which does no more than correctly describe a strategy to minimise the effects of such systematic error. It applied to ANY method of processing the data; not just to the least-squares method, which has no magic powers to differentiate between random errors and systematic errors. Indeed, its processing presumes that all errors are random ones.

Zevering suggests that "when offering the data to a least-squares program, it is advisable to omit inconsistent sights first." If he has taken sets of simultaneous altitudes of three bodies, then assuming that errors are random rather than systematic, observation from half of these sets would have to be rejected as failing his own "inconsistent" test. And if he takes repeated sights to three objects at say 120deg, 180deg, 240deg, and the systematic errors happen to dominate the random ones, then in every set-of-three he takes, the one at 180deg will have to be rejected by his own test.

4. What is the point of trying to discover exactly where, within a cocked-hat, a "fix" (whatever that is supposed to be) should be placed? If all errors are random ones, then the cocked hat has only a one-in-four chance that it envelops the true position at all. Three times out of four, the true position will lie outside the cocked hat, no matter how precise the observer is. The cocked hat provides no more than an indication, a "smudge" on the chart, as to the general area in which the observer is likely to be. Attempts to squeeze more information than that out of a cocked hat are only going to mislead."

— George Huxtable FRIN

Member Herbert Prinz sent on February 28, 2004:

"As a member of the Foundation, I read the Newsletter regularly with interest and joy. My focus is on the subtler technical issues of celestial navigation methods, old and new. The articles in the Newsletter on this subject are usually of high standard. All the more was I disappointed after having read Mr. Zevering's contribution in issue #81. I cannot imagine how this article managed to slip by the editor's watchful eye . . . . In my opinion the article was not worthy of the Newsletter and should not have been printed . . . ."

— Herbert Prinz

Member K. H. Zevering sent this note on March 14, 2004:

I have in fact taken the argument also beyond the simple mistake and the results which obviously don't support my theoretical contentions on the IM. I have prepared a comprehensive rejoinder on this issue which I will send to you shortly. I am in touch with Mr. Huxtable, but the difference between his and my approach is that I am not interested in getting practical results, but in getting results that are independent of initial DR assumptions. Apparently Huxtable is sending in his own rejoinder so I hope that you can accommodate both his and my submissions in the next issue. The plot thickens and it certainly becomes very interesting. I do hope you have recovered from your illness and assure you that I at not time felt inconvenienced by your correspondence. I was a bit slow in understanding that it all boiled down to a mistake and the wrong example, while I was actually focussing on real dilemmas.

—Regards, Herman Zevering

YACHT FIONA ROUND THE WORLD THE WAY OF THE CLIPPER SHIPS, 2002-2003

Newsletter 5

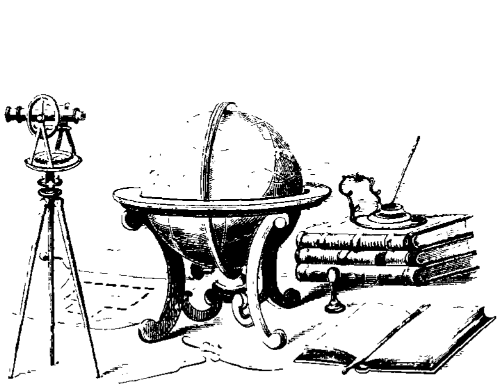
Eric B. Forsyth, Master

Barbados to BVI, Bermuda

Editor's note: Newsletter 4 was inadvertently published in Issue 80 as Newsletter 3.

"Dear Friends, the character of the cruise changed radically after I returned to Barbados in early June. No more long hauls across thousands of miles of open ocean; what I envisaged were leisurely sails in the islands of the Caribbean, Bermuda and the coast of Maine. The longest legs would be Puerto Rico to Bermuda and Bermuda to Maine, each about 800 nautical miles. It did not quite work out that way, as you will learn. I brought back two duffel bags packed with spares, including the radar, depth finder, newly-machined support tube for the self-steerer and a new lower unit for the jib furler. American Airlines were nice enough not to charge for excess baggage. I had left *Fiona* at a very odd marina called Port St. Charles, which consists of luxury condos costing half a million dollars and up with slips for the owners' yachts. The marina was a small addition to the development; unfortunately the builders apparently ran out of money before they completed the toilets, showers and any social amenities such as a bar. It was like living on a film set. The day after I got back I moved the boat to Carlisle Bay year Bridgetown, completed a few repairs and waited for the new crew, Jacqui, to fly in. Unfortunately, the refrigerator would not work after I got back. In the 90° heat this was a serious problem, especially as I was expecting my daughter Brenda and her husband Rich to spend a week on the boat when we got to the Virgin Islands. When Jacqui showed up we lugged the refrigerator out of the galley, into the dinghy and took it to a repair shop. Fruitless, as it turned out. It still didn't work. One day we took a bus along the winding lanes of the Barbados back country to an old slave plantation that had been restored for the tourists. The bus home filled up with chattering school children and the driver turned up the volume of the rock music on the radio. He drove faster and faster, screeching the old bus round the tight bends. Suddenly he stopped at a gas station. The conductor dashed inside for a bottle, which I assumed was to drink. Wrong. It was brake fluid. He poured it down a hole in the dash, pumped vigorously on the pedal for a couple of minutes and, satisfied with the pedal pressure, resumed his mad ride to the center of Bridgetown. About a week after Jacqui joined the boat we sailed overnight to Union Island in the Grenadines. As we were checking in with the customs and immigration officials at the airport, a yachtie came up to me and said, 'Eric, remember me?' I confessed to a senior moment. 'Rich and Nancy,' he replied. 'We met at the marina in Portland, oh, about four years go.' It slowly came back to me: I had been on the way to Maine after the cruise to Antarctica in 1999. Such is the small world of the cruising fraternity. We agreed to meet at a bar on the shore for a sundowner, but we never made it. Why? Because about an hour before our rendezvous we dinghied to a tiny island in the harbor called the 'Happy Hour Bar." We had a very acceptable rum punch and then hauled the inflatable dinghy alongside for the ride to shore. I then discovered the 'dock' was made of conch shells set in concrete. As Jacqui and I climbed in, the dinghy rubbed against the shells, which tore a one-inch gash in the rubber. The dinghy began to deflate very quickly. We made a dash to the boat as it settled lower and lower in the water and stepped aboard just as the dingy sank. Fortunately, one pontoon was still intact and we were able to hook up a halyard just as the outboard motor was about to disappear under the waves. Rich and Nancy finally came looking for us, only to find me gluing a patch on the remains and muttering about idiots and conch shells. We had our sundowner on *Fiona*, in fact, several. From there we sailed to Mayero, a small island that was a favorite anchorage of Edith and me when we cruised the

Caribbean aboard *Iona* in the late 1980's. Progress had come to Mayero; they now had a central generator and the village had sprouted poles festooned with street lights and electric distribution wires. We climbed to the stop of the hill for a breathtaking view of the islands and reefs forming Tobago Cays lying to the east; they were to be our next stop. Unfortunately, it was very windy and the next day as we edged out through the shallows and dropped the hook in company with about twenty other boats behind Horseshoe Reef. Snorkeling in half a gale wasn't much fun and the wind was too strong for us to rig the awning to keep off the sun. The next day we sailed to Bequia. We discovered Rich and Nancy anchored off the village. We dined with them a couple of times, hiked over to the south shore (there is a very friendly bar) and got our laundry done. The plan next was to sail to Martinique, but fate intervened. As we sailed out of the lee on the west side of St. Vincent we encountered a notorious wind acceleration zone. Although we only had a reefed jib set, *Fiona* heeled in the gusts. Suddenly there was a loud bang. I made a quick trip forward to confirm my fear. Yes, the bobstay had snapped again. It had broken before on the transatlantic leg of the cruise. We had then used a piece of anchor chain which seemed thick enough to last the remainder of the trip. But when I examined it after this failure I found deep corrosion on the link attached to the hull at the waterline. The loss of tension on the bobstay caused the bow platform to move up and this, in turn, jammed the jib furler. I could not roll the jib in or out. The flogging sail made a tremendous racket and the slack headstay snapped viciously in the wind gusts. Poor Jacqui, who did not have much sailing experience, was clearly very frightened but she managed to steer the boat downwind to keep the tension off the sail while I worked with a chain wrench to slowly roll in the jib, inch by inch. Then I had to brace the headstay. When I looked closely at the bow platform I noticed a heavy stainless steel bracket which attached it to the hull had cracked. Obviously I was in for some heavy maintenance again. I decided the only practical solution was to sail directly to St. Martin, more than 400 nautical miles to the north. All the facilities I needed could be found there. We set a reefed mainsail and with an assist from the engine made the trip in two and a half days. We were both heartily thankful that the hot, refrigeratorless trip was over when the anchor dropped into ten feet of clear water in Marigot Bay. My old friend, Kay Pope, has an apartment overlooking the bay. She immediately invited us to dinner preceded by a shower. Her daughter Victoria came over too. She was a playmate of my son Colin when they were both small children living on boats in the 1960's. How time flies. The next week was mostly devoted to fixing the boat, although every morning we started the day with a delicious breakfast ashore featuring French croissants. We usually picked up a baguette at the same time for our lunch. I installed a new refrigerator, bobstay and jib furler. One day Jacqui and I powered *Fiona* over to the Dutch side of St. Martin for a visit to the welder. The next day we started to bend on the jib, but the sail caught on a protruding cotter pin and tore. When I went to inspect the offending pin the boat gave a roll in the wind and I gashed my leg badly on the same pin! Kay ran me over to the emergency room of the local hospital where a doctor put in five stitches — total cost, $23. When I took the sail for repair it cost $40, but they put in more stitches. When the sail was returned we were ready, but Jacqui had had enough of the continuous maintenance. It certainly had not been the kind of cruise she hoped for, and she left by air. I sailed the boat single-handed to Tortola in the British Virgin Islands just in time to meet my daughter Brenda and her husband Rich, who are, incidentally, the mistress and master of the Yachtfiona website. Rich brought a new laptop. My old one was never the same after the rigors and dampness of Cape Horn.



"We sailed from Trellis Bay to the beautiful, unspoiled (relatively) island of Anegada. We hiked along the sandy beach, stopping for refreshments at convenient small hotels. From there we sailed to West End and the next day we took the ferry to St. John in the U.S. Virgin Islands. After this brief taste of the U.S. we made the short sail to Great Harbour and the famous Foxy's Bar on Yost Van Dyke. The next day we re-entered the U.S. at Culebra and then sailed to the huge marina just south of Fajardo in Puerto Rico. Brenda and Rich liked the showers. We rented a car and drove to the old part of San Juan for a day. While Brenda and Rich explored the casino I scouted for a doctor to take the stitches out of my leg, which had become swollen and red. We finally wound up at the emergency room of the local hospital, where a very nice young physician snipped away. Total cost, $106. I was back in the U.S. Brenda and Rich flew home the next day, and the day after that I picked up the first of my new crew, William, who runs his own computer company. He brought along his laptop so that he could do some work while sailing. Combined with my new one I suspect we had more computing power aboard than was possessed by the Pentagon ten years ago. While waiting for the arrival of the second crew member, William and I drove to the Caribbean National Forest, a wonderfully scenic rain forest on the slopes of El Yunque, 'the Rainmaker.'

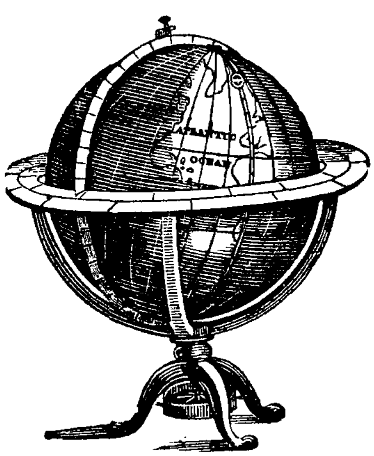
We parked the car and climbed the last 1000 feet in the trees to the summit. It was shrouded in cloud so we did not get a view, and the top was cluttered with antennas, transmitting equipment and a diesel generator. The next day Andrew showed up to sign on the crew list. He is a young Australian on a six month walkabout. We left the marina almost immediately for the 850 nautical mile leg to Bermuda. We enjoyed great beam winds for the first four days, then we ran into a windless high pressure ridge lying over Bermuda and had to fire up the old Perkins, but we still managed to tie up at St. George's in a little over six days from leaving Puerto Rico.

"Bermuda seems much the same. We arrived at the peak of the cruise ship season. During the week there were usually two in St. George's. The locals appreciate the weekends when the hordes of pale, often overweight tourists are briefly gone. Several days after we arrived, Bermuda had a general election. The ruling Progressive Labour Party was returned to power. The scandal came a couple of days later when the party fired the leader, who is automatically the premier, in an internal coup. The new deputy premier was quite frank that this change was in the works before the election but they kept it quiet so as not to affect the outcome. I was amazed at the passivity with which the voters and the opposition party accepted this bit of double-dealing. We stayed over a week in St. George's, tied up to Somers Wharf. We got the mainsail repaired and did other maintenance chores, but it was about 90°F each day, so we didn't push it. The next big event was the annual cricket match between St. George's representing the east end and Somerset the west end. The two day affair ended in a draw, but nobody minded it. It was the festivity that everyone enjoyed. William and I went to the first day. Andrew saw the match through to the end. Visitors were able to sit on benches in a shaded stand. Free drinks and fresh fruit were frequently passed out to counteract the heat. After the match we moved the boat to Mangrove Bay, just in time for another big party, this time on the water, the annual Non-Mariners Race. Spoof boats are specially built to take part. None are expected to finish as it is a non-race. The event was attended by literally hundreds of boats, with many of the spectators jumping in the water and swimming over for a better view. This was no hardship; the water temperature is 85°F this time of the year. We anchored near the head of the bay early in the morning, but by lunchtime we were hemmed in by dozens of boats that came within a few inches of us as the rafted clusters swung in the light breeze. It was all very noisy and jolly and a great deal of beer was swigged. From there we sailed to another favorite anchorage, Ely's Harbour. This is a beautiful spot with small beaches, clear water and great snorkeling. Andrew had bought a disposable underwater camera he was eager to try. We visited the massive fortifications of the old naval dockyard by bus and then sailed in Great Sound to anchor in Paradise Cover. On the north side of the cove is Long Island. During the Boer War the most obstreperous Boer prisoners of war were sent to Bermuda, as escape is virtually impossible from there. About a couple of dozen died and they are buried on Long Island. For some reason the gravestones are identified only by a number. At some stage the Boers themselves erected a memorial which named each numbered grave. We landed by dinghy and wandered through the lovely cemetery. It was impossible not to feel sorry for these men dying so far from home. The next day we picked up a mooring at Hinson Island belonging to Tony Jones, the Rear Commodore of the Bermuda Station of the Cruising Club of America. He and his wife Liz treated us to a memorable supper in a gazebo on the lawn overlooking Hamilton Harbour. Then it was time to return to St. George's and get our clearance for the leg to Maine.

"We experienced mostly fair winds for the trip. We encountered some adverse currents in the Gulf Stream but we sailed out of them in a day or so. As we sailed north we finally encountered cooler weather. Near 40°N *Fiona* crossed her outward track and thus completed her second circumnavigation. A day later we picked up a mooring in Bar Harbor, Maine, a week after leaving Bermuda. During this leg, William assiduously practiced celestial navigation. He is planning to buy a sailboat of his own and the trip aboard *Fiona* was a way of getting back in the swim after a long break. He left us at Bar Harbor. His place was taken by Lew, an old friend who is now a professional video editor. We anchored or moored at several lovely islands as we slowly made out way through Penebscot Bay. In Stonington we ran into a young woman at the old opera house who was working on its restoration. She gave a us a guided tour of the dark interior. Many Maine towns had an opera house during the late 19th century. The one at Stonington is quite large. It is listed on the National Register of Historic Buildings. After a night at Belfast we spent two nights at Rockland, a small town with two great museums, the Farnsworth and the Owl's Head Transportation Museum. The Farnsworth always has a number of Andrew Wyeth paintings on view as he spent his summers nearby where he often painted members of the Olson family. From there we explored Hurricane Island, where the Outward Bound School is located. We watched the students learning rope climbing at an abandoned granite quarry and when I stepped off the trail to inspect an old, rusting steam engine, I nearly poked my eye out on a tree branch, and sported a black eye for my pains. I had arranged to meet a fellow vintage car enthusiast at her summer cottage on Muscongus Bay. Sarah is a Buggati fan. Several other Buggati drivers were staying with her before attending a meet in Connecticut. We all went out for a sail aboard the boat to give them a taste of Maine cruising.

"Unfortunately, I made it too realistic by running the boat onto a ledge as we entered the anchorage at Harbor

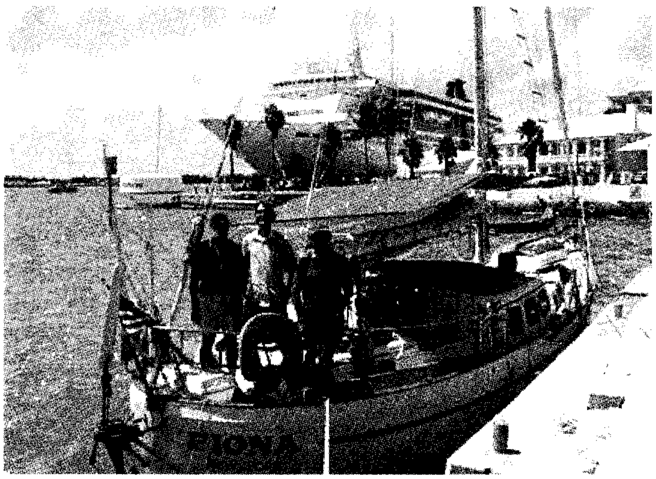
Island for lunch. In my defense, the ledge was not on the chart. Andrew and Lew got a lift to Brunswick from Sarah's place and departed on the daily bus to Portland and points south. I was joined by Malcolm, who is a friend from vintage Bentley rallies. We sailed west at a leisurely pace. One day we sailed to Damariscove Island for lunch and anchored in the narrow harbor. It is a small island about a quarter mile wide and a mile and a half long. It lies five miles south of Boothbay Harbor in the Atlantic Ocean. Despite its small size and remoteness, it has an amazing history. It was visited by the Mayflower in 1620 and frequently used by ships from Europe in the 17th century for the transshipment of cargo so they avoided running closer to the coast. It was very busy in the 17th century when hundreds of colonists fled to the island during the Indian wars. Much later a farmer kept cows and delivered milk to nearby islands by rowing a boat, winter and summer. It is now a Nature Conservancy. We walked along one of the trails. Scattered foundations and dry stone walls were testimony to its past. In the late afternoon we sailed to Monhegan Island, about 12 miles to the east. We arrived an hour before sunset so that we could use one of the moorings of the charter vessels that make daily visits to the island. This is perfectly acceptable provided you leave before 10 AM the next morning. As the sun sank we sat in the cockpit with our *Fiona* rum cocktail and witnessed a strange sight. A lobster boat circled the harbor with a knot of people standing at the stern. A small crowd gathered on the wharf. Then the boat launched something on the sea that blazed with crimson flames and sent a plume of black smoke into the sky. Looking through the binoculars I saw it was a miniature Viking ship. We found out the next morning when we went ashore that we had witnessed the Viking funeral of a local resident whose ashes were in the little ship. They do things differently at Monhegan. At Five Island Harbor on the Sheepscot River we collected mussels off the rocks and put them in a bucket to clear themselves of sand. We ate them for happy hour at Seguin Island the next afternoon. This remote offshore island has one of the first lighthouses to be built in the United States. It was authorized by George W. himself. We spent a night at Sebacus where Malcolm and I contacted some friends who live locally and we had dinner together. The next day we sailed to a yacht club on Orr's Island where we made contact with the family of a CCA member we had met in the Azores last year at the start of our cruise. His mother arranged for the commodore of the CCA to visit the next day. He and his wife came for happy hour. They were interested in the trip and it turned out that they and Malcolm had mutual friends — small world. The next day we sailed to Eagle Island, the retirement home of Admiral Peary, but the house, which is now a museum, was closed. We sailed on in thick fog to Jewel Island for the night. The island has WWII fortifications. We climbed to the top of the old watch tower and then squelched our way through the thick undergrowth to the rocky south side. From Jewel we sailed to South Freeport and then Portland, where Mike came up from Long Island to join us for the jaunt down the coast of New England. I was sorry to leave the wonderful coast of Maine. We had enjoyed great warm weather, even though we could have used more wind. We were delayed a day by a gloomy weather forecast caused by hurricane Isabel.



"There was no wind as we left Portland. We powered to Isles of Shoals and stopped for supper. There we met another CCA member and his wife, Skip and Ilze, who lived on their boat and had completed a circumnavigation of several years. I decided not to waste the night sleeping so we cranked up the engine and powered overnight to Provincetown on the tip of Cape Cod. Compared to my previous visits, it seemed very quiet, a situation attributed equally to the economy and hurricane Isabel, the locals said. The next day we had a wonderful sail across Cape Cod Bay to the canal but when we emerged into Buzzards Bay we encountered steep, unpleasant seas kicked up by a southerly wind blowing down the bay at up to 30 knots. We sought a sheltered bay for a quiet night on the anchor. The following day we had great sailing conditions for a sail to Newport, a charming town. We were just in time for a party at the Ida Lewis Yacht Club, where we picked up a mooring. After exploring the town in the morning, we sailed to Block Island but head winds delayed us and we arrived after dark. In the old tradition of the square riggers, we spruced up the ship the next day and then left for the drag down the south shore of Long Island, which we did under power. We had a tense time sailing the shallows of Great South Bay in a thick fog. When we tied up at Weeks Yachtyard it was a year and fifteen weeks since we departed with 32,869 nautical miles logged. The condition of *Fiona* certainly reflects high mileage, about half of it in the Southern Ocean. It will take many months to get her shipshape again. After that, who knows?"

— *Best wishes, Eric*

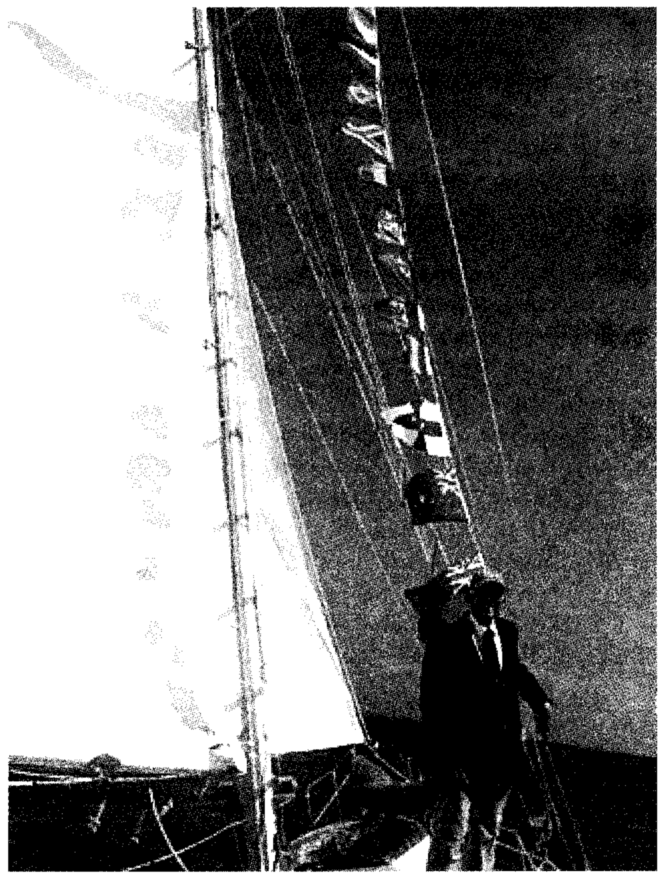
Rich, Eric and Brenda at the famous Foxy's Bar on Jost Van Dyke, British Islands.



L to R, William, Andrew and Eric on the aft deck with a massive cruise ship in the background, St. George's, Bermuda.

The island of Monhegan. It was here we witnessed the unique Viking funeral.

Fiona approaches the Robert Moses Bridge on Long Island's south shore as the fog thickens on the last day of the cruise



Eric poses with flags of some of the countries visited as Fiona sails close-hauled towards Patchogue

Press Release from Brookhaven National Laboratory

Eric Forsyth to Show Film at Brookhaven Lab About His Sailing Adventures, March 4

UPTON, NY — Eric Forsyth will present a one-hour sailing video, featuring highlights from his recent circumnavigation of the world aboard his 42-foot yacht, *Fiona*, on Thursday, March 4, at noon in the Laboratory's Berkner Hall. Forsyth is a retired engineer from the Department of Energy's Brookhaven National Laboratory. This video presentation is free and open to the public. All Visitors to the Laboratory age 16 and over must bring a photo ID.

During his presentation, sponsored by the Brookhaven Retired Employees Association, Forsyth will tell the story of how he followed the routes of the old clipper ships that were used before the opening of the Suez and Panama Canals. He will chronicle his voyage to Cape Town in South Africa, past the Cape of Good Hope, across Antarctica's Southern Ocean, to Cape Leeuwin in Australia, and Cape Horn at the tip of South America. He will also describe his visit to the remote island of Kerguelen, which is a French possession located between Africa, Antarctica, and Australia some 13,000 kilometers from France in the Southern Indian Ocean, and to the remote island of South Georgia, once part of the Falkland Islands — now a British territory. The 15-month voyage was completed with leisurely cruising in the Caribbean, Bermuda, and Maine.

This was Forsyth's second circumnavigation made since 1995. He has also sailed to the High Arctic and the Antarctic. For this latter cruise he was awarded the 2000 Blue Water Medal by the Cruising Club of America. This medal has been awarded annually since 1929 to an amateur sailor from any country for "a meritorious example of seamanship and adventure."

Forsyth joined Brookhaven in 1960 to work at the Alternating Gradient Synchrotron, one of the Lab's particle accelerators. From 1986 until 1990, he was Chair of the Accelerator Department, at that time responsible for the pre-construction design and planning of the Lab's newest accelerator, the Relativistic Heavy Ion Collider (RHIC), among other projects. In 1990 he took a leave of absence and sailed to the South Pacific with his wife Edith who was a former physician in Brookhaven's Medical Department and died in 1991. Forsyth worked part-time on technical aspects of RHIC from 1992 and retired in 1995. More details of the cruise are available at www.yachtfiona.com.

One of the ten national laboratories overseen and primarily funded by the Office of Science of the U.S. Department of Energy (DOE), Brookhaven National Laboratory conducts research in the physical, biomedical, and environmental sciences, as well as in energy technologies and national security. Brookhaven Lab also builds and operates major scientific facilities available to university, industry and government researchers. Brookhaven is operated and managed for DOE's Office of Science by Brookhaven Science Associates, a limited-liability company founded by Stony Brook University, the largest academic user of Laboratory facilities, and Battelle, a nonprofit, applied and science and technology organization. Visit Brookhaven Lab's electronic newsroom for links, news archives, graphics, and more: http://www.bnl.gov/newsroom.

NOTE TO LOCAL EDITORS: Eric Forsyth is a resident of Brookhaven Hamlet, NY.

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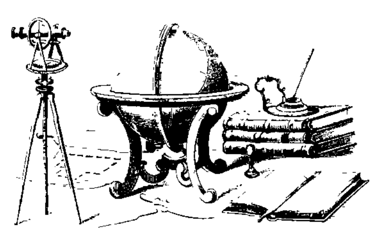
On February 9th, 2004, Eric Forsyth presented a three hour lecture on the History of Marine Navigation at the Carmans River Maritime Center on Long Island. He touched on the Polynesian methods using stars, birds, vegetation and reflected swell. This was illustrated with a Polynesian shell and bamboo 'chart' obtained many years ago in the South Pacific. Next he turned to the Viking voyages and he demonstrated the use of a shadow pin with a home-made replica. The principle was illustrated with an analogy of flat-landers observing the passage of a high light on a post. This established the ideas of zenith altitude, local noon and a line of position for the audience. From there he went on to describe the developments in Western Europe in the Middle Ages and the growth of astronomical understanding. He described the problem of longitude and the development of the chronometer and the sextant. This period was illustrated by a US Navy chronometer circa 1940s, an old vernier-type Hezzanith sextant and a modern Plath micrometer drum instrument. He then described the evolution of the noon latitude into the Sumner line. The need for rapid calculations for a fix prior to WWII resulted in the invention of sight reduction tables. Forsyth ran through the procedure for obtaining a position by celestial means on a modern yacht making a transoceanic passage. The talk concluded with a discussion of the Global Positioning System.



NAVIGATION NOTES

H. O. 229 Interpolation

By E. B. Brown and J. J. Speight

NAVIGATION: *Journal of the Institute of Navigation*

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Abstract

This paper amplifies and, in some cases, clarifies the instructions for the various interpolation procedures as printed in each volume of H.O. Pub. No. 229, *Sight Reduction Tables for Marine Navigation.* The designs of the special interpolation diagrams and tables are outlined. The relationship of the Interpolation Table with the second and third terms of Bessel's Interpolation Formula is shown.

A graphical correlation of the several manipulations of the interpolation diagrams with the simple alternative procedure described in H.O. 229 for interpolating altitude for hour angle and latitude increments is used to illustrate the principles upon which the design of the diagrams is based. Knowledge of the principles, in turn, enables more expeditious use of diagrams. Also, the latter correlation indicates the relative merits of the two basic procedures. The alternative procedure requiring a simple graphical construction on the plotting sheet or chart is considered more suitable for great-circle solutions. The precisions with which the solutions are determined using the diagrams are not justified when using the assumption that the spheroidal Earth is a perfect sphere; the relative complexity of the use of the diagrams tends to increase the number of blunders.

The treatment of interpolation for second differences provides a graphical illustration of why the double second-difference correction is always positive. The coverage of the linear part of the Interpolation Table reveals the inclusion of certain modifying quantities in the tabular values. Their inclusion explains why the values as extracted from the tens part of the table are not always to the nearest tenth of a minute according to the entering arguments.

Introduction

H.O. Pub. No. 229, *Sight Reduction Tables for Marine Navigation,* published in six volumes by the Defense Mapping Agency Hydrographic Center is essentially a compilation of the solutions of a spherical triangle, of which two sides and the included angle are known. Solutions are tabulated for all possible combinations of integral values of the two sides and the included angle. In cases in which one or more of the three known parts of the spherical triangle are nonintegral, the tables contain provisions for interpolating the tabular value of the third side for the differences of the known parts from integral values.

As illustrated in Fig. 1, the parts of the celestial (spherical) triangle are polar distance (90° + or - declination), colatitude (90° - latitude), zenith distance (90° + or - altitude), local hour angle (LHA), azimuth angle (Z), and parallactic angle* (M). In celestial sight reduction the three known parts of the triangle are colatitude, polar distance, and local hour angle — two sides and the included angle of the triangle. For simplicity the sight is usually reduced from an assumed position of the observer which provides integral values of colatitude and local hour angle. Thus there usually is only need for interpolating the third side (zenith distance) for any difference of the polar distance of the celestial body from an integral value.

**The parallactic angle is not usually of interest in celestial navigation; its value can be found in the tables through the use of substitution.*

Because the navigator works in terms of latitude, declination, and altitude rather than their co-values,

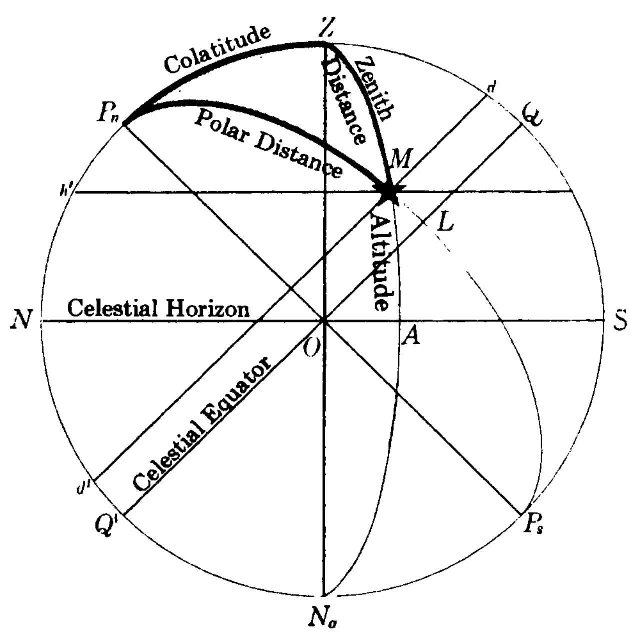


Figure 1.

local hour angle and azimuth angle are the only actual parts of the celestial triangle tabulated in the tables as entering argument or respondent. The use of latitude, declination and altitude in the tables rather than their corresponding parts of the celestial triangle, therefore, must be kept in mind when using the tables for the general solution of the spherical triangle, of which two sides and the included angle are known.

In recognition of the fact that virtually all users of H.O. Pub. No. 214, *Tables of Computed Altitude and Azimuth,* reduce their sights from a position so chosen that the hour angle and latitude arguments are integral, the main part of the H.O. 229 table does not include the equivalent of the Δt values in H.O. 214, i.e., the change in altitude for change in hour angles. Special diagrams are contained in each volume for graphical interpolation of altitude for minutes differences of hour angle and latitude from integral values to afford means for such interpolation when desired. Although the tables contain no formal means for interpolation of the azimuth angle, the interpolation table designed for interpolation of altitude for minutes and tenths of minutes of declination (Declination Increment) can be used in most cases for interpolation of azimuth angle for declination increments.

The Entering Arguments

In Fig. 2 the respondents are bracketed for the following arguments:

LHA 30°
Latitude 38°N
(Same Name as Declination)
Declination 10°N
(actual declination (10°52.'0 N)

Unlike H.O. 214, the tabular declination used to extract the respondents is always the integral degree of declination just numerically less than or equal to the actual declination. Even though declination 11° is closer to the actual value of the declination, declination 10° being the integral degree of declination just numerically less than the actual declination is used to extract the data.

The Respondents

For the entering arguments, the respondents are:
tabular altitude (ht) 51°10.'0
altitude difference (d) (+46.'4 and
azimuth angle (Z) N 128°.3W*

The altitude difference (+46.') is the first difference of the tabular altitudes for declination 10° and 11°, latitude and hour angle being constant. The sign of the altitude difference is assigned in accordance with the change in altitude as the declination increases in numerical value.

First and Second Differences

Although the accuracy of linear interpolation usually decreases as the altitude increases, linear interpolation of altitude using only the first difference is deemed adequate, generally, for altitudes below 60°. In some instances when the altitude is in excess of 60°, it may be necessary to include the effects of second differences. When the effects of second differences should not be neglected, the altitude difference (first difference) is printed in italic type followed by a small dot. Although the use of second differences may not be indicated by italic type and a small dot, the effects of second differences can be included in the interpolation whenever it is desired to obtain greater accuracy.

Fig. 3 (Please see page 12.) is a curve constructed in accordance with various tabular altitudes and declinations for latitude 38° (Same Name as Declination) and LHA 30° given in Table 1.

If the actual declination lies between 41° and 42° and straightline or linear interpolation is used to correct the tabular altitude for declination increment, the corrected altitude lies on the broken line in Fig. 3. Thus, allowing for first differences only, the altitude is too low. Consequently, the correction for second difference is always positive.

30°, 330° L.H.A. **LATITUDE SAME NAME AS DECLINATION**

	38°			39°			40°			41°			42°			43°		
Dec.	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
0	43 02.1	+50.4	136.8	42 18.1	+50.9	137.5	41 33.6	+51.5	138.1	40 48.8	+51.9	138.7	40 03.6	+52.3	139.2	39 18.0	+52.7	139.8
1	43 52.5	50.0	136.1	43 09.0	50.6	136.7	42 25.1	51.1	137.4	41 40.7	51.7	138.0	40 55.9	52.1	138.6	40 10.7	52.6	139.1
2	44 42.5	49.8	135.3	43 59.6	50.4	136.0	43 16.2	50.9	136.7	42 32.4	51.4	137.3	41 48.0	51.9	137.9	41 03.3	52.4	138.5
3	45 32.3	49.5	134.5	44 50.0	50.0	135.2	44 07.1	50.6	135.9	43 23.8	51.1	136.6	42 39.9	51.7	137.2	41 55.7	52.1	137.8
4	46 21.8	49.0	133.7	45 40.0	49.7	134.5	44 57.7	50.3	135.2	44 14.9	50.9	135.9	43 31.6	51.4	136.5	42 47.8	51.9	137.2
5	47 10.8	+48.7	132.9	46 29.7	+49.4	133.7	45 48.0	+50.0	134.4	45 05.8	+50.5	135.1	44 23.0	+51.1	135.8	43 39.7	+51.7	136.5
6	47 59.5	48.3	132.0	47 19.1	48.9	132.8	46 38.0	49.6	133.6	45 56.3	50.2	134.4	45 14.1	50.8	135.1	44 31.4	51.3	135.8
7	48 47.8	47.9	131.1	48 08.0	48.6	132.0	47 27.6	49.3	132.8	46 46.5	49.9	133.6	46 04.9	50.5	134.3	45 22.7	51.1	135.0
8	49 35.7	47.4	130.2	48 56.6	48.2	131.1	48 16.9	48.8	131.9	47 36.4	49.6	132.7	46 55.4	50.2	133.5	46 13.8	50.8	134.3
9	50 23.1	46.9	129.2	49 44.8	47.7	130.2	49 05.7	48.5	131.0	48 26.0	49.1	131.9	47 45.6	49.8	132.7	47 04.6	.50.4	133.5
→ 10	[51 10.0	+46.4	128.3]	50 32.5	+47.2	129.2	49 54.2	+48.0	130.1	49 15.1	+48.8·	131.0	48 35.4	+49.5	131.9	47 55.0	+50.1	132.7
11	51 56.4	45.9	127.2	51 19.7	46.7	128.2	50 42.2	47.5	129.2	50 03.9	48.3	130.1	49 24.9	49.0	131.0	48 45.1	49.8	131.9
12	52 42.3	45.3	126.2	52 06.4	46.2	127.2	51 29.7	47.1	128.2	50 52.2	47.9	129.2	50 13.9	48.6	130.1	49 34.9	49.3	131.0
13	53 27.6	44.7	125.1	52 52.6	45.7	126.2	52 16.8	46.5	127.2	51 40.1	47.3	128.2	51 02.5	48.2	129.2	50 24.2	48.9	130.1
14	54 12.3	44.0	124.0	53 38.3	45.0	125.1	53 03.3	45.9	126.2	52 27.4	46.9	127.2	51 50.7	47.7	128.3	51 13.1	48.5	129.2

Figure 2.

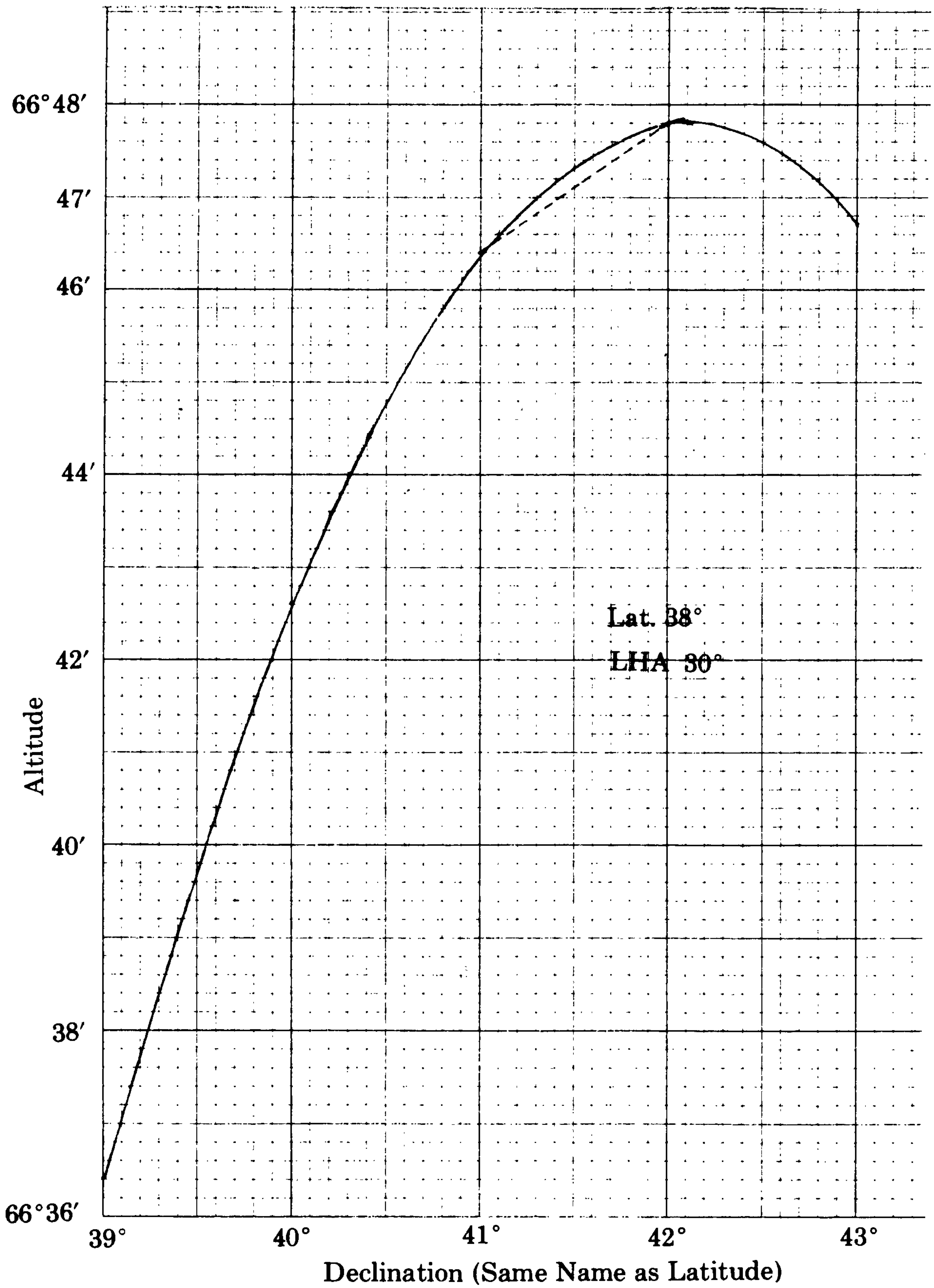

66°48′
47′
46′
44′
42′
40′
38′
66°36′
Altitude
39°
40°
41°
42°
43°
Declination (Same Name as Latitude)
Lat. 38°
LHA 30°

Figure 3.

Table 1

30°, 330° L.H.A. LATITUDE SAME NAME AS DECLINATION

Dec.	38°			39°			40°			41°			42°			43°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
39	66 36.4	6.2·	78.1	66 47.6	8.7·	80.4	66 56.3	11.4·	82.7	67 02.7	14.0·	85.1	67 06.6	16.6·	87.4	67 08.0	19.2·	89.8
40	66 42.6 +	3.8·	75.6	66 56.3 +	6.4·	77.9	67 07.7 +	9.0·	80.2	67 16.7 +	11.6·	82.6	67 23.2 +	14.3·	85.0	67 27.2 +	16.9·	87.4
41	66 46.4 +	1.4·	73.1	67 02.7	3.9·	75.4	67 16.7	6.5·	77.7	67 28.3	9.2·	80.0	67 37.5	11.8·	82.4	67 44.1	14.5·	84.8
42	66 47.8 –	1.1·	70.6	67 06.6 +	1.4·	72.8	67 23.2	4.0·	75.1	67 37.5	6.6·	77.4	67 49.3	9.3·	79.8	67 58.6	12.0·	82.3
43	66 46.7	3.5·	68.0	67 08.0 –	1.0·	70.2	67 27.2 +	1.5·	72.5	67 44.1	4.1·	74.8	67 58.6	6.8·	77.2	68 10.6	9.6·	79.6
44	66 43.2	6.0·	65.5	67 07.0	3.5·	67.7	67 28.7 –	1.0·	69.9	67 48.2 +	1.6·	72.2	68 05.4	4.2·	74.6	68 20.2	6.9·	77.0

Latitude 38° (Same Name as Declination)
LHA 30°

Dec.	Tabular Altitude	Altitude Difference (1st difference)
39°	66°36ʹ.4	+6ʹ.2
40°	66°42ʹ.6	+3ʹ.8
41°	66°46ʹ.4	+1ʹ.4
42°	66°47ʹ.8	−1ʹ.1
43°	66°46ʹ.7	

Table 2 is essentially the same as Table 1 except for a change in format and the addition of second differences, i.e., the differences between successive values of first differences.

**Prefix and suffix being added following extraction of tabular value.*

Table 3 illustrates the format and notation used to distinguish the various differences associated with Besselian interpolation.

In the form of the Besselian interpolation formula allowing for first and second difference only

$$f_p = f_o + p\Delta'_{1/2} + B''(\Delta''_0 + \Delta''_1),$$

$f_{-2}, f_{-1}, f_0, f_1, f_2$, and f_3 correspond to successive values of tabular altitude. The quantity f_p corresponds to the tabular altitude interpolated for declination increment, i.e., tabular altitude interpolated for some fraction p of the interval between tabular values of declination (p = Declination Increment/60'. The quantity B'', a function of p, is a Besselian Coefficient* and is always negative. The quantity $(\Delta''_0 + \Delta''_1)$ is the double second difference (DSD).

The Signs of the Differences

To lessen the chance for algebraic error in Besselian interpolation, differences should be formed by subtracting an upper tabular value from the tabular value just below it in the column. For example: In forming our first difference in Table 2, an upper tabular value 66°36.'4 is subtracted from the tabular value just below it in the column (66°42.'6) to produce the first difference +6.'2. In forming the second difference -2.'4, the upper tabular value +6.'2 is subtracted from the tabular value just below it in the column, (+3.'8).

**Tabulated in Table XIII of The American Ephemeris and Nautical Almanac.*

Table 2

Latitude 38° (Same Name as Declination)
LHA 30°

Dec.	Tabular Altitude	1st Diff.	2nd Diff.
39°	66°36ʹ.4		
		+6ʹ.2	
40°	66°42ʹ.6		−2ʹ.4
		+3ʹ.8	
41°	66°46ʹ.4		−2ʹ.4
		+1ʹ.4	
42°	66°47ʹ.8		−2ʹ.5
		−1ʹ.1	
43°	66°46ʹ.7		

Table 3

Function	1st Diff.	2nd Diff.
f_{-2}		
	$\Delta'_{-1\,1/2}$	
f_{-1}		Δ''_{-1}
	$\Delta'_{-1/2}$	
f_0		Δ''_0
	$\Delta'_{1/2}$	
f_1		Δ''_1
	$\Delta'_{1\,1/2}$	
f_2		Δ''_2
	$\Delta'_{2\,1/2}$	
f_3		

Interpolation by Bessel's Formula

For LHA 30°, declination 41°40.'0, and latitude 38° (Same as Declination), the tabular altitude as extracted from the table is 66°46.'4. Using Bessel's formula and the data as given in Table 2, identified by the notation in Table 3, the interpolated altitude is found as follows:

$f_p = f_0 + p\Delta'_{1/2} + B''(\Delta_0'' + \Delta_1'')$

$H_c = 66°46.'4 + \frac{40.'0}{60.'}(1.4.)$

$+ (-0.056)(-2.'4 - 2.'5)$

$H_c = 66°46.'4 + 0.'9 + 0.'3$

The 0.'9 is the linear interpolation correction; the value 0.'3 is the double second difference correction. Note that $\Delta_0'' + \Delta_1'' = \Delta'_{1\,1/2} - \Delta'_{-1/2}$ Taking care to perform the subtraction algebraically, it is usually more convenient to form the double second difference from H.O. 229 tabulations by subtracting the tabular value of the altitude difference immediately above that on the line defined by integral portion of the declination from the altitude difference immediately below. Referring to Table 1 the double second difference is formed by subtracting +3.'8 from -1.'1. The result is -4.'9.

Interpolation by Table

The main part of the 4-page Interpolation Table is essentially a multiplication table in which the products of the following factors* are tabulated:

$\frac{\text{declination increment}}{60'}$

(altitude difference = $\frac{\text{Dec.Inc.} \times d}{60}$

The design of the Interpolation Table is such that a desired product must be determined from component parts of the altitude difference. Examples of component parts are as follows:

*$p\Delta'_{1/2}$ of Bessel's formula.

Altitude Difference (d)	*Component Parts (Tens and (Units and decimals)*
16.3	10 and 6.3
20.3	20 and 0.3
34.5	30 and 4.5
44.8	40 and 4.8
51.7	50 and 1.7

In the use of the first component of the altitude difference, the arguments are Dec. Inc. and the integral multiple of 10' in d; the respondent is

$\frac{\text{Dec.Inc.} \times \text{Tens}}{60'} + \epsilon$, where ϵ

is a modification introduced to reduce total error. In the use of the second component of the altitude difference, the arguments are Dec. Inc.$_1$ (the nearest Dec. Inc. ending in 0.'5 and Units and Decimals. The respondent is

$\frac{\text{Dec. Inc.} \times \text{Units and Decimals}}{60'}$

The modifying quantity ϵ is

$\frac{\text{Dec. Inc.} - \text{Dec. Inc.}_1}{12}$

It has the following values:

Dec. Inc.	ϵ
XX.'0	-.'042
XX.'1	-.'033
XX.'2	-.'025
XX.'3	-.'0.17
XX.'4	-.'0.08
XX.'5	0.'0
XX.'6	+.'008
XX.'7	+.'017
XX.'8	+.'025
XX.'9	+.'033

In the range of declination increment (Dec. Inc.) 52.'0 to 52.'9, the values tabulated in the tens columns and on the same horizontal lines as Dec. Inc. 52.'3 and 52.'7 are

$\frac{52.3}{60.'0} \times 10.'0 - .'017 = 8.7$

$\frac{52.'7}{60.'0} \times 10.'0 + .'017 = 8.'8$

$\frac{52.'3}{60.'0.} \times 20.'0 - .'017 = 17.'4$

$\frac{52.'7}{60.'0} \times 20.'0 + .'017 = 17.'6$

$\frac{52.'3}{60.'0} \times 30.'0 - .'017 = 26.'1$

$\frac{52.'7}{60.0} \times 30.'0 + .'017 = 26.'4$

$\frac{52.3}{60.'0} \times 40.'0 - .'017 = 34.'9$

$\frac{52.7}{60.'0} \times 40.'0 + .'017 = 35.'2$

$\frac{52.3}{60.'0} \times 50.'0 - .'017 = 43.'6$

$\frac{52.'7}{60.'0} \times 50.'0 + .'017 = 43.9$

The values tabulated in the Units and Decimals suitable immediately to the right of the range of Dec. Inc. 52.'0 to 52.'9 are for examples:

$\frac{52.'5}{60.'0} \times 1.'7 = 1.'5$ and $\frac{52.5}{60.'0} \times 2.'3 = 2.'0$

(See Table 4)

Whether the actual Dec. Inc. is any value from 52.'0 to 52.'9, the same product to the nearest tenth of a minute is *usually* obtained for a component of altitude difference in the ranges 0.'1 to 9.'9.

Extracting DSD Correction

The DSD correction is extracted from that DSD table opposite the Dec. Inc. used in the linear interpolation of tabular altitude for declination increment. (See Table 5).

With a Dec. Inc. of 55.'1 and a DSD of 4.9, the correction to tabular altitude is +0.'1. The DSD correction is positive *always*. As is the usual case with critical type tables, if the DSD is exactly equal to one of the tabular values of DSD in the correction table, the correction lies immediately above. For example, if the DSD were 14.'4, the DSD correction would be +0.2.

To be continued. The continuation will include:

(1) Interpolating Altitude for Latitude and Local Hour Angle
(2) Interpolation Diagram Principles
(3) Negative Altitudes
(4) Interpolation Near the Horizon
(5) Interpolating Near the Zenith
(6) Interpolating Azimuth Angle
(7) Great Circle Sailing

Table 4

INTERPOLATION TABLE

Dec. Inc.	Tens 10'	20'	30'	40'	50'	Decimals	Units 0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	Double Second Diff. and Corr.	
52.0	8.6	17.3	26.0	34.6	43.3	.0	0.0	0.9	1.7	2.6	3.5	4.4	5.2	6.1	7.0	7.9	1.8	0.1
52.1	8.7	17.3	26.0	34.7	43.4	.1	0.1	1.0	1.8	2.7	3.6	4.5	5.3	6.2	7.1	8.0	5.5	0.2
52.2	8.7	17.4	26.1	34.8	43.5	.2	0.2	1.0	1.9	2.8	3.7	4.5	5.4	6.3	7.2	8.0	9.1	0.3
52.3	8.7	17.4	26.1	34.9	43.6	.3	0.3	1.1	2.0	2.9	3.8	4.6	5.5	6.4	7.3	8.1	12.8	0.4
52.4	8.7	17.5	26.2	34.9	43.7	.4	0.3	1.2	2.1	3.0	3.8	4.7	5.6	6.5	7.3	8.2	16.5	0.5
52.5	8.8	17.5	26.3	35.0	43.8	.5	0.4	1.3	2.2	3.1	3.9	4.8	5.7	6.6	7.4	8.3	20.1	0.6
52.6	8.8	17.5	26.3	35.1	43.8	.6	0.5	1.4	2.3	3.1	4.0	4.9	5.8	6.6	7.5	8.4	23.8	0.7
52.7	8.8	17.6	26.4	35.2	43.9	.7	0.6	1.5	2.4	3.2	4.1	5.0	5.9	6.7	7.6	8.5	27.4	0.8
52.8	8.8	17.6	26.4	35.2	44.0	.8	0.7	1.6	2.4	3.3	4.2	5.1	5.9	6.8	7.7	8.6	31.1	0.9
52.9	8.9	17.7	26.5	35.3	44.1	.9	0.8	1.7	2.5	3.4	4.3	5.2	6.0	6.9	7.8	8.7	34.7	

Table 5

INTERPOLATION TABLE

Dec. Inc.	Tens 10'	20'	30'	40'	50'	Decimals	Units 0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	Double Second Diff. and Corr.	
55.0	9.1	18.3	27.5	36.6	45.8	.0	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.5	7.4	8.3		
55.1	9.2	18.3	27.5	36.7	45.9	.1	0.1	1.0	1.9	2.9	3.8	4.7	5.6	6.6	7.5	8.4		
55.2	9.2	18.4	27.6	36.8	46.0	.2	0.2	1.1	2.0	3.0	3.9	4.8	5.7	6.7	7.6	8.5	2.9	0.1
55.3	9.2	18.4	27.6	36.9	46.1	.3	0.3	1.2	2.1	3.1	4.0	4.9	5.8	6.8	7.7	8.6	8.6	0.2
55.4	9.2	18.5	27.7	36.9	46.2	.4	0.4	1.3	2.2	3.1	4.1	5.0	5.9	6.8	7.8	8.7	14.4	0.3
55.5	9.3	18.5	27.8	37.0	46.3	.5	0.5	1.4	2.3	3.2	4.2	5.1	6.0	6.9	7.9	8.8	20.2	0.4
55.6	9.3	18.5	27.8	37.1	46.3	.6	0.6	1.5	2.4	3.3	4.3	5.2	6.1	7.0	8.0	8.9	25.9	0.5
55.7	9.3	18.6	27.9	37.2	46.4	.7	0.6	1.6	2.5	3.4	4.3	5.3	6.2	7.1	8.0	9.0	31.7	0.6
55.8	9.3	18.6	27.9	37.2	46.5	.8	0.7	1.7	2.6	3.5	4.4	5.4	6.3	7.2	8.1	9.1	37.5	
55.9	9.4	18.7	28.0	37.3	46.6	.9	0.8	1.8	2.7	3.6	4.5	5.5	6.4	7.3	8.2	9.2		
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		

Tin Clock and Sextant

By Bruce Stark

Last month I bought a Chinese-made wind-up alarm clock. It has a sweep second hand, and it is a good stand-in for the kind of watch most navigators had to content themselves with before the middle of the nineteenth century. The navigation manuals of the era defined a suitable watch as one that could hold the time within a minute over a period of six hours.

The only problem with my clock is slack in the gear train. The minute hand lags slightly, then kicks ahead. If it isn't precisely adjusted, I can't be sure which minute the seconds belong to. So, having gone to some trouble to coordinate the hands, I don't reset them.

One morning, with a clear sky, and nothing better to do, I took the clock, sextant, and artificial horizon out to the apron of our carport for a test. The purpose of the test was entertainment, but my reason for writing about it is serious. I would like to draw attention to a radical difference between the old nautical astronomy—as practiced by Bowditch and his contemporaries--and celestial navigation as we have come to understand it. Failure to appreciate this difference is, I believe, a stumbling block to researchers.

Other than the sun rising through the trees I had no clue as to time. The clock had run down. To add further interest, I would pretend I'd lost track of the date, and knew only that it had to be October of 2003.

Going further still, I would pretend that latitude and longitude could be pinned down only as somewhere in the Pacific Northwest—Washington, Oregon, or Idaho.

With sextant, artificial horizon, and run-down alarm clock I would find the latitude and longitude of our house. I expected a satisfactory result on first try.

From the apron of the carport I could see the moon overhead in the daytime sky. As soon as the sun was above the trees, I would take a time sight for local time and a lunar distance for Greenwich time. But, to keep things simple, I'd wait until noon to find the latitude. Then, with the latitude in hand, I'd calculate time and longitude.

Here's the catch—altitudes are needed to clear the lunar distance, and the moon's reflection was too dim to be seen in the artificial horizon. Since I couldn't measure the altitude, I would have to calculate it. That would call for the correct time — which I wouldn't have until after the distance was cleared. In other words, I had to clear the distance to get the time required to calculate the altitude required to clear the distance.

The only way to get out of this circular trap, according to the logic of present-day celestial navigation, would be to repeat the calculations again and again until the difference between consecutive results became acceptably small

That wasn't an appealing prospect. So I abandoned the present-day mindset and took the old point of view. The old nautical astronomy wasn't founded on accurate Greenwich time. It was founded on accurate local time. Local time (not be confused with zone time) is the hour angle between you and the sun, and is easily found by time sight.

While waiting for the sun to clear the trees I wound the clock and set up the artificial horizon. When the sun was in the open I took its altitude. I could have taken it in the usual way but, to get a little more accuracy, borrowed a technique from Lewis & Clark's Journals. When taking a morning altitude Lewis would bring the sun in the sextant mirror down below the sun in the artificial horizon and leave the index set at that point. As the sun rose he noted (or perhaps an assistant noted) the times when the images first made contact, overlapped, and separated. That done, he read the sextant.

My clock times were 10:14:31, 10:16:31, and 10:18:28. Their average, 10:16;30, corresponded to the sextant reading, which was 39° 22.'2.

Next, six measurements of the sun's diameter, on and off the arc, showed index error to be 0.'8, off the arc.

on	off		
31.8	32.9		
31.6	33.6	99.7	0.'8 off the arc
31.6	33.2	-95.0	6)4.7
95.0	99.7	4.7	

The difference between the sums of the two columns (4.'7), divided by the number of measurement (6), gives the index error (0.'8). It's off the arc, since the largest sum is under the off-the-arc column.

Adding the 0.'8 index correction to the sextant reading of the time sight, then halving it (it was taken from the sun's reflection in an artificial horizon) and subtracting 2.'6 for refraction and parallax gave the observed altitude of the sun's center: 19° 38.'9.

After a short break I took eleven measurements of the distance between the sun and moon.

Clock	Sextant
10:31:19	51° 4.'3
10:32:02	51° 4.'2
10:32:45	51° 3.'7
10:33:27	51° 3.'8
10:34:44	51° 2.'9
10:35:41	51° 2.'8
10:36:39	51° 2.'1
10:38:26	51° 1.'6
10:40:48	51° 1.'2
10:41:53	51° 0.'7
10:43:30	51° 0.'4

The average clock time is 10:36:29. The average sextant distance is 51° 2.'5.

Although the calculations for local and Greenwich time would have to wait for the latitude I could find the date now. Adding half a degree (as the approximate semidiameter correction) showed the apparent distance to be about 51° 30.'0. Since the apparent distance is always within 1° 8.' of the true, this was close enough to determine the day of the month. Steven Wepster's table of pre-computed distances makes that easy. The table can be found, and printed off, from his site at: http://www.math.uu.nl/people/wepster.

Looking in the October 2003 part of Wepster's table, with a sun-moon distance of 51° 30.', decreasing, I found the date had to be the 21st. The distance at 15:00:00 was larger, the distance at 18:00:00 smaller.

At noon, the sun's altitude showed the meridian zenith distance to be 54° 47.'4. But what about declination? Declination was changing fast, nearly a minute of arc each hour.

Taking the old road to find Greenwich time for entering the Almanac, I applied dead reckoning longitude to local time. Since Washington, Oregon, and Idaho come together at about 46° N 117° W, I took that as the DR position. Local apparent time of the noon sight was, obviously, noon.

Longitude was west, so it had to be past noon at Greenwich. Converted to time, the supposed DR longitude of 117° indicated it was 7:48:00 past noon there.

That is, 19:48:00. This was apparent time. To convert it to mean time I took the equation of time from the Almanac, rounded it to the nearest minute, and applied it with reverse sign. This gave a GMT of 19:33:00.

According to the Almanac, the sun's declination at 19:33:00 on the 21st was 10 ° 45.5 south. Combined with the meridian zenith distance of 54° 47.'4 north, the made the latitude 44° 1.'9 north.

Next, to work the time sight. That required the sun's declination at the moment the morning altitude was taken. Clock time of the observation was 10:16:30.

Unfortunately I hadn't monitored the sun's altitude nearly often enough at noon. But when I did notice it had dipped, the clock read 1:38 and some seconds, so I took the clock to be roughly 1:38 fast on local apparent time.

10:16:30	clock time of morning altitude
- 1:38:00	clock fast
8:38:30	LAT
+7:48:00	117° West
16:26:30	GAT
-15.21	reverse equation of time
16:11:09	GMT

According to the Almanac, the sun's declination at 16:11 on the 21st was 10° 42.'5 south. Since declination is south and latitude north, I added 90° to get the sun's polar distance, "p."

In working the time sight, sec. csc. cos. sin. represent the tabular logs of the secant, cosecant, etc. Half the sum of the altitude, latitude, and polar distance is termed "s."

h	19° 38.'9			
L	44° 1.'9	sec.	0.14 330	
p	100° 42.'5	csc.	0.00 705	
	164° 23.'3			
s	82° 11.'6	cos.	9.13 301	
s-h	62° 32.'7	sin.	9.94 811	
	log. haversine		9.23 147	(after dropping 10)

For these and similar calculations I used a WW II era copy of the "Useful Tables From the American Practical Navigator." Time headings in the haversine table can be confusing. They conform to the old-style astronomical day, which began at noon and ran through twenty-four hours to the next noon. PM hour angles, from zero to twelve, are given at the top of the table. AM hour angles, from twelve to twenty-four, are given at the bottom.

So, since this was a morning time sight, I took the hours and minutes corresponding to the log. haversine 9.23147 from the bottom of the page, and the seconds from the right side. That gave 20:44:57. Dropping twelve hours converted it to the modern value of 08:44:57. This was the correct local apparent time at the moment the clock read 10:16:30. So the clock was 1:31:33 fast

I still had only a vague idea of the time at Greenwich, and of the longitude. But I DID know what part of the celestial sphere was over my head at any given moment. All I had to do was subtract 1:31:33 from whatever the clock read. For the next few hours at least, the clock would accurately track the westward spin of the celestial sphere. Within the sphere, all is quiet. Things that do move, move slowly.

For most of its existence the Nautical Almanac simply told where—in the celestial sphere—the various bodies were. You could get accurate data without accurate Greenwich time. But with the introduction of the Greenwich hour angle, which linked the Almanac's east-west data directly to the spinning earth, Greenwich time became critical.

You can still get accurate data from the Almanac without accurate GMT. It just takes an extra step or two.

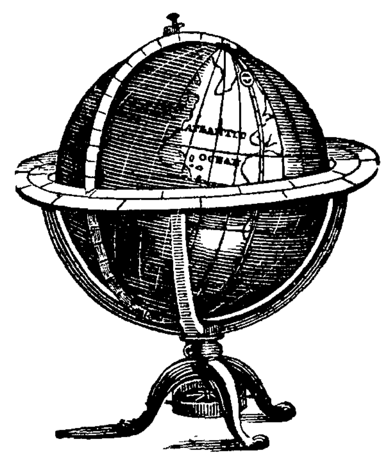
To get back to the problem of locating the house: I had to calculate altitudes for clearing the distance, and needed hour angles and declinations. The sun's local hour angle was already in hand, being the same thing as local apparent time. But the moon's hour angle was needed also.

Adjusting the clock time of the lunar for clock error, the supposed longitude, and the equation of time gave a GMT of 16:37:35. With that I took the GHA's and declinations of the sun and moon from the Almanac in the usual way. Then, taking the *difference* of the sun's and moon's GHA's, I found that the moon was 46° 9.'4 west of the sun. Converted to time. This put the moon 3:04:38 ahead of the sun.

10:36:29	clock time of lunar
- 1:31:33	clock fast on LAT
09:04:56	LAT, or Sun's local hour angle (2:55:04 till noon)
+3:04:38	moon ahead of sun
12:09:34	the moon was 00:09:34 past the meridian of our house

At this point I still didn't know the correct GMT or longitude, but had everything needed to calculate the altitudes and clear the distance. Here are the cosine-haversine calculations for the altitudes:

A copy of the work sheet clearing the distance and



SUN		MOON	
		LAT 9:04:56	
		+3:04:38	
t (AM) 9:04:56	I. hav 9.14 276	t (PM) 0:09:34	6:63 903
lat. +44° 1.9	cos 9.85 670	lat. +44° 1.'9	9.85 670
dec. -10° 42.9	cos 9.99 236	dec. +14° 0.'5	9.98 688
	I. hav 8.99 182		6.48 261
	n. hav .09 814		00 030
I~d 54° 44.'8	n. hav .21 141	I ~ d 30° 1.'4	.06 709
z = 67° 36.'7	n. hav .30 955	z = 30° 5.'5	.06 739
Hc=22° 23.'3		Hc = 59° 54.'5	
+2.'3		-28.'9	
Sa=22° 25.'6		Ma= 59° 25.'6	

finding the longitude appears on page 19. It supposes a familiarity with my "Tables for Clearing the Lunar distance." The values that converted the calculated altitudes to "Sa" and "Ma" (the apparent altitudes of the centers) came from the same set of tables.

The cleared distance falls between values given in Steven Wepster's table for 15 and 18 hours. To proportion this interval for the GMT of the lunar you need regular proportional logarithms. Tables 7 and 8 in my set are for one hour, and don't work for this three-hour interval. You can find a P.L. table in any nineteenth-century navigation manual, and Steven tells me he intends to calculate one for his web site.

The lunar gave a GMT of 17:01:40, which put the house at 123° 1. west longitude, only 3. east of the true position. As expected, I'd gotten an acceptable longitude on my first try. More than acceptable, really. Seven times that error in a lunar wouldn't be an embarrassment for me.

My DR longitude had been off a full 6°, and the Greenwich time used in calculating the altitudes had been off 24 minutes. Even with this old-fashioned procedure it can sometimes be worthwhile to recalculate the moon's altitude and rework the lunar if GMT found differences more than 12 minutes from the GMT used. For this paper I went further than that. I recalculated everything: latitude, time sight, both altitudes, and the lunar.

Latitude changed 0.'4.

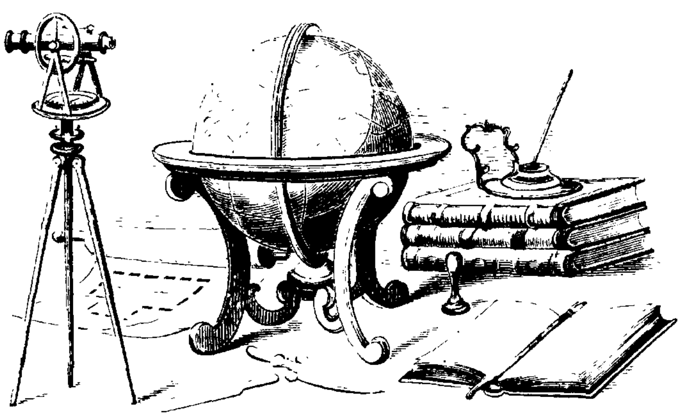
Local time, per time-sight, changed one second.

GMT, per lunar, changed eleven seconds. But if I'd interpolated between values in the K table when taking out the cleared distances it would have changed only four seconds.

Celestial navigators hardened in the GMT-centered logic of the last century will find this demonstration hard to swallow. They may be inclined to suspect a trick. But the only trick was in uncoupling the earth's rotation from GMT and using local time — found by time sight — to track the westward sweep of heavens.

Writers on the history of navigation tend to arrange things according to the logic they, and their readers, already understand. This is the sensible thing to do. But much can be lost in the translation.

I've written this paper in the hope it may awaken, in one reader at least, a desire to understand the old nautical astronomy on its own terms.



from Almanac, the moon's H.P.= 58.2

Table 1		Table 1	
Sa	22° 25.6	Ma	59° 25.6
(subtract lesser)		or	22° 25.6
Ma~Sa			37° 00.0
	–		+ 31.2 (round)
H~H			37° 31.2

Table 2	2842	601.6
	.61	13.3
Table 3	2.21	.7
	31.24	615.6
		Q

Table 4	16.10	add
SUN ? 5	16.09	
	32.2	
Low sun or moon? 6	– .	
(round)	.	

	off +	on -
Index error	.8	.
Instrument	.	.
Moon's Limb Near?	32.2	. or Far?
Ds (Sextant Distance)	51° 25	.
	° .	
	– .	
Da	51° 35.5	
Ma~Sa	37° 00.0	
Da - (Ma~Sa)	14° 35.5	
Da + (Ma~Sa)	88° 35.5	

K	1.79	244	add
K	.31	184	
	2.10	428	
half	1.05	2140	add
Q		6156	
	1.05	830	(round)
or	.98	536	(subtract lesser)
	.07	~~294~~	

H-H	37° 31.2	K	.98 | 536
15h = 52° 52.8			.26 | 609
D	51° 48.6		.71 | 927
	1° 4.2		

P.L. 4477
P.L. 2776
1701

GMT	17:01:40
eq. of t.	+ 15:20
GAT	17:17:00
LAT	9:04:56
	8:12:04

123° 1′ W

ANSWER TO DO YOU KNOW . . .?

(from page 1)

Dr. Ivan Getty (1912-2003) and Dr. Bradford W. Parkinson were recognized by the National Academy of Engineering in 2003 for their achievements in the creation of NAVSTAR GPS (Global Positioning System) and were awarded the prestigious Charles Stark Draper Prize.

Getting received a Bachelor of Science degree from the Massachusetts Institute of Technology (MIT) as an Edison Scholar in 1933. He was a Graduate Rhodes Scholar at the University of Oxford from which he received a Ph.D in astrophysics in 1935.

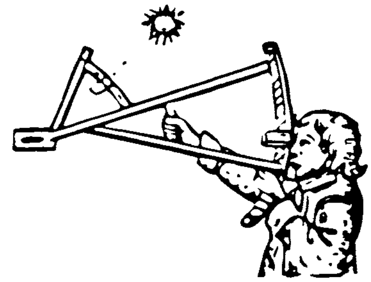
Dr. Getting, the founding president of The Aerospace Corporation, provided the leadership and tenacity of purpose that encouraged the support needed to see that the creation of the Global Positioning System (GPS) succeeded.

Dr. Parkinson received a Bachelor of Science degree from the U.S. Naval Academy in 1957, at which time he was commissioned in the U.S. Air Force. He received his Master of Science degree in aeronautics and astronautics from MIT in 1961 and his Ph.D. from Stanford University in aeronautics and astronautics in 1966. He served in the U.S. Air Force from 1957 to 1978, retiring as a colonel.

Dr. Parkinson created and ran the NAVSTAR GPS Joint Program Office from 1972-1978, during which time he received the Defense Department Superior Performance Award as the best program director in the U.S. Air Force. As the program's first manager, he was the "Chief Architect" of GPS throughout the system's concept, engineering development, and implementation.

Since 1984 at Stanford University, Dr. Parkinson continues to teach and research new and innovative ways to take advantage of GPS technology's extraordinary centimeter-level accuracy capability.

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY-THREE, SPRING 2004

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a readers forum for the expression of our members' opinions and their questions.

ACTIVITIES

By Terry Carraway

The Navigation Foundation is having a house cleaning. We have an excess of the original 82 issues of The Navigator's Newsletters with the exception of 5 issues. We are offering them all to current members for $25.00 with a $4.50 Mailing and Handling charge. With these issues you will have almost the complete set of Navigator's Newsletters to bind or read and enjoy at your leisure.

If you wish to purchase this one time offer, either send me an e-mail with your member number, name and address to: navigate1@comcast.net or a note to our P.O. Box 1126, Rockville, Maryland 20850, or to The Navigation Foundation, 12509 White Drive, Silver Spring, Maryland 20904.

You will be invoiced in the packet of Newsletters. Take advantage of this one time offer and save them for your children, grandchildren, maritime library or for your boating organization. There will never be another chance for such a generous offer. Order today but expect up to several weeks delay in receiving the packet.

Keep Celestial Navigation From Becoming Extinct. Sign Up A New Member!

READERS FORUM

Edited by Ernest Brown

Member Captain R. A. Bowling, USN(Ret) wrote on June 2, 2004:

"Many thanks for the copy of 'Celestial Navigation, an Armchair Perspective.' Enclosed is my personal check for twenty-five dollars ($25.00): $15.00 for the copy and $10.00 toward the postage fund.

"I haven't made a thorough read of Roger's work yet, but a more casual leafing through it indicates a very compact rendering of the subject. In general, it follows the same framework as the course developed and taught here by cutting through a maze of theory and getting directly down to 'working the problem.' One advantage of a course that is taught directly to individuals versus written material that has to be read is that the former can use visual aids. For example, we use a USN WW II training film, reproduced and titled, 'Basic Celestial Navigation,' by Magic Lamp Productions. In less than an hour it covers theory and then goes on to demonstrate the plotting of an LOP. After showing it, we can get right down to actually working problems.

"The passing of John Luykx was a loss for all. I became associated with him several years ago. Shortly after WW II I purchased a used bubble sextant, Type A-8A, at a

DO YOU KNOW . . . ?

By Ernest Brown

Why the Institute of Navigation plans to establish a virtual museum of navigational instruments?

(Answer at back of issue)

CORRECTION

On the first line of ANSWER to DO YOU KNOW...? of Issue Eighty-two, change Dr. Ivan Getty to Dr. Ivan Getting.

military surplus outlet with the intent of converting it to a table lamp (never happened). In 1997 I broke it out and attempted to use it. No way. Through the 'Foundation' I got in touch with John who determined that it could be repaired. And he did an absolutely first-class repair job at a very reasonable charge. In addition, at no additional charge, he provided me with a personally made adapter — superbly crafted — to better illuminate the bubble for night observations. Since then I consistently get fixes that are within 2 miles of GPS coordinates provided by my neighbor — assuming that his are accurate.

"In short, whenever I take out that bubble sextant I think fondly of John and regret never having had the pleasure of meeting him personally.

"Again, Terry, thanks for the copy of Roger's 'Celestial Navigation, an Armchair Perspective.'"

— *Best to all, 'Chic'*

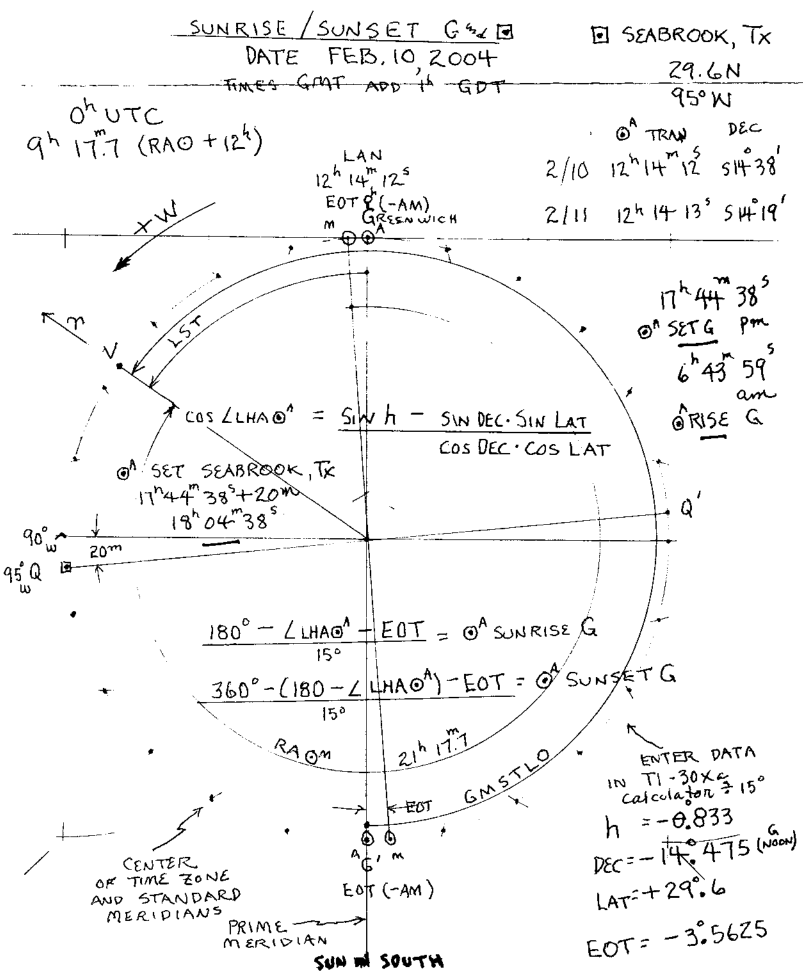
Member Jack B. Craven wrote on June 18, 2004:

"Enclosed is my calculation of Sunrise/Sunset for the USS Seabrook, TX. I used Feb. 10 2004 as the date for this calculation since it had a large unchanging equation of time (EOT). This made calculations easier and would show quicker the errors if they occurred. I used the New York Times bestseller 'The World Almanac for 2004 Book of Facts.' The document has the same data that is found in the Nautical Almanac with one exception. The value 'h' of -0.833 degrees is value adopted by the international convention to represent the center of the real sun as the upper limb comes into view. It also includes atmosphere refraction and uses no height of the observer eye in these calculations. To understand these calculations better the reader should read the sunrise/sunset data in the referenced World Almanac document.

"The other items that are useful are a straight-edge ruler, compass, and a Scientific Calculator, such as a TI-30Xa. The angle LHA in the formula is the angle that the real aun must turn to get from sunrise to noon or from noon to sunset."

— Jack B. Craven

"P.S. As an ex-naval aviator, the last time that I calculated an LAN was as a midshipman on the battleship USS New York, and I never performed a sunrise calculation as a pilot flying an airplane."



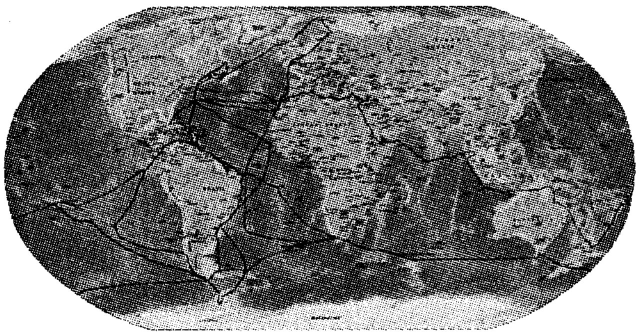
Fiona: A Brief History

By Capt. Eric B. Forsyth

Fiona is a Westsail 42. My wife, Edith, and I saw the first hull of the series under construction at Costa Mesa, California in 1974. The salesman was very pressing and for a small deposit we arranged to have a hull delivered in 1975. We had sold our beloved Dutch boat, *Iona*, a couple of years before. On that boat we had cruised the Caribbean with our son, Colin, then 3 years old, for 15 months in 1968-69. Both *Iona* and *Fiona* have the old-fashioned long keel of the genuine ocean cruiser and when Edith first saw the Westsail 42 on the stocks she exclaimed, "My God, another f-ing *Iona!* This how *Fiona* got her name.

Our daughter Brenda arrived on the scene in 1971 and it was clear our cruising days were over for a while. When I saw the Westsail 42 I figured I could complete her in about 3 to 4 years. In fact it took 8 years; she was launched in 1983.

The interior is mostly mahogany and teak. The head liner and most bulkheads are made of white Formica glued to plywood. I added some structural reinforcing in the form of 1_ inch diameter stainless steel poles between the hull and cabin top. These are also very handy to grab for when the boat rolls unexpectedly. The engine is an 85-hp Perkins diesel. The engine room is lined with 1/16 inch thick lead sheet for sound-proofing. There is an engine-driven cold-plate freezer (made from a old air conditioning unit from a Chrysler Newport) and a prop-shaft alternator that charges the battery banks when under sail.



Fiona's Vooyages: 1983-2003

A brief summary of her cruises:

1983	Shakedown cruise to Bermuda
1984	Cruise to Bras d'or Lake, Cape Breton Is., Prince Edward Is. and St. Pierre
1985	Cruise to St Martin and Virgin Is.
1986	Cruise to the Azores and Bermuda
1987	Cruise to Bermuda and Maine
1988	Cruise to St Martin and Grenadines *FIONA was dismasted between Bermuda and New York on the return leg*
1989	Cruise to Newfoundland, Nova Scotia and Maine
1990	Cruise to the S. Pacific via the Caribbean, Panama Canal and Galapagos

Edith flew home from Tahiti and contracted what proved to be a fatal attack of cancer. FIONA was left on the hard at Raiatea, French Polynesia.

Eric returned in late October 1991 to sail FIONA home via the

1991-92	Gambier Is, Pitcairn Is, Cape Horn, Brazil, the Cape Verde Is and Bermuda
1993	Cruise to Newfoundland, the Bras d'or, Nova Scotia and Maime
1994	Cruise to Newfoundland, Labrador and Maine
1995-97	Circumnavigation of the world. Cruise to Antarctica via Easter Is, the Chilean Canals and Cape
1998-99	Horn. Returned via S. Georgia, Tristan da Cunha, Cape Town, St. Helena, Fernando de Noronha and the Caribbean
1999	Maine Cruise to Iceland, the Arctic, Spitzbergen, Norway, the British Isles, Portugal, Caribbean, Cuba, Bahamas and Bermuda
2000-01	Cruise to Maine
2002-03	Eastabout circumnavigation following the old clipper ship route 'round the southern capes. Leave Patchogue in mid-June and sail to the CCA Irish Cruise at Kinsale. After that transit the Caledonian Canal and enter the Baltic Sea.
Preliminary Cruising Plans For 2004/2005	Leave via the Kiel Canal and tie up in London for a few weeks, including a flight home. Leave London late October and sail to Portugal. From there head for the South Atlantic, possibly going to the Falkland Is and the Antarctic Peninsular. Return to the South Atlantic via the Magellan Strait and cruise Brazil, planning to arrive Patchogue in Mid-May, 2005.

FIONA has now sailed over 185,000 nm.

NAVIGATION NOTES

H.O. 229 Interpolation

By E. B. Brown and J. J. Speight

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(Continued from Issue Eighty-two)

Interpolating Altitude for Latitude and Local Hour Angle

Graphical means are employed to interpolate altitude for the differences between the actual values of the latitude and local hour angle and the integral values used to extract the tabular altitude and azimuth angle from the tables.

For the case in which the actual values are:

LHA 348°27.'1
Lat. 35°31.'2 N and
Dec. 24°57.'0 N

The altitude and azimuth angle, computed from an assumed position chosen to provide integral LHA and latitude arguments, are 74°53.'4 and N 133.°7 E, respectively. To determine the altitude from the position corresponding to the actual latitude and LHA values, it is necessary to interpolate the altitude for 28.'8 difference of latitude (assumed latitude 36°N) and 27.'1 of LHA difference. The interpolations are effected using Diagrams A, B, and C of H.O. 229 as follows:

(a) Mark the actual latitude, 35°31.'2 N, on the center line of Diagram A, Fig. 4. Also mark the foot of the center line as 348°, the nearest integral degree of 348°27.'1.

(b) On Diagram A, mark the intersection of the parallel of latitude, as defined in step (a) with the actual LHA. 348°27.'1.

(c) Place transparent Diagram C over Diagram A with the center lines in coincidence and with the odd minutes of the actual latitude indicated on the center line of Diagram C over the mark made on the center line of Diagram A in step (a). In those cases in which the odd minutes of latitude are between 30. and 60., the radial of Diagram C graduated from 25. to 60. is used.* Note that if the actual latitude were 35°40.'N, the 40. graduation on the center line of Diagram C would be placed over the mark made on the center line of Diagram A in step (a). See Fig. 5.

(d) On Diagram C trace the point of intersection made in step (b).

(e) Remove Diagram C from Diagram A and mark on Diagram C the azimuth angle 133.°7, interpolated for declination increment only, choosing the angle

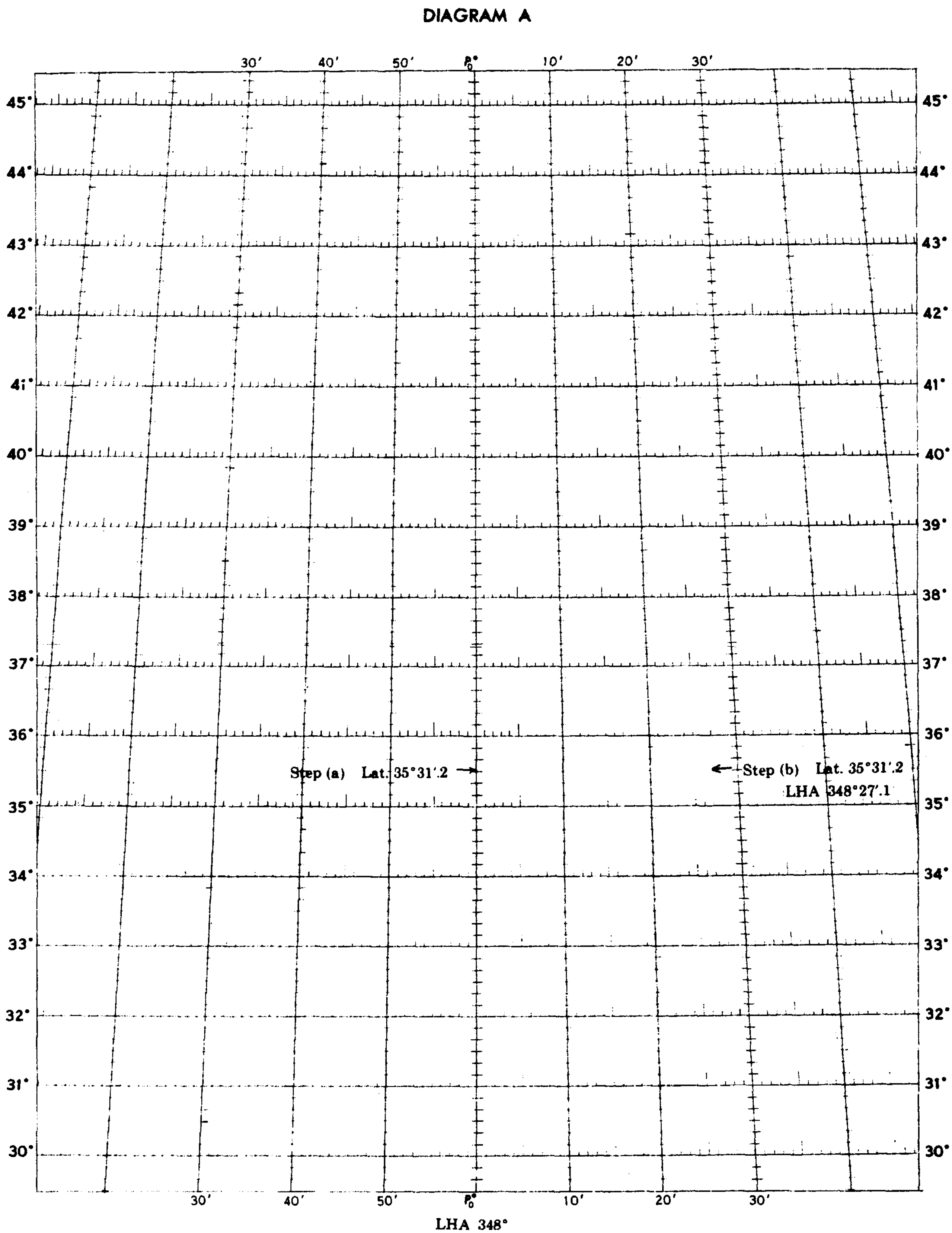


Figure 4.

Figure 4

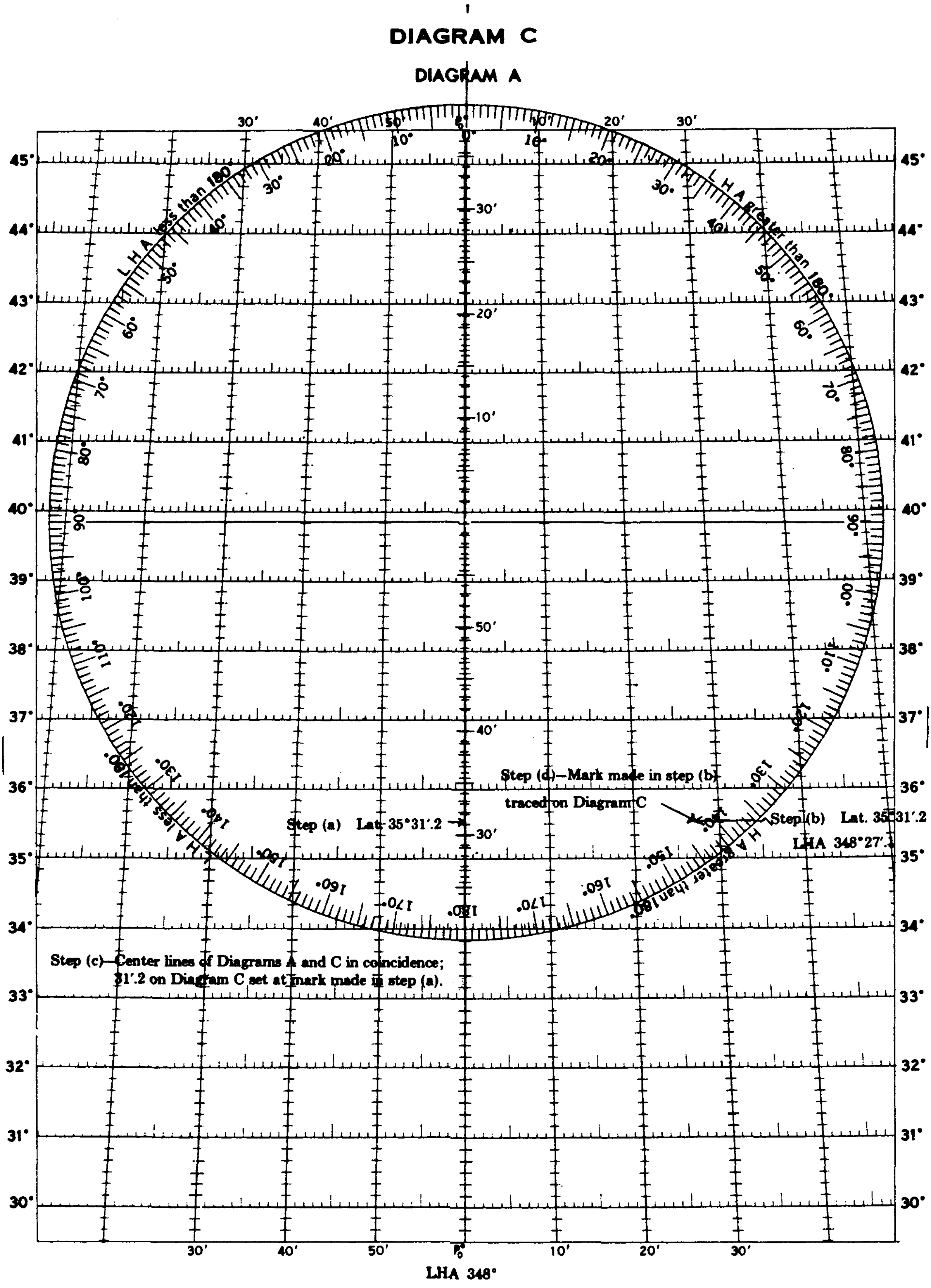


DIAGRAM C
DIAGRAM A
LHA less than 180
LHA greater than 180
Step (a) Lat 35°31′.2
Step (b) Lat. 35°31′.2
LHA 348°27′.1
Step (c)—Center lines of Diagrams A and C in coincidence;
31′.2 on Diagram C set at mark made in step (a).
Step (d)—Mark made in step (b)
traced on Diagram C
LHA 348°

Figure 5.

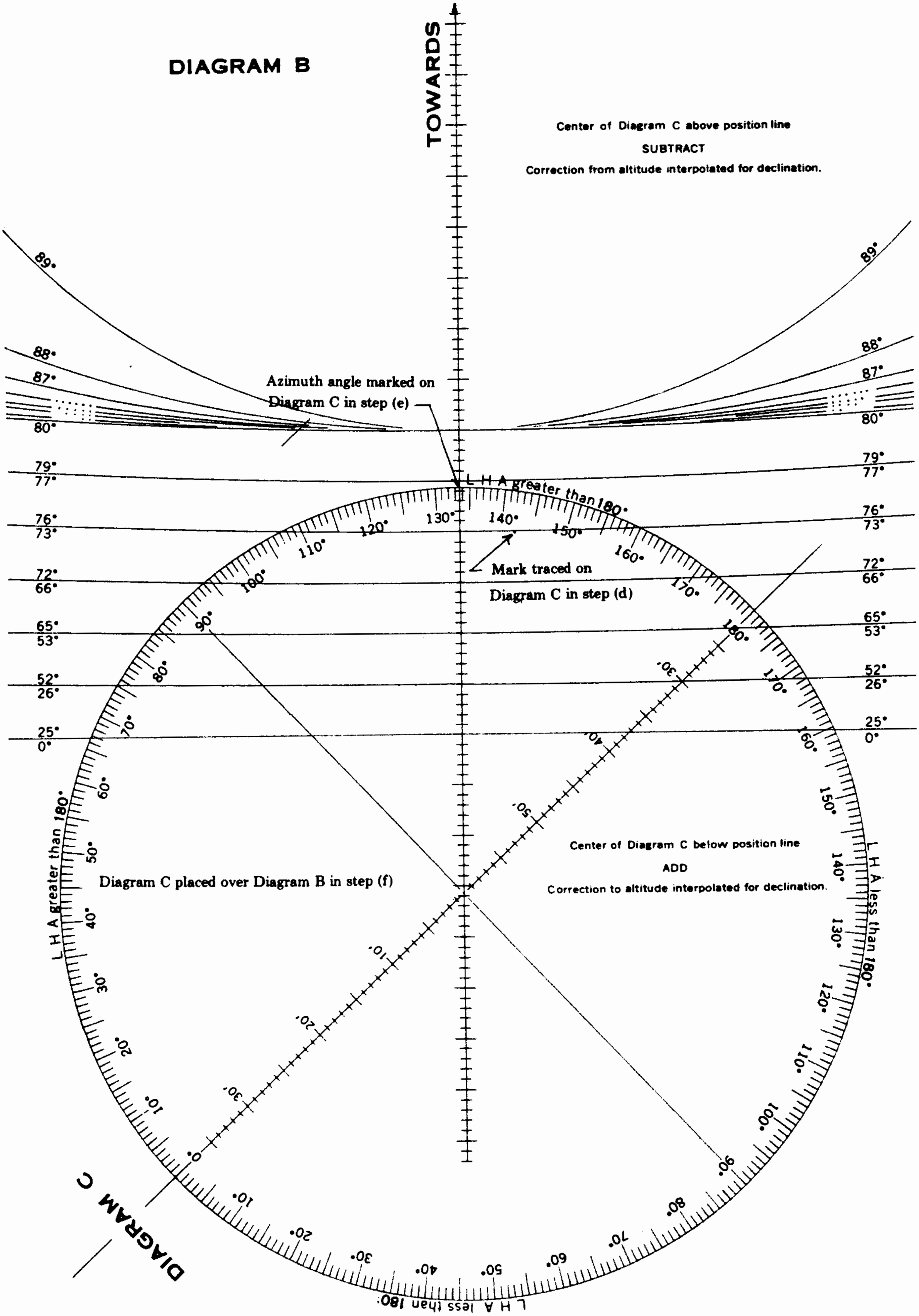


Figure 6.

Figure 6

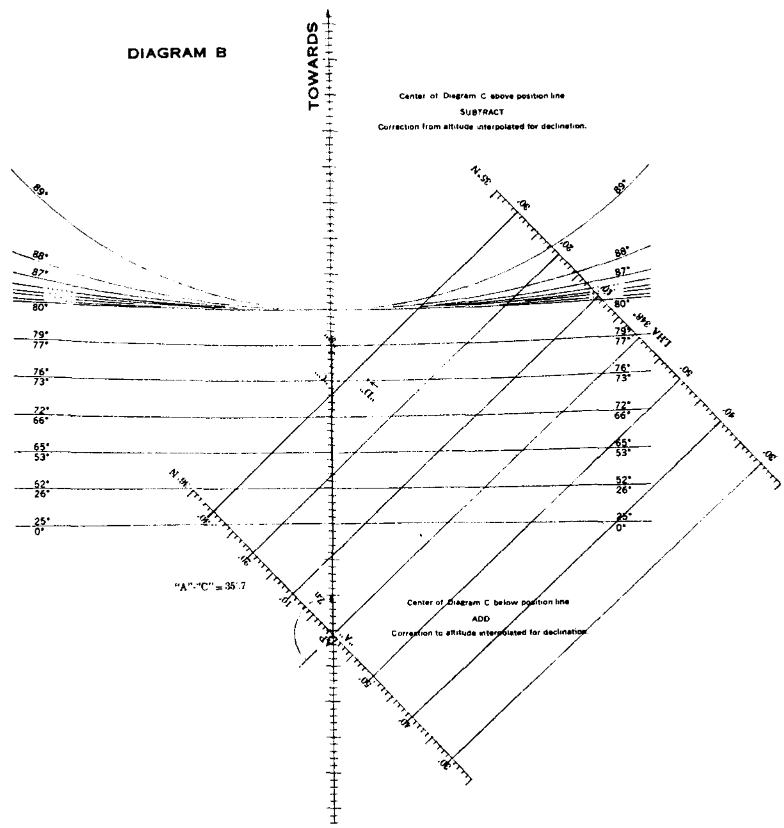


Figure 8.

to the right of 0° because the LHA is greater than 180°.

(f) Place Diagram C over Diagram B as shown in Fig. 6. Note that the center of Diagram C is placed over the center line of Diagram B, and the azimuth angle marked on Diagram C in step (e) is placed in the "toward" direction over the center line of Diagram B. Diagram C is adjusted vertically to bring the mark traced on it in step (d) over the position line on Diagram B, the range of which includes the altitude interpolated for declination increment, 74°53.'4.

(g) Measure the distance in minutes of arc, along the center line of Diagram B, from the position line used in step (f) to the center of Diagram C. This distance is the altitude correction, +35.'7, for latitude and LHA increments. The sign of the correction is plus because the center of Diagram C lies below the position line.

Interpolation Diagram Principles

The calculation of the altitude of a celestial body from an assumed position, such as geographic point "A" in Fig. 7, also determines the radius (Zenith distance) of the circle of equal altitude, the center of which is at the subpoint of the body and the circumference of which passes through point "A". In calculating the altitude of the body from a position such as point "D", which can be a dead reckoning position, one can first determine the altitude from the assumed position, point "A", and then adjust the latter altitude by the difference between the radii of the circles of equal altitude passing through points "A" and "D".

* The 5.overlap of the graduation of the radials does permit alternatives for placement of Diagram C over Diagram A when the minutes of latitude are between 25. and 35.' If latitude 35° is used instead of latitude 36° to extract the tabular data from the basic tables, it is necessary to interpolate the altitude for 31.'2 difference of latitude. In which case, the radial graduated from 0. to 35. is used.,

An approximation of the difference of the radii or the zenith distances can be effected through drawing a line from point "D" perpendicular to the azimuth line (or its extension) drawn from point "A". The difference, in units of minutes of latitude, is the segment "A"-"C". Usually a very close approximation of the difference of zenith distance can be effected through drawing an arc of a circle of equal altitude, based upon the tabular altitude interpolated for declination increment, instead of the straight line approximation of such arc. The Table of Offsets in each volume of H.O. 229 can be used for reasonably accurate construction of the small-circle arcs. Note that the azimuth line drawn from the assumed position is based upon the azimuth angle interpolated for declination increment only. This simple alternative to the use of Diagrams A, B, anc C gives good results except when plotting on a Mercator chart in high latitudes.

As is shown in the following figures, the interpolation by means of Diagrams A, B, and C is effected similarly. The advantage of the latter diagrams is that the circles of equal altitude (small circles) are constructed with greater accuracy than can usually be obtained by means of the Table of Offsets. Using the instructions given in each volume, a polar stereographic plotting sheet can be constructed by tracing the intersections on Diagram A. Following construction of a plotting sheet, it will be noted that the spacing between successive integral degrees of latitude on the plotting sheet is the same as 60.on Diagram C.

Placing Diagram C over the plotting sheet constructed from Diagram A as shown in Fig. 7, note that the mark made on Diagram C in step (d) lies over point "D" on the plotting sheet. Fig. 8 illustrates the correlation of Diagram B with the plotting sheet. Diagram A being in effect a "compressed" plotting sheet, Diagram C must be used to "expand" Diagram A. Through transferring the point corresponding to the DR position on Diagram A to

Diagram C, the latter diagram can be used as a substitute for the plotting sheet.

Negative Altitudes

For all local hour angles at the top of the right-hand page, all tabular altitudes on that page for declinations below the C-S Line are negative. For the local hour angles at the bottom of the right-hand page, all tabular altitudes for declinations above the C-S Line are negative. The corresponding interpolated altitudes for declinations other than the one-degree intervals of declination containing the C-S Line are negative also. Interpolation of altitude in the latter one-degree interval of declination is discussed below. For latitude and declination of contrary name and the local hour angles at the bottom of the right-hand page, the tabular and interpolated altitudes on the left-hand page are negative. Interpolation of altitude for declination increments within these areas of negative altitude should, however, be accomplished as if the altitudes were positive, adhering strictly to the sign given *d*. Then, after interpolation, regard the results as negative. In all instances involving negative altitudes, except the one-degree interval of declination which includes the C-S Line, the supplement of the pertinent tabular azimuth angles is that to be converted to true azimuth by the rules to be found on each opening of the basic tables.

Interpolation near the Horizon

Within the 1° interval of declination bracketing the celestial horizon (indicated in the tables by horizontal rules), interpolation of tabular altitude for declination increment is effected using the last tabular altitude and altitude difference appearing above the horizontal rule. In that the last tabular altitude above the horizontal rule (also known as the C-S Line) is the altitude of a body above the celestial horizon for the LHA at the top of the page, the last integral declination above the rule, and for the pertinent latitude, interpolation resulting in *positive altitudes* can be carried out for increments of declination of *contrary name* as long as the interpolated altitude correction *does not exceed* the last tabular altitude above the rule or C-S Line. If the latter altitude and the correction are equal, the body is on the celestial horizon. For the LHA at the bottom of the page, interpolation resulting in *positive altitudes* can be carried out for increments of declination of *same name* so long as the interpolated altitude correction *exceeds* the last tabular altitude above the C-S line. Interpolation for declination increments not within the foregoing limits results in negative altitudes.

The tabular azimuth angle pertinent to the arguments is that immediately above or that immediately below the C-S Line, as the entering arguments are contrary or same name respectively. The difference in azimuth angle from the 1° interval of declination bracketing the celestial horizon is determined by taking the value of tabular azimuth angle, on the same side of the C-S Line as the LHA arguments, from the supplement of that on the opposite side of the line.

Interpolation near the Zenith

At altitudes of 86° and higher, normal interpolation methods are inadequate; not only do second differences exceed the limits of the Interpolation Table, but higher differences are significant also. A special method for interpolating both altitude and azimuth angle when the altitude is 86° or higher is presented in H.O. 229.

The special method is based on the fact that usually both altitude and azimuth angle can be readily interpolated when the difference is entering arguments, latitude ~ declination, remains constant. The line of position is plotted with the altitude intercept determined by the tabular altitude interpolated for equal intervals of latitude and declination. The line of position is plotted from the pertinent integral latitude increased by the numerical value of the increment of declination for which interpolation was made. Although the Interpolation Table is employed in carrying out the interpolation, it should be noted that the values of altitude and azimuth angle extracted from the tables constitute data which require independent differencing; the tabular altitude difference, *d*, is not used.

The basic tables are entered with the pertinent LHA, declination, and the integral degree of latitude so chosen that on being increased by the numerical value of the declination increment, it is within 30.of the best estimate of the latitude of the observer. For the latter arguments and for a latitude and declination one degree less and one degree more than the arguments as additional arguments, the tabular altitude and azimuth-angle respondents are extracted. The respondents are then differenced. With these differences interpolation of altitude and azimuth angle is made utilizing the Interpolation Table.

The following solutions illustrate the special interpolation method:

Example	LHA	Lat.	Dec.	Ho
I	3°27'	31°06'N	28°35.'1N	86°05.'5
II	356 45	32 36 S	34 24.2S	86 44.7

Example I

Lat.	Dec.	Tab. Hc	diff.	Tab. Z	diff.
30°	27°	86°00.'4		138°.0	
			(+)1.'0		(+)0°.2
31	28	86 01.4		138.2	
			(+)1.0		(+)0.3
32	29	86 02.4		138.5	

Interpolate to Dec. = 28°35.'1

Dec. Inc. = 35.'1, diff. = (+)1.'0, Z diff. = (+)0°.3

ht(Tab. Hc)	86°01.'4	Tab. Z 138°.2	
Int. Tab. 1st Part	0.0		
2nd Part (+)	0.6	(+) 0.2	
Hc	86 02.0	Z N 138.4 W	
Ho	86 05.5		
Intercept	3.5 T	Zn 221.6	

Plot from Lat. 31°35.'1 N

					Example II
Lat.	Dec.	Tab. Hc	diff.	Tab. Z	diff.
31°	33°	86°45.'8		51°.0	
			(+)1.'4		(-)0.°3
32	34	86 47.2		50.7	
			(+1.3)		(-)0.3
33	35	86 48.5		50.4	

Interpolate to Dec. = 34°24.'2

Dec. Inc. = 24.'2, diff. = (+)1.'3, Z diff. = (-)0°.3

ht(Tab.) Hc) 86.°47.'2 Tab. Z 50°.7

Int. Tab. 1st Part 0.0

2nd Part (+) 0.5 (-) 0.1

Hc 86 47.7 ZS 50.°6 E

Ho 86 44.7

Intercept 3.0 A Zn 129.4

Plot from Lat. 32°24.'2 S

Interpolating Azimuth Angle

Because the successive azimuth angle differences for integral-degree changes in declination are always less than 10° for altitudes less than 84°, for normal observations the Interpolation Tables provide an accurate and convenient means for interpolating the azimuth angle, Z, for declination increment. The degrees and tenths of degrees of azimuth angle difference are treated as Units and decimals.

If the azimuth angle difference in the direction of increasing declination is - 1°.5 and the declination increment is 52.'4, the change in azimuth angle for Dec. Inc. 52.'4 is found in the Units and Decimals subtable to the right of Dec. Inc. 52.'4. In the Units column labeled 1. and opposite Decimal .5, the change in azimuth angle for Dec. Inc. is found as -1°.3.

Great Circle Sailing

The basic tables can be used to effect a solution for great-circle distance and initial great-circle course by relating the problem to the solution of the navigational triangle. Using the latitude of the point of departure as latitude, latitude of the destination as declination, and the difference of longitude as LHA, solutions for altitude and azimuth angle are then converted to distance and course. The zenith distance is the great-circle distance; the azimuth angle or its supplement is the initial great-circle course angle.

If the latitude of the destination is nonintegral, interpolation for the minutes of latitude is effected as in interpolating altitude for declination increment; if the latitude of the point of departure or difference of longitude, or both are nonintegral, interpolation for the minutes differences is effected as in interpolating the altitude from a DR position. Although Diagrams A, B, and C can be used to obtain the correction to the altitude, previously interpolated for the minutes of the latitude of the destination, the more practical approach is to use the alternative graphical procedure, the simplicity of which should tend to reduce the blunders compared with the more complex use of the diagrams. Also, the precisions with which the solutions are determined using the diagrams are not justified when using the assumption that the spheroidal Earth is a perfect sphere.

If the latitude of the point of departure and the initial great-circle course angle are integral degrees, the basic tables can be used to determine the latitudes and longitudes of points along the great-circle track. Using the integral course angle as the LHA argument, the integral latitude of the point of departure as the latitude argument, and 90°--the equivalent of zenith distance as the declination argument, the tabular altitude and azimuth-angle respondents correspond, respectively, to the latitude of a point on the track and the difference of longitude of the latter point and the point of departure.

Some Dilemmas in Multiple Sight Position Solutions

By K. Herman Zevering

Issue Eighty-one, Fall 2003

In response to the criticism in Eighty-two of the above article, the author has written a 28-page rejoinder. We intend to publish member Zevering's paper "Dilemmas in Position Solutions Revisited (A Rejoinder) as a limited distribution addendum to this issue to be available to members on request at a nominal cost to cover postage and handling.

Requests for the addendum can be made via E-mail to navigate1@comcast.net, or by mail to: The Navigation Foundation, P.O. Box 1126, Rockville, Maryland 20850 or by telephone to 301-622-6448. The fax has been disabled for automatic operation due to the exorbitant number of "Spam" advertisements.

ANSWER TO DO YOU KNOW . . .?

(from page 1)

As reported in *The Quarterly Newsletter of The Institute of Navigation,* Volume 13, Number 4, Winter 2003-2004:

> The Institute of Navigation (ION) is launching an initiative to create a virtual museum of navigation instruments embracing land, sea, air and space, emphasizing historical genealogy. Even though the ION and its members have quite a collection of historically and educationally significant navigational instruments, unfortunately, at present, there is no place to showcase them. Furthermore, few museums of navigational instruments exist and those that do are mostly limited to traditional marine artifacts. With the rapid emergence of electronic navigation, the danger exists there will be no retention or legacy of historical navigational instruments and devices.
>
> At this time, the effort is envisioned as a two-step project. In the near term, all the instruments from participating members and those already held by he ION will need to be cataloged. Photos and appropriate descriptions will be loaded to the ION "Virtual Museum" at the ION web site. In the long term, the ION may want to consider housing and exhibiting the instruments in a physical building.

The ION virtual museum will be available to ION members and nonmembers. To see a mock-up of the site go to www.ion.org/museum.

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION ISSUE EIGHTY-FOUR, SUMMER 2004

A C T I V I T I E S – *By Terry Carraway*

Mr. Ernest B. Brown, the editor of "The Navigator's Newsletter" for the past few years passed away several weeks ago. He had a tragic accident. Getting out of bed he tripped, hit his head that caused a massive brain hemorrhage. Because he was taking blood thinner for a heart condition, the Doctors could not save him. We will all miss him, his knowledge and history of celestial navigation. His years as editor of "The American Practical Navigator" "Bowditch was reflected in The Navigation Foundation's Newsletter. A formal obituary will be printed when we receive information from his family.

The reason for the delay in getting the Summer issue printed was due to my being in Rochester, MN at the Mayo Clinic. Our niece had a medical emergency and flew in to the Clinic from Hawaii. Her family could not accompany her so my wife and I stayed with her. Upon returning home I tried to contact Mr. Brown for several weeks via E-mail, FAX and telephone. I continued to call daily. Finally his brother answered the telephone and gave me the terrible news.

This new format is only temporary. It is being used to publish Member Herman Zevering's article "Dilemmas in Position Solutions Revisited" (A Rejoinder). It was originally to be published in the Summer Issue but our layout artist had great difficulty with the symbols. An offer was made in Issue Eight-Three to print out the article for a small fee for those who ordered the entire article. After conferring with our printer and finding he can print the article as is, we decided to go forth with this format and print Member Zevering's article. The article will be printed in two segments. The first half being printed in this Newsletter and the second half in the next Newsletter. A refund will be mailed to all members who ordered the article as recommended in Issue 83 Spring 2004.

My apology to all members who wrote with questions or comments. All those letters were forwarded to Mr. Brown. Their current location is unknown as Mr. Brown lived alone. If and when they are located we will answer each one. Please send all future letters to, The Navigation Foundation, P.O. Box 1126, Rockville, Maryland 20850

A note for those who responded to "The House Cleaning". I am still sorting out the 82 copies of past newsletters. I do not know how many are missing, however, I believe it will be less than 5. For all who pre-paid, your check will not be deposited until your copies are in the mail. Please be patient.

A reminder: Members can reach The Navigation Foundation via the Intemet at navigate1@comcast.net or by telephone or FAX at 301-622-6448

A chronology of Member K Herman Zevering's articles and criticisms: "Some Dilemmas in Multiple Sight Position Solutions", Page 8 Issue Eighty-One, Fall 2003; Member George Huxtable's critique of "Some Dilemmas in Multiple Sight Position Solutions", Page 3 Issue Eight-Two, Winter 2003 – 2004: K.Herman Zevering's response to George Huxtable's criticisms, Page 9 Issue Eighty-Three.

The first part of K. Herman Zevering's article, "Dilemmas in Position Solutions Revisited (A Rejoinder). The second part will be published in The Navigator's Newsletter, Issue 85 Fall 2004.

DILEMMAS IN POSITION SOLUTIONS REVISITED (A REJOINDER)

By K. Herman Zevering

1 Introduction

In this rejoinder to the "Dilemmas" article in Issue 81 I will try to answer George Huxtable's comments in this Issue, but this rejoinder's main purpose is actually to analyze the dilemmas in more detail and try to understand the differences in position solution.

The various methods referred to in "Dilemmas" and in this rejoinder may for convenience be recapitulated as follows:

- $IM_{CH/E}$. The pre-electronic approach for working a sight from the DR plot as described and used in the Admiralty Navigation Manual (ANM)[1] was basically the *cosine-haversine* method, which is equivalent to the electronic IM solution, hence referred to here as $IM_{CH/E}$.
- IM_{TAB}. This is the method to work each sight from its special Long and rounded Lat position, using the *Sea and Air Navigation Tables* as computational aid. This method is inferior to $IM_{CH/E}$ because the special positions approach may introduce its own deviation in position solution relative to $IM_{CH/E}$'s.
- The K-Z method[2] for solving the double sight. This method and the geometric method obtain exactly the same results and I will only use the K-Z method.
- The Yallop-Hohenkerk or LSQ method.

I have further recognized three techniques for updating sight information in the sight-run-sight case, the DR method used in $IM_{CH/E}$ and LSQ, the GHA-Dec updating technique (GD-UT) and the Altitude updating technique (A-UT). After altitude is updated (run on) the double sight is solved with the Geometric or K-Z method.

In the sight-run sight case, which is of primary concern here, I convert all sights information to the time and/or assumed (DR) position of the last sight. In the multiple sight analyses provided later I will therefore use the results of the following applications:

1. LSQ - 1st iteration. The Zn and intercept results are the same as $IM_{CH/E}$'s
2. LSQ - final iteration. The result is fix F_2 or F (in the double sight case)
3. LSQ+GD-UT. The result is fix F_1 or F_o (in the double sight case)
4. GD-UT+K-Z. This method yields Lat-Long of the intersection of two position circles, one of which is run on.
5. A-UT+K-Z. This method also yields Lat-Long of the intersection of two position circles, one o f which is run on

The vertex or intersection coordinates of two position lines (PL) obtained with methods 1, 2 or 3 above are found with the vertex program outlined in Appendix 2 of "Dilemmas" (also see section 3.4 for more detail).

Errata box

Vega (2nd sight)

$20^h12^m20^s$
287°.7705
38°.7668
21°.**3722**
0.0
0°.0
0°.0
0°.0
32°.3876 N 15°.0669 W

Double sight method:
(Alt-updating)
(3)

32°.2329 N **15°.1235** W

Sun
Vega

-
-

-
-

30°.5918
-

80°.1594
56°.7**603**

279°.8406
56°.7**603**

not used
not used

As noted by Huxtable, the position solutions given for $IM_{CH/E}$ and IM_{TAB} in Table 1 of "Dilemmas" were incorrect. They should have been respectively 49°.8419/-3°.9716 and 49°.8425/-3°.9715. The Dec of the Moon in Fig 3 should read 3°.6469 and the Lat of vertex A in Fig. 5 should read 31°.9252. The coefficients *a* and b of the confidence ellipse of the triangle ABC (=A'B'C') in Fig 5 should be respectively 25'.8 and 18'.8 and those of triangle A"B"C" in the same Fig 5 should be 1'.1 and 0'.8 respectively.

The GHA for Vega appears as 21°.4135 in Tables 2 and 3 of "Dilemmas", where it should have been 21°.3722. Unfortunately in Table 2 it was used to compute the A-UT case. The corrected A-UT results are highlighted in the table column reproduced to the left.

2 Huxtable's Comments

The comments are contained under four points as paraphrased below.

Point 1

Mistaken conclusion from arithmetic errors

See box on various corrected errors, including the one noticed by Huxtable. Indeed, especially in the simultaneous sight situation, $IM_{CH/E}$, IM_{TAB}, LSQ and K-Z will give equivalent solutions in a practical sense. I am not disputing the practicality of the IM. Nonetheless, the assumed initial DR position affects the position solution with $IM_{CH/E}$, and of course IM_{TAB} in a general sense (see Section 3.1). In the case of multiple sights I regard IM as no more than an (inferior) "proxy" method.

The IM was invented because azimuth cannot be observed reliably enough, not even in the case of the Pole Star. Furthermore, the lack of electronic computing facility hindered any application of the double sight solution method, even though position circle mathematics were fully developed long before the advent of the calculator. In the ANM there appear to be only two references to the use of intersecting position circles as indicating the "observed position". One is the Large Alt-Low Lat case[3], which I analyze below in section 3.2, where the ANM contends that the fix (observed position) should be found by drawing the position circles from their respective run on GPs. The other is the description of the "Star Altitude Curves"[4] method, where the curves represent intersecting position circles, a method mostly useful to air navigation.

If azimuth could be observed sufficiently accurately there would be no need for an assumed position and the IM approach would be redundant, even in the single-sight case (see Technical Appendix 1). I once had a monocular with a built-in compass card, thinking I could 'sight' azimuth, for example with a setting or rising sun. The single-sight position solution with the IM is basically totally unreliable.

Point 1 (continued) and point 2

The presumed differences in position solution are due to faulty programs and wrong drawings.

The fault was actually in my vertex program (inadvertently dividing by Mean Lat instead of Cos(Mean Lat). The same "faulty program" was not used in any of the other results in "Dilemmas" and it has been corrected now (see section 3.4). Alas, the dilemmas as far as I can ascertain do not disappear.

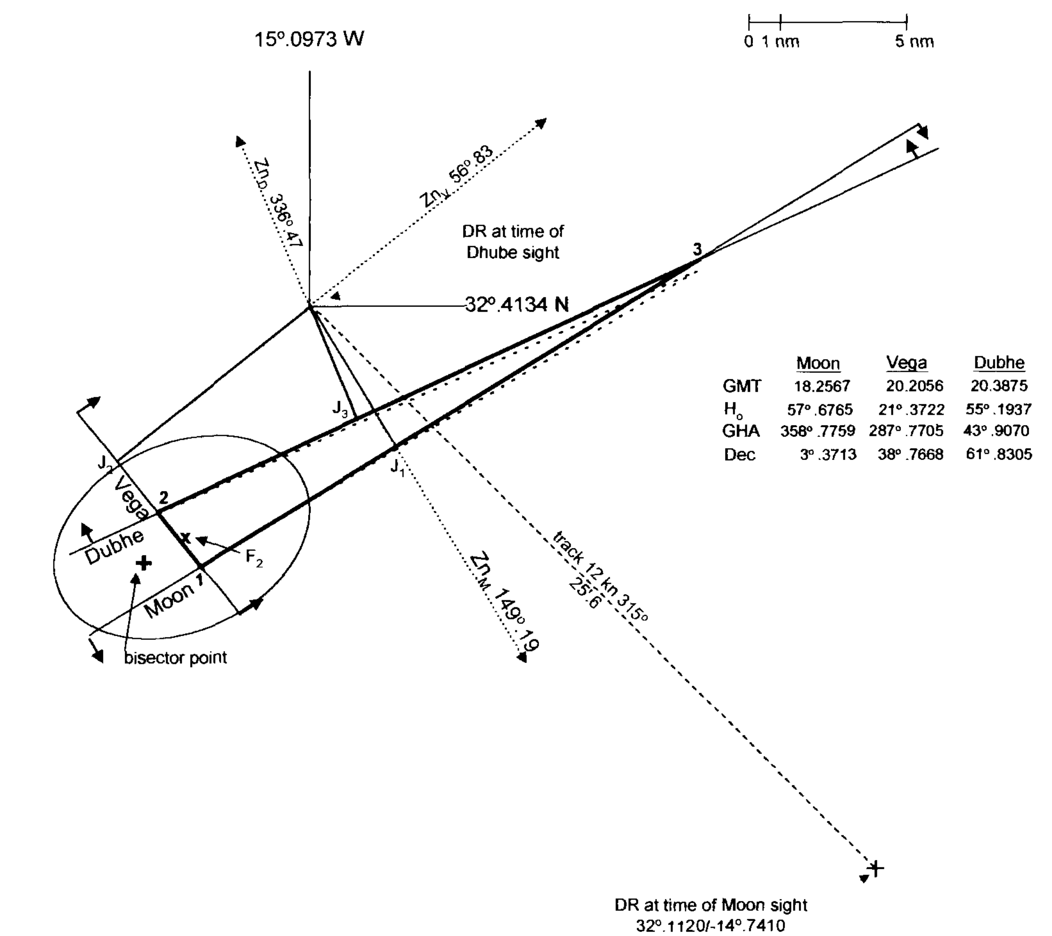
Readers who acquired CelestNav could simulate the $IM_{CH/E}$, LSQ, LSQ + GD-UT results and through the vertex program (see section 3.4) obtain the coordinates of the polygons ABC... = A'B'C'..., A"B"C"...and A*B*C*... (see below). One doesn't need to apply GD-UT+K-Z to follow the argument, but I would be happy to provide my actual program in Lotus123 (transferable to Excel) to any interested reader. We simply need calculating power and more actual cases to bear on this subject. Like Huxtable, I tend to advance a *null hypothesis*, i.e it has to be assumed that the results with the different methods should be the same or at least in practical terms equivalent. If there is no error in the calculations, then perhaps there is a theoretical flaw somewhere.

I nevertheless feel that at this stage of the debate it is important to establish the credentials of the programs I am applying. Technical Appendix 2 shows that my programmed version of Y-H's LSQ method gives results that are the same as published by the authors of the LSQ method. Technical Appendix 2 also shows that the K-Z method obtains exactly the same result as the geometric double sight method. Of course, when there is no run between sights, the results obtained by all methods are in practical terms the same, as mentioned in "Dilemmas". It is only in the sight-run-sight situation that the discrepancies occur.

Huxtable nevertheless makes two observations that are absolutely to the point. Figs 3

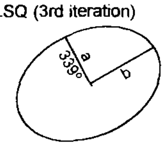
Huxtable nevertheless makes two observations that are absolutely to the point. Figs 3 and 5 in "Dilemmas" were indeed not on Mercator scale and consequently my own impressionistic drawings led me to believe that the final LSQ iteration may project a smaller (internal) polygon A'B'C'.... In this rejoinder I have tried to draw things to scale and this will perhaps make it easier to follow the arguments. Indeed, in all the cases I re-analyzed and subsequently analyzed, a polygon such as ABC... coincides with A'B'C'..., i.e the vertex coordinates found with LSQ+GD-UT and the vertex program are for all practical purposes and perhaps mathematically identical to those obtained with GD-UT+K-Z. The reason that they could be mathematically equivalent is that in LSQ+GD-UT the run-displacement subroutine of LSQ is cancelled.

Fig 1: Moon-Vega-Dhube case with run between sights solved with LSQ



	polygon obtained with $IM_{CH/E}$	Vertex coordinates:	polygon obtained with LSQ 3rd iteration	Vertex coordinates:
	1	32.2731/-15.1653	1	32.2727/-15.1648
	2	32.3072/-15.1917	2	32.3073/-15.1917
	3	32.4354/-14.6430	3	32.4312/-14.8529

Method			Moon	Vega	Dubhe
$IM_{CH/E}$ (= LSQ 1[st] iteration)		Zn	149.19	56.83	336.47
		Interc.	5'.47	-7'.49	-3'.93
LSQ (3rd iteration)	F_2 = 32.2910/-15.1752	Zn	148.96	56.76	336.59
		Interc.	1'.21	-0'.16	1'.23



a = 2'.9
b = 4'.2

Huxtable is not making this point, but the triangle projected via the intercepts from fix F_2 tends to coincide with A"B"C" too, although in Fig 5 of "Dilemmas" I showed a smaller (internal) triangle, which in this particular case is, again, mostly due to sloppy plotting. If we call the triangle defined by the final LSQ iteration's intercepts for convenience A*B*C*, it appears that A*B*C* generally coincides with A"B"C".

In both instances, i.e ABC... and A"B"C"... all LSQ does is therefore to shuffle the intercepts inside the polygons obtained with respectively LSQ+GD-UT and $IM_{CH/E}$ in such a way that their absolute average value is minimized[5]. A"B"C" is in fact the outcome of $IM_{CH/E}$ as produced by LSQ's 1st iteration.

As I will not further dwell on this matter of coinciding polygons later, I present the Moon-Vega-Dubhe case in Fig 1-Rej. When the vertices of A"B"C", i.e the result of LSQ's 1st iteration (triangle 1-2-3 in Fig 1-Rej.) and A*B*C*, result of LSQ's final iteration (the dotted triangle in Fig 1-Rej.) are calculated they do not fully coincide. The difference in position of vertex 3 is too significant to be relegated to rounding. So perhaps the locus of ABC... is always identical to that of A'B'C'... but this is not necessarily so for A"B"C"... and A*B*C*...[6]. If the results A'B'C'... and A"B"C"... were mathematically identical to respectively ABC... and A*B*C*..., perhaps also the Zn should be identical, but they tend not to be.

The matter of polygons coinciding or not, however, is not the crux of the dilemma. The crux as discussed further later is really that when the run covers a significant distance and/or time and perhaps when the angle between sights becomes significantly obtuse as well, ABC... (= A'B'C'...) will move significantly away from A"B"C"... or in the case of two sights the fix obtained with the DR-based methods may deviate significantly from the fix obtained with non DR-based methods. This forms the core of the dilemma I have tried to draw attention to.

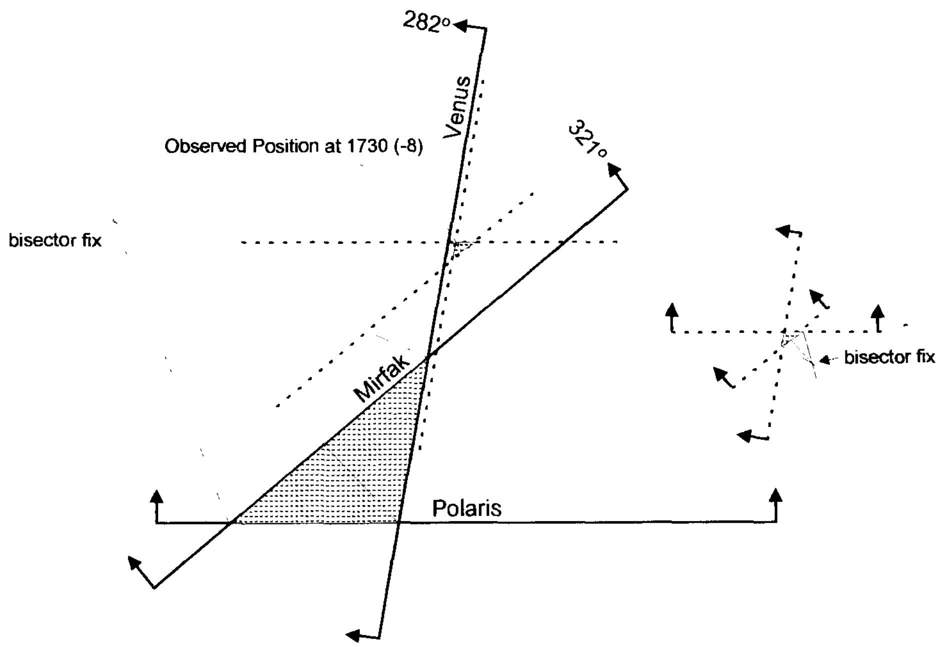
<u>Points 3 and 4</u>

The entanglement of systematic and random errors. Inconsistent versus consistent sights. Cocked hat a 'mere smudge' on the chart

I think Huxtable has basically the same appreciation of the difference between systematic and random error. I do not dispute that they are 'tangled up' but believe the two error sources should nevertheless be distinguished, as in fact in the ANM. The LSQ procedure may be seen geometrically as moving lines drawn parallel to the PLs to an intersection point from where the combined intercept distance is in absolute terms smallest. This method of construction resembles the bisector one which moves the parallel lines equidistant from their respective PL.

What I nonetheless tried to get at in "Dilemmas" is that it seems necessary to reconcile LSQ's resolution of the cocked hat and the traditional one. Taking the cocked hat triangle derived with $IM_{CH/E}$, the fix (F_2) obtained with LSQ is likely to always lie within the triangle. In the traditional view, which is based on the assumption of systematic error, this is only to be expected when all intercepts are either 'towards" or 'away'. For example, the traditional approach would have a problem with the case shown in Fig 1-Rej., because two intercepts are 'away' and one 'toward'. This is the "Intercepts 'towards' and 'away'" case mentioned in the ANM and the position is expected to lie on the bisector of vertex 3 if there is a case for systematic error. As the three azimuths enclose an arc smaller than 180° (360° - 336° + 149° = 173°) the bisector fix lies outside the triangle, as predicted. However, in its Polaris-Mirfak-Venus case, the ANM apparently puts the fix or OP inside the (tiny) cocked hat, Huxtable's 'smudge', formed by the run on intercepts (see sketch below).

Sketch only - ANM Polaris-Mirfax-Venus*



*ANM, Ch. XX "The Observed Position" - "Simultaneous Star and Planet sights" (Fig 135)
Run = 30° at 25 kn
Run-on time: Polaris 9^m.75; Mirfak 5^m.5; Venus 0^m.5 to 1730 (-8)
- - - - - - - - = run-on PL

If the ANM's systematic error theory is consistently pursued, the fix would lie outside the cocked hats (the observer's position would lie outside the cocked hat because the three azimuths enclose less than 180°, in fact 78°). I am not sure whether Huxtable has taken these various aspects into account.

As the confidence ellipse in Fig 1-Rej. tends to indicate, there is about an equal chance that the "observed position" lies to the West rather than to the East of the Vega PL, but how much faith should one put in such deductions? The fix F_2 is still a fraction of a mile northwesterly and the bisector fix more significantly southeasterly from the Vega PL.

M. Blewitt is adamant that "In a truly reliable series of sights the arrows should either all point out from the enclosed area or all point in towards it. If some arrows point in and others out there is an inconsistency."[7] But Gerry Keys simply states: "The locations of the corners of the triangle are found by considering the sights in pairs and the OP is then taken as the center of the triangle or the average of the Lat and Long values for the intersection points"[8].

In another ANM case discussed later (see Fig 2-Rej.), the three position circles do not actually intersect in one point but form a triangle, but on a small chart scale the triangle again becomes Huxtable's "smudge" and the OP becomes a single point about where the smudge is. Nevertheless the cocked hat conundrum has been dealt with seriously in the navigation literature and it is perhaps time to reconcile the traditional notions, if they are still valid, with the Y-H error theory if one is serious on continuing to rely on IM- and DR-based methods to resolve multiple sights.

Yallop-Hohenkerk assert that "in general as the number of observations increases the error in the estimated position decreases". I presume this is perhaps true if the sights are 'consistent'. Unfortunately it is not borne out by their own case study. The fix when the 'inconsistent' Dubhe sight is included as 4th sight is different and its confidence ellipse (= error zone) also larger than when the solution is based on the three (consistent) sights only[9]. Blewitt's idea to exclude 'inconsistent sights' is perhaps not so bad.

I am not sure I fully comprehend Huxtable's argument about systematic errors dominating the random ones and the significance of the three celestial objects at 60° apart. How serious should one take the traditional precepts about minimizing systematic errors and is it practical at sea to do so? M. Blewitt is equally adamant that "..the bisector method is only reliable when the difference in azimuth is greater than 60°"[10]. Her discussion and examples on the subject seems to indicate that the larger the separation in azimuth the better. Yallop claims that the bearings should be "equally spaced" to reduce systematic errors. How equal should the spacing be? The successive sights in his example in Compact Data are respectively 131°, 92°, 80° and 56° apart.

Huxtable's remark that "half of these sets would have to be rejected as failing his own inconsistent test" is perhaps caused by unclear statements on my part, but I do not understand why "half of the sets" would be affected. If three or more sights are worked with IM, one or more may initially have a positive and others a negative value. As mentioned, at the 1st iteration LSQ calculates these intercepts for you with the same sign as you would obtain with $IM_{CH/E}$. At subsequent iterations, if some intercepts continue to be negative and others positive it means that at least one sight in the collection is 'inconsistent' in the traditional sense of this term. For example, with the Sun-Moon-Vega sights the intercept values are respectively:

initial (1st) iteration	+ + -
2nd iteration	- - -
3rd iteration	- - -

This collection is 'consistent'. With the Sun-Moon-Vega-Dubhe sights one gets

initial (1st) iteration	+ + - -
2nd iteration	- + - +
3rd iteration	- + - +

and this not only changes the fix but also creates a relatively larger error margin (based on LSQ theory).

This latter collection is 'inconsistent'. This may also be discovered by plotting the results of the 1st iteration or with one's own IM-based plot with these 4 sights. The only 'consistent' polygon found would be the triangle formed with the PLs of Sun-Moon-Vega. However, I tend to agree with Huxtable that the traditional approach based as it is on systematic error is perhaps not compatible with a methodology like LSQ's, which claims to find a mean value at the centre of an entangled error ellipse. The ANM states clearly that only if systematic error is suspected may one apply the bisector method. I therefore rest my case in this particular issue.

But should one then agree with what seems to be Huxtable's conclusion on the subject, namely that in the final analysis one cannot be sure of anything at all: "Three times out of four, the true position will lie outside the cocked hat, no matter how precise the observer is". It is not made clear what the basis is for this presumption and it appears to be needlessly pessimistic. 'Precision' has in fact nothing to do with location of the fix inside or outside the cocked hat, but a smaller cocked hat is more likely to indicate greater precision. Using the wrong pages of the Almanac or making similar mistakes are simply trivial in the sense that they have nothing to do with either random or systematic error as discussed here.

Huxtable's statement cited above is perhaps based on the very confidence ellipse projected with the LSQ method, on area inside the cocked hat relative to area outside it. Such an interpretation of statistical probability would of course be wrong. If the statistical error treatment with LSQ is meaningful at all, the probability that the 'observed position' will lie eccentrically from where its fix is inside the polygon becomes increasingly remote towards the periphery of the confidence zone, like the probability of finding someone who is 2 m tall or taller when average height of the population group is 1.68 m.

IM practioners generally have no difficulty in accepting the underlying idea of triangulation when taking two or more sights. Taking the results of LSQ for granted in the sight-run-sight situation, I wouldn't be looking for my position outside the enclosed area, unless perhaps in the situation depicted in Fig 1-Rej. or when there is an 'inconsistent' sight. What is the alternative to the multiple sight solution and the cocked hat? It is certainly not IM based on the single sight, which cannot reliably determine any position.

3 The Relative Dependability of Solution Methods

This section contains a further elaboration on the question of the relative dependability of techniques based on the Intercept Method (IM) and other DR-based methods versus methods that do not require an assumed position.

Interesting is that one will not find a single example nor drawing in the ANM, at least not in my 1938 edition, of the IM applied to two or more truly simultaneous sights. All the worked examples relate to sight-run-sight cases. Even in the section "Simultaneous Star and Planet Sights" (ANM Vol II, Chapter XX), the Polaris-Mirfak-Venus case (see sketch above) is actually converted to a sight-run-sight case by accounting for the speed of the vessel and time of the sights[11].

3.1 The position solution with $IM_{CH/E}$

The practicality of the $IM_{CH/E}$ with two sights lies indeed in its tolerance to variation in assumed initial position. Up to a point it will 'correct' the DR plot. What I had in mind in "Dilemmas", however, is that you cannot assume to be just anywhere and expect $IM_{CH/E}$ to put you on the chart. In one article, for example, it was proclaimed: "Do not agonize too much over the DR latitude and longitude when working out your line of position ... the final line of position obtained will be precisely the same whether you think you are 200 miles away from where you really are"[12]. It can be numerically demonstrated that such notions are incorrect, as in the following two examples, which use respectively the Blewitt Sun-Moon and Y-H Sun-Vega cases in Tables 1 and 2 of "Dilemmas".

	Blewitt Sun-Moon case (simultaneous)		Y-H Sun-Vega case (sight-run-sight)	
Ass. DR - base case	49°.8333 N 4°.3333 W		32°.3876 N 15°.0669 W	
Ass. DR – arbitrary	47°.8333 N 6°.3333 W		36° N 18° W	
Fix	49°.8758 N 4°.1442 W		32°.0890 N 14°.9469 W	
	Sun	Moon	Sun	Vega
Intercept	112'.38	-203'.21	-174'.17	-4'.03
Zn	82°.68	203°.35	276°.59	56°.89
Deviation* - d'Lat - d'Long	2'.1 10'.3		From LSQ fix: 8'.7 10'.6 From GD-UT+K-Z fix: 9'.8 3'.7	

*Absolute deviation from true Fix

The double sight position solution with $IM_{CH/E}$ is therefore in a general sense affected by the assumed initial DR position. I should perhaps to some extent recant the statement in "Dilemmas" that "it is impossible to deduce the degree of position accuracy from the length of intercepts". A very large intercept may well indicate that the assumed DR position is way off, while two relatively short intercepts may point to a DR position that is not far away from the fix. Assuming an initial DR position anywhere on the globe (-180°<Long >+180° and -90°<Lat>+90°) is only possible when LSQ is used to find the final iteration's fix.

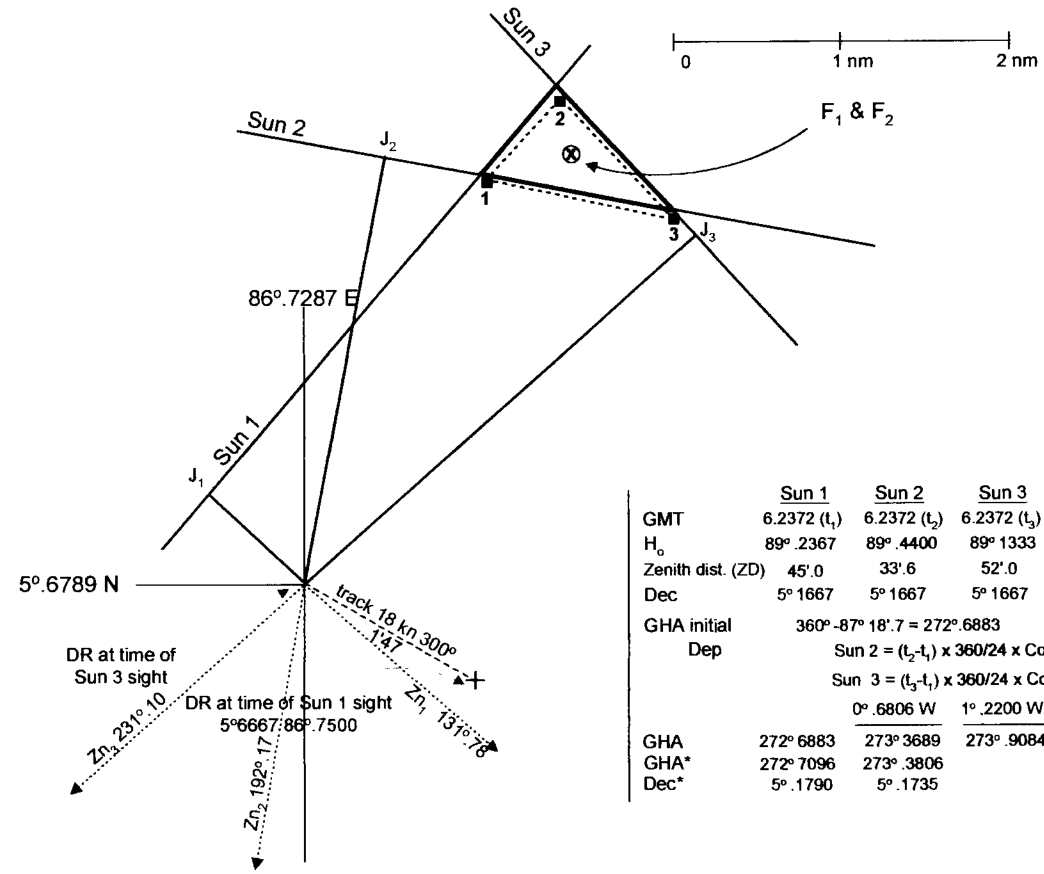
3.2 The IM and the Large-Alt/Low-Lat situation

One limitation of the IM seen in the ANM is large altitudes, especially combined with low latitudes. In such a case the straight-line PL is deemed to be no longer capable of representing a position circle segment, which would call for a special construction of the point of intersection of the position circles. In fact it appears that the IM stands up much better to a Large-Alt/Low-Lat situation than presumed. Analyzing the case given in ANM Vol III (Chapter IV "Procedure when the Altitude is Large") gives the results summarized in Fig 2-Rej.

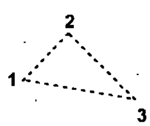
As is seen from Fig 2-Rej., the cocked hat obtained with $IM_{CH/M}$ and its fix F_2 (obtained with LSQ) and the one obtained with GD-UT+K-Z and its fix F_1 (obtained with LSQ+GD-UT) are practically the same. The construction method deemed necessary in the ANM would in fact obtain the vertices of the GD-UT+K-Z triangle.

At least in this case, when the zenith distances are still well in excess of 30', the ANM appears unduly worried about the curvature of the position lines. The PLs would be practically tangential in the points J_1, J_2 and J_3 to the position circles drawn with the zenith distances as radii from the run on (GHA-Dec) coordinates of the three sights' GPs. I discovered this case only recently but it validates, among others, the GD-UT technique I presented in "Dilemmas" (also see Fig 3 in "Dilemmas"). The deviation between PL and position circle at the points of intersection are still relatively insignificant in this case. With still larger altitudes, the deviations would become more significant. Nevertheless, the effect of position circle curvature is clearly seen when the Zn of the two methods are compared. The Zn of the three sights worked with $IM_{CH/E}$ differ respectively 3°.72, 1°.70 and 1°.11 from the Zn obtained with the GD-UT+K-Z method.

Fig. 2 : Large Alt-Low Lat case with three Sun sights and run between sights solved with various methods



	Sun 1	Sun 2	Sun 3
GMT	6.2372 (t_1)	6.2372 (t_2)	6.2372 (t_3)
H_o	89° .2367	89° .4400	89° 1333
Zenith dist. (ZD)	45'.0	33'.6	52'.0
Dec	5° 1667	5° 1667	5° 1667
GHA initial	360° -87° 18'.7 = 272°.6883		
Dep		Sun 2 = (t_2-t_1) x 360/24 x Cos Dec	
		Sun 3 = (t_3-t_1) x 360/24 x Cos Dec	
		0° .6806 W	1° .2200 W
GHA	272° 6883	273° 3689	273° .9084
GHA*	272° 7096	273° .3806	
Dec*	5° .1790	5° .1735	



polygon obtained with GD-UT - K-Z method

Vertex coordinates:

1	5.7186/86.7481
2	5.7266/86.7562
3	5.7139/86.7667

polygon obtained with $IM_{CH/E}$+ vertex program

Vertex coordinates:

1	5.7190/86.7478
2	5.7282/86.7554
3	5.7149/86.7660

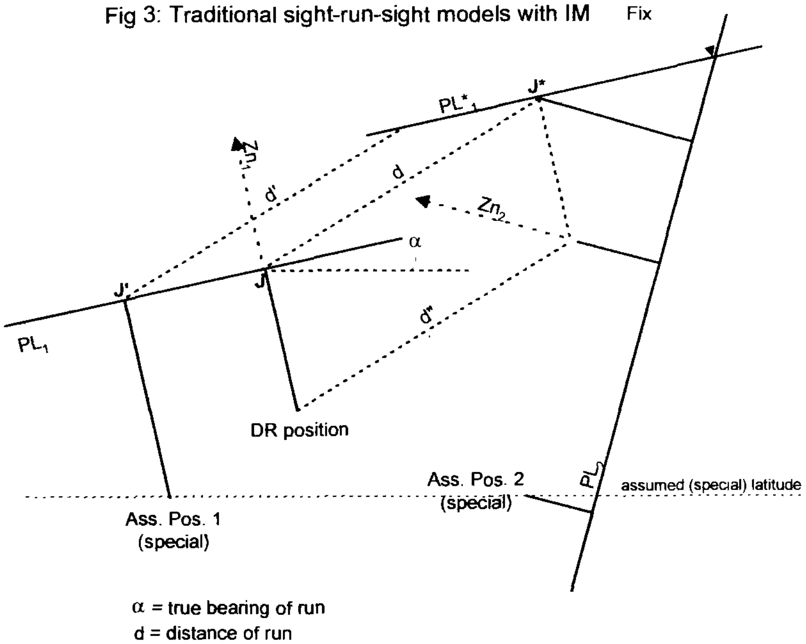
Method	Fix		Sun 1	Sun 2	Sun 3
$IM_{CH/E}$ (= LSQ 1st iteration)		Zn	131.78	192.17	231.10
		Interc.	-0'.79	-2'.58	-3'.09
LSQ (3rd iteration)	F_2 = 5.7217/86.7551	Zn	135.50	193.87	229.99
		Interc.	-0'.16	0'.28	-0'.24
LSQ + GD-UT (4th iteration)	F_1 = 5.7217/86.7551	Zn	135.50	193.87	229.99
		Interc.	-0'.16	0'.28	-0'.24

3.3 LSQ and the DR method of transferring position lines

In my edition of the ANM one finds the situation sketched in Fig 3-Rej. With IM_{CH}, the ANM makes it appear obligatory to lay the run (distance **d**, course α) out from point J and use the position in point J* to work the second sight. The transferred PL_1 (=PL^*_1)

passes through point J*. When using IM_{CH}, laying out **d** can be done equally well and with less fuss from the DR position.

Fig 3: Traditional sight-run-sight models with IM_{Fix}



This is equivalent to directly drawing the intercepts and PLs from the DR position of the second sight, which is the approach to be followed when drawing LSQ results. Incidentally, Fig 3 also shows that the graphical (and also mathematical) determination of the fix is not straightforward with IM_{TAB}. After finding PL_1 from the special position, it is necessary to construct (compute) the 'dummy' intercept to PL_1 from the DR position, in order to transfer PL_1 either from J or from the DR position. The IM_{TAB} construction is only possible under the assumption made in the ANM that for all practical purposes points like J' and J lie on the same straight line (PL).

3.4 Program for calculating the coordinates of the Fix

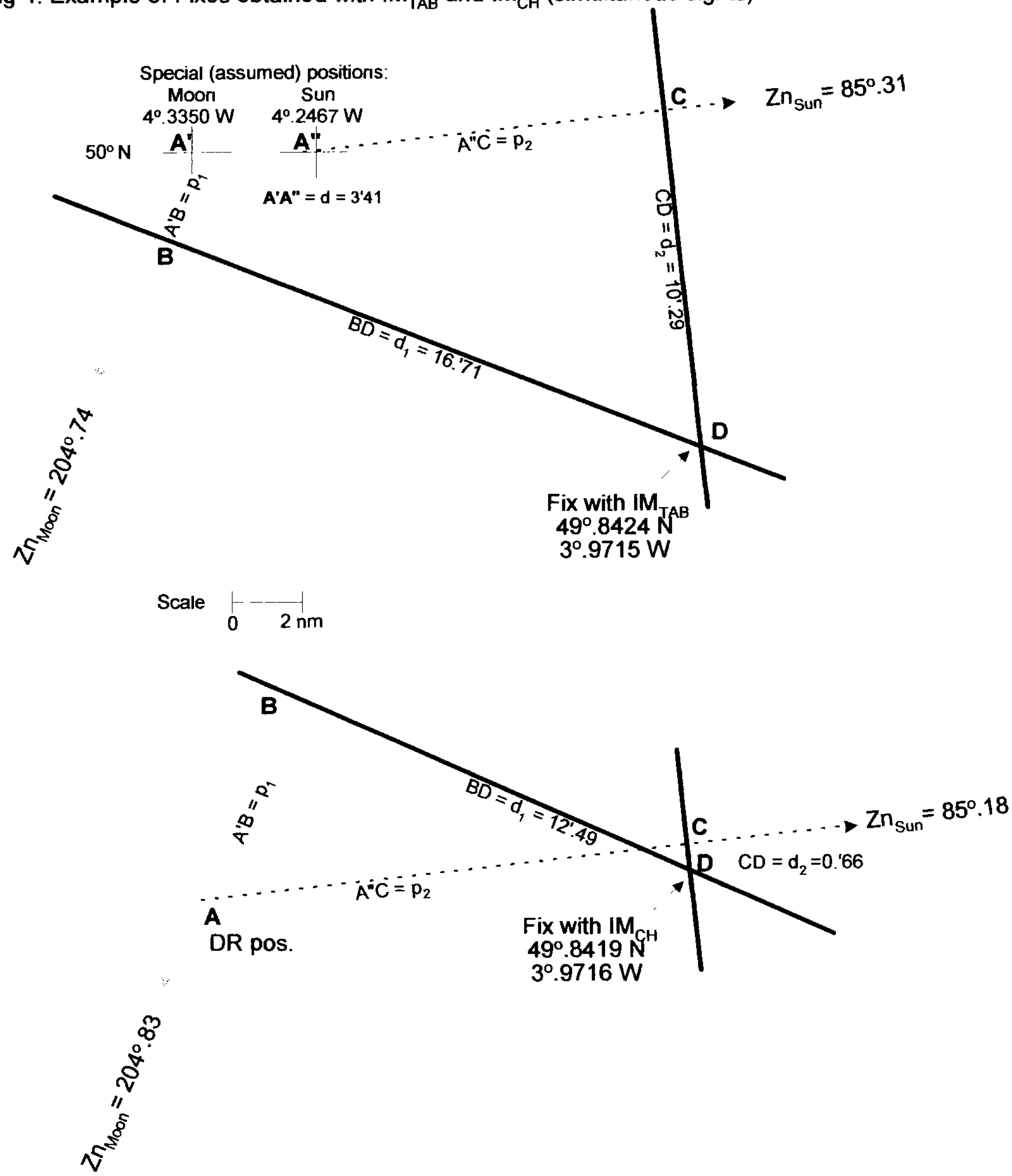
As it is necessary to compute rather than plot the coordinates of PL intersection points (vertices) I should perhaps say a bit more on the vertex program. The general form was already given in Appendix 2 of "Dilemmas". In this formulation the intercepts are always to be used with the algebraic sign (+ or -) as returned by the IM.

In establishing Equations 1 and 2, it is convenient to think of comparing equally long "routes" from the DR to the Fix, or from the Fix to a vertex, one via p_1 and d_1 and the other via p_2 and d_2. A check on the correctness of the calculations is that the d'Lat and Dep obtained via either "routes" are equal. Once the **d** are found the Lat and Long of the Fix are calculated from the usual rhumb line equations:

$$Lat_{Fix} = Lat_{DR/previous\ fix} + d'Lat$$
$$mean\ Lat = ½(Lat_{DR/previous\ fix} + Lat_{Fix})$$
$$Long_{Fix} = Long_{DR/previous\ fix} + Dep/Cos(mean\ Lat)$$

The program can probably be fully automated, also allowing for run between two sights and for longitude difference in the case of IM_{TAB}. An example is in Fig 4-Rej., which depicts the Blewitt Sun-Moon case resolved with IM_{TAB}.and IM_{CH} in "Dilemmas" (Table 1)[13]

Fig 4: Example of Fixes obtained with IM_{TAB} and IM_{CH} (simultanous sights)



A'C, A"B are the intercepts of Sun and Moon from special pos., resp. 2'.71(toward) and 9'.83 (toward)

AC, AB are the intercepts of Sun and Moon from the DR pos.,resp. 13'99 (toward) and -6.35 (away)

CD, BD are the distances along the respective PL to the Fix

To compute the Fix with IM_{TAB} equate (for example) "route" **A'BD** with **A'A"CD**

To compute the Fix with IM_{CH} equate "route" **ABD** with **ACD**

Equations 1 and 2 in the IM_{TAB} case (top Fig 4-Rej.) can be derived directly by looking at the figure:

$$p_1 \mathrm{Cos}Zn_1 + d_1 \mathrm{Cos}(Zn_1 - 90) = p_2 \mathrm{Cos}Zn_2 + d2\mathrm{Cos}(Zn_1 + 90)$$

Eq1. $p_1 \mathrm{Cos}Zn_1 + d_1 \mathrm{Sin}Zn_1 = p_2 \mathrm{Cos}Zn_2 - d_2 \mathrm{Sin}Zn_2$

$p_1 SinZn_1 + d_1 Sin(Zn_1 - 90) = p_2 SinZn_2 + d_2 Sin(Zn_2 + 90) + dsin90$

Eq2. $p_1 SinZn_1 - d_1 CosZn_1 = p_2 SinZn_2 + d_2 CosZn_2 + d$

$Ad_1 + Bd_2 + C = 0$	$A^* d_1 + B^* d_2 + C^* = 0$
$A = SinZn_1$	$A^* = CosZn_1$
$B = SinZn_2$	$B^* = CosZn_2$
$C = p_1 CosZn_1 - p_2 CosZn_2$	$C^* = -p_1 SinZn_1 + p_2 SinZn_2 + d$

The same can be done for the IM_{CH} case. The numerical solutions are shown in Table 2

Table 2: Calculation with vertex program of the coordinates of a Fix obtained with IM_{TAB} and IM_{CH} (M. Blewitt's Sun-Moon example)

	Sun (IM_{TAB})	Moon (IM_{TAB})	Sun (IM_{CH})	Moon (IM_{CH})
Zn	85°.3057	204°.7353	85°.1796	204°.8322
Lat_{ass}	50°.0	50°.0	49°.8333	49°.8333
$Long_{ass}$	-4°.2467	-4°.3350	-4°.3333	-4°.3333
Intercept	9'.8265 ('toward')	2'.7063 ('toward')	13'.9926 ('toward')	-6'.3456 ('away')
	A=-0.4184	A*=-0.9083	A=-0.4200	A*=-0.9075
	B=0.9966	B*=0.0818	B=0.9965	B*=0.0840
	C=-3.2622	C*=14.3327	C=-4.5831	C*=11.2781
	d_1=16'.7075		d_1=12'.4886	
	d_2=10'.2876		d_2=0'.6640	
	d =3'.4068*		n.a	
Lat_{DR}		50°.0	49°.8333	
$Long_{DR}$		-4°.3350	-4°.3333	
d'Lat	-9'.4489		0'.5142	
d'Lat		-9'.4489		0'.5142
Lat_{Fix}	**49°.8425**		**49°.8419**	
Mean Lat	49°.9213		49°.8376	
Dep	14'.0422		13'9989	
Dep		14'.0422		13'9989
$Long_{Fix}$	**-3°.9715**		**-3°.9716**	

*d = d'LongCosMnLat

3.5 The difference in position solution between LSQ and GD-UT + K-Z in the case of three or more sights

In this section I am supporting my dilemma with regard to three or more sights with run between sights with four cases, presented in Fig 2-Rej. (see section 3.2) and in Attachm. Figs. 1, 2 and 3. In the ANM case analyzed in Fig 2-Rej. the total time between the 1st and the 3rd sight is less than 5 minutes and the distance covered is about 1'.5. In the Rigel – Canopus – Peacock - Alpharatz case of Attachm.-Fig 3, reconstructed from M.Blewitt's book, the time between the 1st and 4th sight is 12.4 minutes. I assumed that the sights were taken from a vessel steaming at 25 kn and 20° so that the distance sailed would be about 5'.2.

In the ANM case of three sun sights (Fig 2-Rej.) there is hardly any displacement between what I have indicated before for convenience as triangle A"B"C" (heavy lines) and ABC (dashed lines). In the 4-Stars case (Attachm.-Fig 3) there is much greater displacement. The displacement of the polygons also means that the position solutions F_1 and F_2 lie further apart.

In the two Y-H cases of Attachm.-Figs 1 and 2 the time between 1st and last sight is several hours and the distance covered well in excess of 30'. The displacement between A"B"C" and ABC is large and F_1 and F_2 are a considerable distance apart.

There appears to be a correlation between distance~time covered between sights and the deviation in position of F_1 from F_2. I am not suggesting that F_1 can be accepted as the (central) fix of ABC, but as a central measure of position it will do for the time being. Perhaps also course bearing and azimuth angle between sights would influence the results[14].

I cannot explain why this dilemma occurs and don't think as Huxtable does that it is simply caused by program or calculation mistakes, but perhaps rather by some theoretical flaw or by an underlying assumption which in certain cases is simply violated. I am in any case looking forward to Huxtable's own further verifications on the matter.

One possible direction in which to look for an explanation might lie in the difference between the conventional PL transfer (constant azimuth, straight line), which also underlies LSQ, on the one hand and GD-UT (+K-Z) on the other. The two might not be mathematically equivalent if distance~time exists between sights, especially when distance~time is stretched.

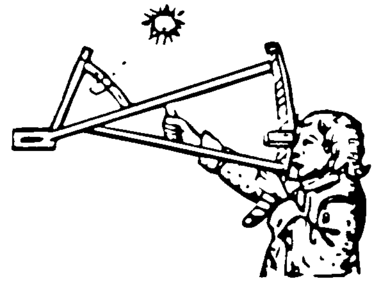
In Technical Appendix 3 I explore the question whether the LSQ solution is mathematically an extreme point and minimum and my conclusion is that this is likely to be the case generally (see Techn. Appendix 3). So it is unlikely that LSQ only attains a relative minimum.

The ANM is apparently only concerned about representing position circle segments by straight lines (i.e PLs) in the case of large altitude, when the zenith distance becomes small enough to draw the position circle on the chart (see the discussion relating to Fig 2-Rej.). In the sight-run-sight situation position circle curvature and its effect on azimuth should perhaps be taken into account more generally when distance~time becomes substantial.

One factor associated with the position solution differences might be that in the case of LSQ, Zn is a function of assumed latitude, in the final iteration a function of the latitude of the fix (F_2)[15], whereas in GD-UT+K-Z Zn is calculated independently from any assumed position. Hence, the Zn computed with GD-UT+K-Z and LSQ can be significantly different. This is taken up further in the next section (see section 3.6).

(End of part one, Part two will be continued in Newsletter #85, Fall 2004)

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY-FIVE, FALL 2004

A C T I V I T I E S – *By Terry Carraway*

The 2005 Nautical Almanac is available from The Navigation Foundation. The Government issue of the Nautical Almanac lists for $43.00, the Commercial version lists for $22.50, members receive a 15% discount on books and publications, shipping and handling is added to the invoice.

The new system of ordering nautical charts has improved. Charts ordered by The Foundation arrive within 2 days and by re-mailing via Priority Mail members can have their charts in about one week. Nautical charts now list for $18.75, however, members receive a 20% discount on orders less than $50.00 and a 25% discount on all orders over $50.00. Postage and handling are added to the invoice.

Both the Government and Commercial Sight Reduction Tables are available. There are 6 publications to PUB229, Marine Navigation and 3 publications for PUB249, Air Navigation. The Government edition list for $47.00 for each publication and the Commercial editions list for $19.95 for each publication. The 15% discount applies to each edition.

The following book of interest to boaters, sailors and cruisers is also available:

"*How to Rename Your Boat and 19 Other Useful Ceremonies, Superstitions, Prayers, Rituals and Curses*", by John Vigor. Softcover 139 pages, ISBN 0-939837-62=5. List price $10.95.

One glance will convince you that this is not at all you usual boating book. It's quirky-funny in some chapters, serious in some and quite over the top in others. And yet, as experienced boaters will realize, it is really a book about safety at sea. This is the basic thread that runs all the way through it, supplemented with plentiful advice about how you can improve you odds of survival in various circumstances.

Some of it may not be standard advice. For instance Vigor's famous "denaming" ceremony does not seem like boating safety advice at first glance. But it is. Sailors the world over acknowledge It protects you from bad luck at sea.

The Foundation, again, solicits your letters, articles or stories. The Newsletter is central in helping The Navigation Foundation stay viable and keeping the art of celestial navigation from further erosion. With the death of our Editor Ernest Brown, who was a real expert on all aspects of navigation, we now need the help of every member to continue to produce a meaningful, entertaining and noteworthy newsletter.

Member Herman Zevering's article, "Dilemmas in Position Solutions Revisited (A Rejoinder)", Part 2. Due to its length (Part 3) will be concluded in The Navigator's Newsletter, Issue #86 Winter 2004 – 2005. All comments, criticism and insights will be greatly appreciated.

3.6 The difference in position solution between LSQ, $IM_{CH/E}$, A-UT + K-Z and GD-UT + K-Z in the sight-run-sight situation with the double sight

An identical dilemma naturally arises with the double sight with run between sights, as mentioned in "Dilemmas". LSQ is, of course, internally consistent, by which I mean that the method in the sight-run-sight case with say three sights gives exactly the same vertex coordinates as when it is run for each pair of sights separately. For example, the vertex coordinates of "A", the Sun-Vega vertex of the Y-H case analyzed in "Dilemmas" (Table 3; also see Attachm. Fig. 1 in this Rejoinder, where the situation of Fig 5 in "Dilemmas" is redrawn to scale) are exactly the same as those obtained with the Sun-Vega double sight (see Table 2 in "Dilemmas"). However, the various methods compared tend to give different results, which are sometimes relatively close and sometimes not. Besides the case analyzed in "Dilemmas" (Table 2), I analyzed several other cases with the different methods. The results I obtain are in Tables 6, 7, 8, 9 and 10. In all cases the 1^{st} sight was run on to the time and DR position at the 2^{nd} sight.

Table 6: Results from Y-H Sun-Moon

	GD-UT+K-Z		A-UT+K-Z		LSQ		$IM_{CH/E}$	
Fix	32.0269 N 14.6995 W		31.9790 N 14.7939 W		31.9789 N 14.7940 W		31.9791 N 14.7942 W	
	Sun (1^{st} sight)				Moon (1^{st} sight)			
GHA	82.5829				358.7759			
Dec	23.3211				3.3713			
H_o	30.1507				57.6765			
Initial DR	32.0068 N 14.6168 W				32.1120 N 14.7410 W			
GMT	$17^h 30^m 45^s$				$18^h 15^m 24^s$			
Run	315° at 12 kn							
d'Lat	0°.1052							
Dep	-0°.1052							
	Sun	Moon	Sun	Moon	Sun	Moon	Sun	Moon
GHA*	82.6975							
Dec*	23.4263							
H^*_o			30.2728					
Z	79.6901	149.1885	79.8658	148.9910	79.7508	148.9908	79.8034	149.1877
Zn	280.3099	149.1885	280.1342	148.9910	280.2492	148.9908	280.1966	149.1877
LHA	67.9980	344.0764	67.7890	343.9820	67.9129	343.9819	67.9661	344.0349
Interc.			n.a	n.a	→0	→0	1'.25	5'.47

Table 7: Results from Y-H Moon-Vega

	GD-UT+K-Z		A-UT+K-Z		LSQ		$IM_{CH/E}$	
Fix	32.2387 N 15.1280 W		32.0142 N 14.9542 W		32.2469 N 15.1344 W		32.2474 N 15.1348 W	
	Moon (1st sight)				Vega (2nd sight)			
GHA	358.7759				287.7705			
Dec	3.3713				38.7668			
H_o	57.6765				21.3722			
Initial DR	32.1120 N 14.7410 W				32.3876 N 15.0669 W			
GMT	$18^h 15^m 24^s$				$20^h 12^m 20^s$			
Run	315° at 12 kn							
d'Lat	0°.2756							
Dep	-0°.2756							
	Moon	Vega	Moon	Vega	Moon	Vega	Moon	Vega
GHA*	359.0520							
Dec*	3.6469							
H^*_o			57.5761					
Z	148.8799	56.7606	148.7512	56.7480	148.9595	56.7611	149.1877	56.8311
Zn	148.8799	56.7606	148.7512	56.7480	148.9595	56.7611	149.1877	56.8311
LHA	343.9240	272.6425	343.8217	272.8163	343.9669	272.6361	344.0349	272.7036
Interc.	n.a	n.a	n.a	n.a	→0	→0	5'.47	-7'.49

Table 8: Results from Y-H Sun-Vega

	GD-UT+K-Z		A-UT+K-Z		LSQ		$IM_{CH/E}$	
Fix	31.9252 N 14.8854 W		32.2329 N 15.1235 W		32.2334 N 15.1239 W		32.2342 N 15.1246 W	
	Sun (1st sight)				Vega (2nd sight)			
GHA	82.5829				287.7705			
Dec	23.3211				38.7668			
H_o	30.1507				21.3722			
Initial DR	32.0068 N 14.6168 W				32.3876 N 15.0669 W			
GMT	$17^h 30^m 45^s$				$20^h 12^m 20^s$			
Run	315° at 12 kn							
d'Lat	0.3809							
Dep	-0.3809							
	Sun	Vega	Sun	Vega	Sun	Vega	Sun	Vega
GHA*	82.9982							
Dec*	23.7020							
H^*_o			30.5918					
Z	79.2915	56.7428	80.1594	56.7603	79.7407	56.7603	79.8034	56.8311
Zn	280.7085	56.7428	279.8406	56.7603	280.2593	56.7603	280.1966	56.8311
LHA	68.1128	272.885			67.9083	272.647	67.9661	272.7036
Interc.	n.a	n.a	n.a	n.a	→0	→0	1'.25	-7'.49

Table 9: Results from the ANM Moon-run-Sun case

	ANM[a]		GD-UT+K-Z		A-UT+K-Z		LSQ		$IM_{CH/E}$	
Fix	50.4917 N 13.8383 W		50.5117 N 13.8323 W		50.6241N 13.7789 W		50.4930 N 13.8412 W		50.4938 N 13.8413 W	
	Moon (1st sight)					Sun Sight (2nd sight)				
GHA	7.9950					309.1783				
Dec	-22.040					5.2050				
H_o	17.4117					19.9450				
Initial DR	50.1667 N 14.8333 W					50.3496 N 14.0474 W				
GMT	$5^h 59^m 45^s$					$8^h 40^m 10^s$				
Run	70° at 12 kn									
d'Lat	0°.1829									
Dep	0°.5025									
	Moon	Sun	Moon	Sun	Moon	Sun	Moon	Sun	Moon	Sun
GHA*			7.4533							
Dec*			-21.8571							
H^*_o					17.1564					
Z			173.7959	106.7762	174.3897	106.8601	173.5559	106.7624	173.3532	106.5426
Zn	173	106.5	173.7959	106.7762	174.3897	106.8601	173.5559	106.7624	173.3532	106.5426
LHA			353.6209	295.3460			353.3655	295.3372	353.1617	295.1338
Interc.	-7'.6	8'.2	n.a	n.a	n.a	n.a	→0	→0	-7'.66	4'.99[b]

a Results given in ANM. In ANM the case is solved with IM_{CH}

b The intercept differs in length from the ANM figure because the transferred DR pos. was used to work the Sun sight instead of the transferred point "J" (See Fig 4).

The case taken from G. Keys (see Table 10) should perhaps have been excluded as it appears that the DR position data of this case were somehow manipulated[i]. But this could prove to be significant in indicating possible boundaries to a particular solution method in the sight-run-sight case.

Table 10: Results from G.Keys' Sun-run-Sun case.

	G.Keys[a] A-UT + Geom		GD-UT+K-Z[b]		A-UT+K-Z[b]		LSQ[b] (3 iterations)		$IM_{CH/E}$[b]	
Fix	47.460 N 12.245 W		47.4402 N (47.4368) 12.2474 W (12.2477)		47.4602 N (47.4563) 12.2449 W (12.2452)		47.4494 N (47.4491) 12.2462 W (12.2461)		47.4522 N (47.4492) 12.2459 W (12.2462)	
	Sun 1st sight					Sun 2nd sight				
GHA	15.2600					89.5000				
Dec	19.8730					19.8320				
H_o	62.4550					22.9720				
Initial DR	47.3300 N 13.1170 W					47.4250 N 12.3530 W				
GMT	(Not provided)									
Run	31'.5602 at 79°.5949 (derived from 1st and 2nd DR)									
d'Lat	0°.0950									
Dep	0°.5174									
	1st sight	2nd sight	1st sight	2nd sight	1st sight	2nd sight	1st sight	2nd sight	1st sight	2nd sight
GHA*			14.7097							
Dec*			19.9680							
H^*_o	62.304				62.3041					
Z			174.9907	85.2291	173.8904	85.2358	175.4218	85.2322	175.6339	85.2979
Zn			185.0093	274.7709	186.1096	274.7642	184.5782	274.7678	184.3661	274.7021
LHA	3.015		2.4623	77.2526	3.0151	77.2551	2.2494	77.2538	2.1430	77.1470
$H_o{}^*{}_1$	62.304				62.3041					
Interc.	n.a	n.a	n.a	n.a	n.a	n.a	→0	→0	-1'.96	-4'.20

a From G. Keys – Practical Navigation by Calculator, 1982, p140-141. The position solution in Keys is found with the Geometric Method (Geom), which gives exactly the same results as A-UT+K-Z. Keys uses his data pre-rounded and gives his results to 3 decimals. Z , Zn not shown in Keys' calculations.

b In applying GD-UT+K-Z, LSQ and $IM_{CH/E}$ we used Keys' rounded data. The positions solutions using the un-rounded data are shown in brackets.

The Sun-Vega case (Table 6), also analyzed in "Dilemmas" (Table 2) gives the impression that GD-UT+K-Z is the odd man out, but this appears to be for some reason particular to the case. In Table 11, I compare the position solutions of the five cases in terms of their absolute deviations in d'Lat and Dep (see "Deviation" in Table 11) and it shows no particular pattern.

Table 11: Deviations in position solution with different methods

	Sun-Moon (Y-H; Table 6)		Moon-Vega (Y-H; Table 7)		Sun-Vega (Y-H; Table 8)		Moon-Sun (ANM;Table 9)		Sun-Sun (Keys; Table 10)	
	(1)		(2)		(3)		(4)		(5)	
Time diff. (hr)	0.74		1.95		2.69		2.67		?	
Run distance	8'.9		23'.5		32'.3		32'.1		31'.6	
Zn angle*	131°		92°		137°		67°		90°	
Deviation**:	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
d'Lat	2'.9	<0'.0	0'.5	14'.0	18'.5	<0'.1	1'.1	7'.9	0'.6	0'.6
Dep	4'.8	<0'.0	0',3	9'.2	12'.1	<0'.1	0'.3	2'.4	0'.1	0'.1
	Sun	Moon	Moon	Vega	Sun	Vega	Moon	Sun	Sun 1	Sun 2
ε	3'.80	-6'.69	-2'.69	-0'.04	28'.15	-1'.26	18'.24	1'.01	12'.44	12'.47

* Angle between the Zn of the sights

** Absolute deviation in position solution: (a) = LSQ dev. from GD-UT+K-Z solution; (b) = A-UT+K-Z dev. from LSQ

ε $= (Zn_o - Zn) \times 2\pi Zd/360$; Zn_o = Zn calculated with GD-UT+K-Z; Zn = Zn calculated with final iteration of LSQ; Zd is zenith distance.

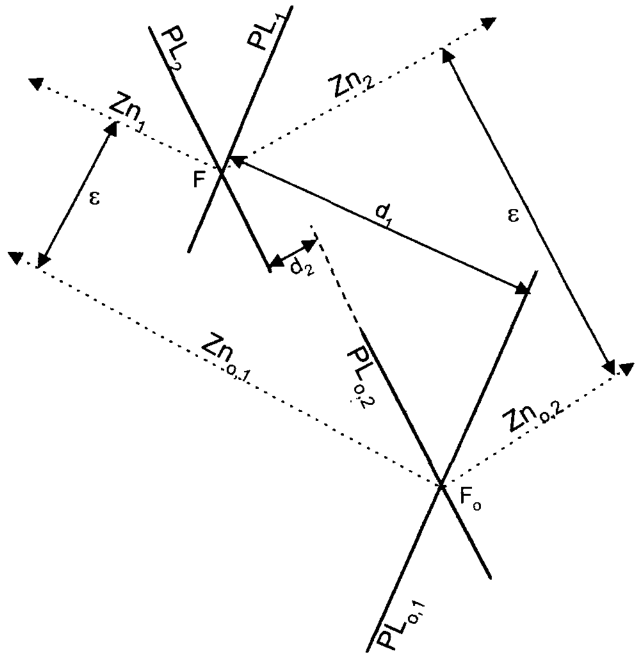
In cases (2) and (4) (see Table 11), the differences in position solution between GD-UT+K-Z and LSQ are very small, whereas between A-UT+K-Z and LSQ they are large. In cases (1) and (3) it is the reverse. The difference in position solution between GD-UT+K-Z and LSQ tends to be small to insignificant when the azimuth angle is 90° or less and substantial to very large when this angle is very much obtuse (e.g 130° or more). But the cases analyzed are too few to make any predictions of this kind, let alone understand why the various methods produce significant differences in some cases but not in others.

A factor that could be related to the difference in position solution between GD-UT+K-Z and LSQ in the sight-run-sight case is perhaps the difference in the azimuth (Zn) of the two sights calculated with these two methods, as already mentioned in section 3.5. A tentative explanation is illustrated with the sketch below. If Zn_o and Zn indicate true azimuth calculated with respectively GD-UT+K-Z and LSQ, the differences ε in degrees measured along the relevant PL are about equal to $(Zn_o - Zn) \times 2\pi Zd/360$, where Zd is zenith distance ($90° - H_o$) of a sight. Tentatively, if $\varepsilon_{1,2}$ is (relatively) large, the displacement of $PL_{1,2}$ from $PL_{o,1,2}$ is (relatively) large and vice versa. This affects the distance between F and F_o. It further seems that if ε is negative (i.e $Zn_o < Zn$), the displacement is 'away' and conversely, if ε is positive (i.e $Zn_o > Zn$), the displacement is 'toward', so that greater over-all convergence between F_o and F might result if in certain situations ε_1 is about equal to ε_2 and both are of equal sign. The displacements then tend to cancel out. However, this should be more thoroughly investigated than I am doing in this paper.

The sketch below resembles the situation with the Y-H Sun-Vega case. The ε_{Sun} is large (28'.15) and this is associated with a large d_{Sun} (see d_1 in sketch); ε_{Sun} is positive because $Zn_{o,Sun} > Zn_{Sun}$.and the displacement is 'toward'. Conversely, ε_{Vega} is small (-1'.26) and this is associated with a small d_{Vega} (see d_2 in sketch); ε_{Vega} is negative because $Zn_{o,Vega} < Zn_{Vega}$. Hence, the displacement is 'away'.

However, readers of NN might have better ideas. In Table 11 I include the $\varepsilon_{1,2}$ of the five cases. Looking at (a) in each case, expected might be that when deviation (a) is large, at least one of the ε should be large, but this seems to be borne out only in the three Y-H cases, and there are obviously other factors at work as well.

Effect of azimuth difference on the sight-run-sight position solution with LSQ and GD-UT+K-Z
(a tentative explanation)



F = Fix with LSQ
F_o = Fix with GD-UT+K-Z
Zn_1, Zn_2 = true azimuth bearings of F
$Zn_{o,1}$, $Zn_{o,2}$ = true azimuth bearings of F_o
ε = distance between Zn_o and Zn measured along posiion circles
d = PL displacement

A more convincing argument that LSQ and GD-UT+K-Z will not arrive at the same position solution is that the Zn (true calculated azimuth) of the sight transferred with LSQ defines GHA and Dec values that differ from the GHA and Dec values updated with GD-UT+K-Z. The implicit values ($Dec^\#$ and $GHA^\#$) obtained in the final iteration with LSQ may be calculated from:

$$SinDec^\# = CosZnCosH_oCosLat_F + SinH_oSinLat_F$$

$Dec^\#$ is then substituted to find:

$$CosMD^\# = (SinH_o - SinLat_F SinDec^\#)/CosLat_F CosDec^\#$$
$MD^\# = GHA^\# + Long_F \rightarrow GHA^\# = MD^\# - Long_F$ (E+, W-; for sights bearing W)
$MD^\# = 360^\circ - (GHA^\# + Long_F) \rightarrow GHA^\# = 360^\circ - MD^\# - Long_F$ (E+, W-; for sights bearing E)

Applied to the L-H Sun-Vega case, the following values would be obtained:

$Dec^\#_{Sun}$	23.4639	$Dec^\#_{Vega}$	38.7668
$MD^\#_{Sun}$	68.0611	$MD^\#_{Vega}$	87.3534
$GHA^\#_{Sun}$	83.1849	$GHA^\#_{Vega}$	287.7705

As may be expected, $Dec^{\#}_{Vega}$ and $GHA^{\#}_{Vega}$ obtained in this manner are exactly the same as the original data (see Table 8), because for un-transferred sights LSQ (final iteration) and GD-UT+K-Z obtain the same position circle. $Dec^{\#}_{Sun}$ and $GHA^{\#}_{Sun}$, however, differ from Dec^{*}_{Sun} and GHA^{*}_{Sun}. Table 12 shows the results for the Sun-Vega case and three other cases.

Table 12: The effect of different methods (GD-UT and LSQ) used in running on an earlier sight

Y-H Sun-run-Vega		ANM Moon-run-Sun		Y-H Vega-run-Dubhe		Y-H Moon-run-Dubhe	
$Dec^{\#}_{Sun}$	**Dec^{*}_{Sun}**	**$Dec^{\#}_{Moon}$**	**Dec^{*}_{Moon}**	**$Dec^{\#}_{Vega}$**	**Dec^{*}_{Dubhe}**	**$Dec^{\#}_{Moon}$**	**Dec^{*}_{Moon}**
23.4639	23.7020	21.8583	21.8571	38.7680	38.7925	3.6813	3.6726
$GHA^{\#}_{Sun}$	**GHA^{*}_{Sun}**	**$GHA^{\#}_{Moon}$**	**GHA^{*}_{Moon}**	**$GHA^{\#}_{Vega}$**	**GHA^{*}_{Dubhe}**	**$GHA^{\#}_{Moon}$**	**GHA^{*}_{Moon}**
83.1849	82.9982	7.2152	7.4533	287.7803	287.8035	359.1275	359.0778

Absolute deviations in position solution:

d'Lat 18'.5 Dep 12'1	d'Lat 1'.1 Dep 0'.3	d'Lat 0'.6 Dep 1'.5	d'Lat 2'.3 Dep 5'.2

In other words, the transferred position circles obtained with these two methods are not coincident, so that LSQ and GD-UT+K-Z will not be mathematically equivalent. This also means that the respective polygons obtained with three or more sights in the sight-run-sight situation will never coincide.

3.7 The difference in position solution with A-UT and GD-UT

If GD-UT is the correct method for transferring an earlier sight's position circle (PC), the question then arises whether A-UT achieves an equivalent result. I first noticed the application of A-UT to the double sight in an article by G.G. Bennett (General Conventions, etc., 1979) and again in G. Keys' publication (op. cit., 1982). I have been unable to find any 'convention' in the ANM that resembles A-UT.

First a few words about A-UT for which I take G. Keys' worked example. The approach is implicitly to first calculate a longitude ($Long_{1,c}$) for the earlier of two successive sights consistent with GHA_1, $H_{o,1}$, Dec_1 and Lat_{DR1}[ii]:

$$\mathrm{Cos}(GHA_1+Long_{1,c}) = \mathrm{Cos}MD_1 = \mathrm{Sin}H_{o,1} - \mathrm{Sin}Lat_{DR1}\mathrm{Sin}Dec_1/\mathrm{Cos}Lat_{DR1}\mathrm{Cos}Dec_1 \quad ..(1)$$

($GHA_1+Long_{1,c}$) may be called 'meridian angle' (Keys' term) or 'meridian difference' (MD, my term). MD_1 will always be returned as the smallest absolute angle or arc, so that $MD_1 = |GHA_1+Long_{1,c}|$ and it is unnecessary to make an intermediate calculation of $Long_{1,c}$. In A-UT, to MD_1 is then added d'Long = $d\mathrm{Sin}\alpha/\mathrm{Cos}(\text{Mean } Lat_{DR})$ = Dep/ Cos(Mean Lat_{DR}), where d = distance sailed and α = true course bearing, so that $MD^*_1 = MD_1$ + d'long, in which MD^*_1 is the adjusted meridian difference. Thus, in eq. (2) below, $\mathrm{Cos}(MD^*_1)$ is always uniquely determined:

$$\mathrm{Sin}H^*_1 = \mathrm{Cos}MD^*_1\mathrm{Cos}Dec_1\mathrm{Cos}Lat_{DR2} + \mathrm{Sin}Dec_1\mathrm{Sin}Lat_{DR2} \quad ...(2)$$

in which H^*_1 is the updated altitude of the earlier sight. There is no need as in Keys' approach to know the azimuth of the sight and laboriously define LHA^*_1 and substitute this value for MD^*_1[iii]. Noted is that A-UT is always influenced by the assumed initial Lat_{DR}.

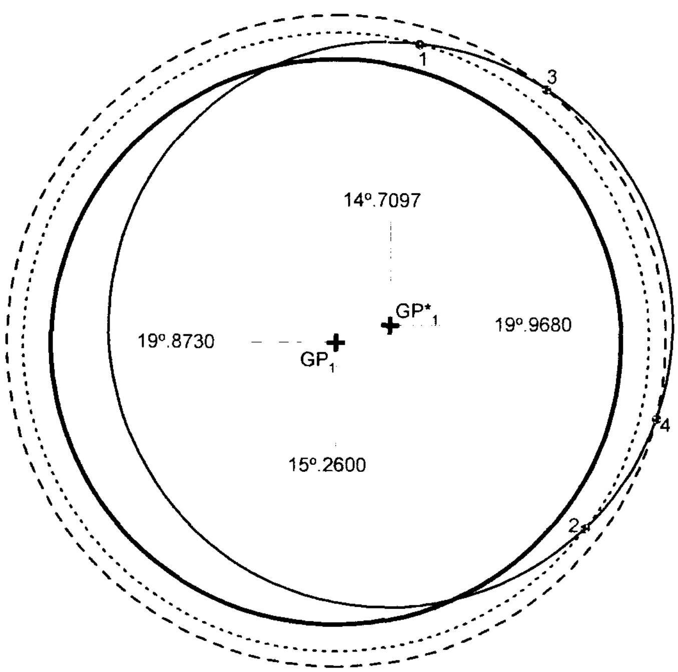
With the sketch below of Keys' case analyzed with A-UT and GD-UT, two things are demonstrated:

1. A-UT and GD-UT are not mathematically equivalent. This could mean that either G-UT is flawed or A-UT is at best another 'proxy' method.
2. The assumed initial Lat_{DR} affects the position solution with A-UT, whereas GD-UT is independent of assumed position.

If A-UT and GD-UT were mathematically equivalent, the 'locus' of their respective transferred position circles should be identical. They should have no point of intersection and should coincide. However, the transferred PC obtained with A-UT intersects with the transferred PC obtained with GD-UT as shown in the sketch with the intersection points marked 1 and 2. As each transferred PC would in turn intersect with the PC of the 2nd sight, whose 'locus' would be the same in both cases, it is mathematically impossible as a general condition that A-UT and GD-UT obtain identical results. As may be visualized with the sketch, A-UT projects a concentric circle with an adjusted (updated) Zd that is larger than the observed Zd, whereas GD-UT shifts the 1st sight's PC with its observed Zd to its adjusted (updated) GP^*_1. In other words, the rationale of A-UT as a generally valid method could therefore be simply flawed.

When the track made good (in terms of distance sailed at a particular course) is assumed to start at a different initial (DR) position, the above-mentioned intersection points will be different. For example, with an assumed position SW (d'Lat and d'Long = -0°.5) from the previous one, the intersection points become 3 and 4, whose coordinates differ from those of intersection points 1 and 2 (see sketch). The absolute deviation in position solution between A-UT+K-Z and GD-UT+K-Z in this case is d'Lat = 5'6 and Dep = 0'.5. In other words, not only does the rationale of A-UT appear to be flawed, its results are affected further by assumed position, although this effect may in certain cases be rather insignificant in practical terms.

Non-equivalence of A-UT and GD-UT shown with G. Keys' Sun sight case (sketch only - not to scale)



Position circle (A) at time of 1st sight; Zd = 27°.5450

Position circle (A*) transferred with GD-UT
(track as calculated: course 79°.5949, distance 31'.5602)

Position circle (B) transferred with A-UT; Zd = 27°.6959
Initial DR pos.: 47°.330 N 13°.117 W
Final DR pos. (at 2nd sight): 47°.425 N 12°.353 W
(track as calculated: course 79°.5949, distance 31'.5602)

Position circle (C) transferred with A-UT; Zd = 27°.7701
Initial DR pos.: 46°.830 N 13°.617 W
Final DR pos. (at 2nd sight): 46°.925 N 12°.860 W
(track as calculated: course 79°.5949, distance 31'.5602)

PC - B Sun sight (1st) (transf. with A-UT)		PC - A* Sun sight (1st) (tansf. with GD-UT)	
GHA_1	15°.2600	GHA^*_1	14°.7097
Dec_1	19°.8730	Dec^*_1	19°.9680
H^*_1	62°.3041	$H_{o,1}$	62°.4550

PC - C Sun sight (1st) (transf. with A-UT)	
GHA_1	15°.2600
Dec_1	19°.8730
H^*_1	62°.2299

•1 •2 Intersection of PC A and PC B, resp. 47°.3195 N/10°.7036 W and 4°.9444 S/2°.7562 W

•3 •4 Intersection of PC A and PC C, resp. 46°.3401 N/5°.0078 W and 3°.0042 S/0°.7698 E

3.8 Conclusions regarding the dependability of position solution methods

From the foregoing analysis, I would be prepared to draw the following conclusions regarding the relative dependability of various methods of position solution in celestial navigation:

1. The single-sight IM is unreliable. The PL it obtains could perhaps help in determining 'distance-off' from a known hazard, e.g a lee shore.

2. With truly simultaneous sights, all methods ($IM_{CH/E}$, LSQ, K-Z) yield equivalent results and are in practical terms equally dependable. The assumption of simultaneity becomes unreliable as speed of a vessel and time between sights become significant.
3. In the sight-run-sight situation:

   (i) $IM_{CH/E}$ and LSQ are unreliable. Their unreliability tends to increase with increased distance~time between sights. With three or more sights, the inclusion of an inconsistent sight increases unreliability of the fix.

   (ii) A-UT+K-Z is unreliable, owing to a possible flawed rationale of A-UT and the influence of assumed position.

   (iii) GD-UT+K-Z is reliable. It is reliable with three sights or more provided consistent sights are used. With three sights or more, the bisector point of intersection, possibly obtained iteratively, is a reliable fix if systematic error is suspected to be dominant.

   (iv) LSQ+GD-UT is reliable. It is reliable with three sights or more provided consistent sights are used. LSQ+GD-UT's fix in this case is a reliable alternative to the bisector fix in (iii) if systematic error is not identifiable or not suspected to be dominant.

Technical Appendix 1: Latitude-solving polynomial

From CosZ = SinDec/(CosAltCosLat) – TanAltTanLat, the azimuth equation, may be derived:

CosZCosAltCosLat = SinDec- SinAltsinLat

This equation may be rewritten as:

$$a\cos x + b\sin x - d = 0$$

a = CosZCosAlt
b = SinAlt
d = SinDec
x = Lat

and can be expanded as:

$$a\cos x + b\sqrt{(1-\cos^2 x)} - d = 0$$
$$a\cos x - d = -b\sqrt{(1-\cos^2 x)}$$
$$a^2\cos^2 x - 2ad\cos x + d^2 = b^2(1-\cos^2 x)$$
$$(a^2 + b^2)\cos^2 x - 2ad\cos x + (d^2 - b^2) = 0$$

From this 2nd degree polynomial follow two solutions for Lat if Z is given, where Z = Zn, one of which is plausible:

$$\text{CosLat}_{1,2} = (A \pm B)/C$$

$$A = \text{CosZnCosAltSinDec}$$
$$B = \text{SinAlt}\sqrt{[(\text{CosZnCosAlt})^2 - \text{Sin}^2\text{Dec} + \text{Sin}^2\text{Alt}]}$$
$$C = (\text{CosZnCosAlt})^2 + \text{Sin}^2\text{Alt}$$
$$[(\text{CosZnCosAlt})^2 - \text{Sin}^2\text{Dec} + \text{Sin}^2\text{Alt} \geq 0]$$

Plausible Lat is then substituted in the position circle equation to find Long.

Technical Appendix 2: Comparison of Method Results

The table below shows a comparison between published results by Yallop-Hohenkerk (Y-H) in Compact Data 1986 and own program results for the 2nd iteration with the data for Sun-Moon-Vega-Dubhe. The GHA, Dec and H_o data used were taken from the publication as shown to 4 places behind the decimal point.

As with H_o, the GHA and Dec data were (most likely) computed from the GHA-GMT and DEC coefficients in Table 1 (for June 1986) with the formulas shown in that publication, including the formula for the time variable x = (d+GMT/24)32. The slight discrepancies in some results at the 3rd and 4th decimal are most likely caused by using Y-H's rounded H_o, GHA and Dec data.

2nd Iteration		Sun	Moon	Vega	Dubhe
Program>	Zn	280.2368	148.9784	56.7680	336.5788
Program>	Alt_c	30.1637	57.6608	21.3841	55.1700
Data Y-H>	GHA	**82.5829**	**358.7759**	**287.7705**	**43.9070**
Data Y-H>	Dec	**23.3211**	**3.3713**	**38.7668**	**61.8305**
Data Y-H>	H_o	**30.1507**	**57.6765**	**21.3722**	**55.1937**
Program>	Mer. Diff.	67.8998	343.9688	272.6379	28.7440
Program>	Z	79.7632	148.9784	56.7680	23.4212
Program>	Lat (ass)	31.8854	31.9906	32.2662	32.2920
Program>	Long (ass)	-14.6831	-14.8071	-15.1326	-15.1630
Program>	Interc. (nm)	-0.78	0.94	-0.71	1.42
Data Y-H>	GMT	**$17^h30^m45^s$**	**$18^h15^m24^s$**	**$20^h12^m20^s$**	**$20^h23^m15^s$**
Data Y-H>	Initial DR	**32° 30' N/15° 12' W**			

Coeff.	Results: Y-H	Results: Own progr.	Own program: Sun	Own program: Moon	Own program: Vega	Own program: Dubhe
A	1.9083	1.9083	0.0316	0.7344	0.3003	0.8420
B	-0.5229	-0.5229	-0.1749	-0.4417	0.4584	-0.3647
C	2.0917	2.0917	0.9684	0.2656	0.6997	0.1580
D	-0.0005	-0.0005	-0.0023	-0.0135	-0.0065	0.0218
E	0.0016	0.0015	0.0128	0.0081	-0.0099	-0.0094
F	0.0011	0.0011	0.0002	0.0002	0.0001	0.0006
G	n.av	3.7182				
A+C		4.0000				
dλ	not av.	0.0008				
dφ	not av.	-0.0001				
S	not av.	0.0011				
σ	1.3883	1.4187				
2θ	not av.	80.0555				
θ	40.0284	40.0277				
a	2.804	2.809				
b	2.136	2.140				

		Lat	Long
Y-H	1st iteration	32.3787	-15.2664
Y-H	2nd iteration	32.3787	-15.2655
Own pr.	1st iteration	32.3786	-15.2655
Own pr.	2nd iteration	32.3785	-15.2647

The following table gives the intermediate and final results of the K-Z method applied to the data used in Gerry Keys' geometric solution method for two star sights:

"Ex. Sextant sights on two stars when at EP 36° 23' S, 69° 33' E gave the following true altitudes and approximate azimuths: H_1 = 33° 20'.8, Z_1 = 030 °, H_2 = 16° 30'.4, Z_2 = 270°. Calculate the OP if the GHA and Dec values obtained from the Almanac were GHA_1 = 265° 19'.0, Dec_1 = 15° 08'.0 N, GHA_2 = 9° 16'.2 and Dec_2 = 12° 42'.3 S." The results were: OP Lat –36°.253 (36° 15'.1 S) and Long 69°.435 (69° 26.1 E) (see G. Keys, op. cit., p 138-139).

K-Z method

	Star 1	Star 2			
GHA	265.3167	9.2700			
Dec	15.1333	-12.7050			
Alt obs	33.3467	16.5067			
cosDec1	0.9653	cosMD1,1a	0.5485	MD1,1a	56.7381
cosDec2	0.9755	cosMD1,1b	0.6792	MD1,1b	47.2153
sinDec1	0.2611	cosMD2,1a	0.9045	MD2,1a	25.2478
sinDec2	-0.2199	cosMD2,1b	0.1959	MD2,1b	78.7055
sinAlt1	0.5497		Group 1		
sinAlt2	0.2841	$Long_1$	322.0547	GHA1+ MD1,1a	
cosAlt1	0.8354		208.5786	GHA1- MD1,1a	
cosAlt2	0.9588		56.4853	GHA2 + MD1,1b	
cosGHA1	-0.0816		-37.9453	GHA2 - MD1.1b	
cosGHA2	0.9869		Group 2 (Lat_2 plausible)		
tanDec1	0.2704	$Long_2$	290.5645	GHA1+MD2,1a **=69.4355 E**	
tanDec2	-0.2255		240.0689	GHA1 - MD2,1a	
sinGHA1	-0.9967		87.9755	GHA2 + MD2,1b	
sinGHA2	0.1611		-69.4355	GHA2 -MD2,1b **=69.4355 E**	
			Star 1	Star 2	
A'	0.5858	$cosAz_c$	0.8701	-0.0671	
B'	-0.2485	$AZ_c = Z$	29.5308	93.8498	
C'	-0.9705	Zn	29.5308	266.1502	
A"	0.3820	LHA = GHA+$Long_c$ (E +. W -)	334.7522	78.7055	
B"	0.1811		LHA>180	LHA<180	
Q	0.0764				
R	0.4751				
S	1.0364				
$SinLat_1$	0.7387	$SinLat_{1,2}=(Q \pm R^{1/2})/S$			
$SinLat_2$	-0.5914				
Lat_1	47.6239				
Lat_2	**-36.2529**				

The position solution is Lat -36°.2529 (Keys: -36°.253) and 69°.4355 (Keys: 69°.435). Note that the identical Long pair in Group 2 is resolved as follows: rule iii (if 180° <Long < 360° → Long E = 360° -Long) = 360° -290°.5645 = 69°.4355 E; rule i (if Long is neg. add 360°) = -69°.4355 + 360° = 290°.5645. Apply rule iii → 360° - (360° -69°.4355) = 69°.4355 E. With the K-Z method, azimuth (Z) is calculated and Zn is decided with the same rules as printed on every page of the old A.P. 3270 (Sight Reduction Tables for Air Navigation).

Technical Appendix 3: The LSQ solution

LSQ as an application of *multiple regression* should pass two important tests, namely does the solution (fix) imply an extreme value and is it at a minimum. The object is to minimize the sum of the squared deviations ($\Sigma\delta_i^2$) between the observed intercept values (p_i), given by $p_i = xSinZn_i + yCosZn_i$ and the calculated intercept values, i.e minimize:

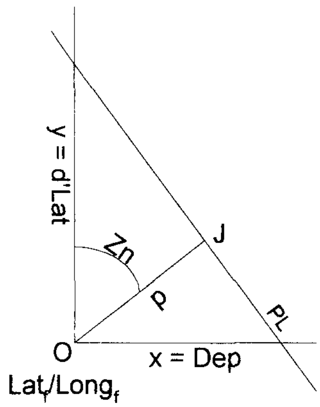
$$\Sigma\delta_i^2 = \Sigma(p_i - xSinZn_i - yCosZn_i)^2$$

If the expression in brackets is indicated as u_i, the two equations for solving x (=dLong) and y (=dLat) follow from the derivatives $2\Sigma u_i SinZn_i = 0$ and $2\Sigma u_i CosZn_i = 0$. Solving with Cramer's rule will then provide the coefficients A, B, C, D, E (A=B) found in Y-H Compact Data 1986 (also see Techn. App. 2). For testing whether the solution indeed attains an extreme value which is also a minimum, the second-order derivatives are:

$$\delta^2 f/\delta x^2 = 2\Sigma Sin^2 Zn_i \,(=q)$$
$$\delta^2 f/\delta y^2 = 2\Sigma Cos^2 Zn_i \,(=r)$$
$$\delta^2 f/\delta x\delta y = 2\Sigma SinZn_i CosZn_i \,(=s).$$

The test for an extreme value is: $qr-s^2>0$ (1st condition) and for a minimum value q or r > 0 (2nd condition), thus:

$\Sigma Sin^2Zn_i \Sigma Cos^2Zn_i - (\Sigma SinZn_i CosZn_i)^2 > 0$ (1st cond.). The 2nd cond., $\Sigma Sin^2Zn_i > 0$ or $\Sigma Cos^2Zn_i > 0$, is always met. It can be proven that the 1st cond. holds in the case of two sights. The condition is met if $(Sin^2Zn_1+Sin^2Zn_2)(Cos^2Zn_1+Cos^2Zn_2)>(SinZn_1CosZn_1+SinZn_2CosZn_2)^2$. Expanding both sides of the inequality gives $Sin^2Zn_1Cos^2Zn_2+Sin^2Zn_2Cos^2Zn_1>2SinZn_1CosZn_1SinZn_2CosZn_2$. Dividing both sides first by Cos^2Zn_1 and then by Cos^2Zn_2 gives $Tan^2Zn_1+Tan^2Zn_2>2TanZn_1TanZn_2$ so that $(TanZn_1 - TanZn_2)^2>0$, which is true for Zn γ any cardinal bearing. It is still possible that a function attains an extreme value in more than one point.



p/x = Cos(90-Zn) --> x = p/SinZn

p/y = Sin(90-Zn) --> y = p/CosZn

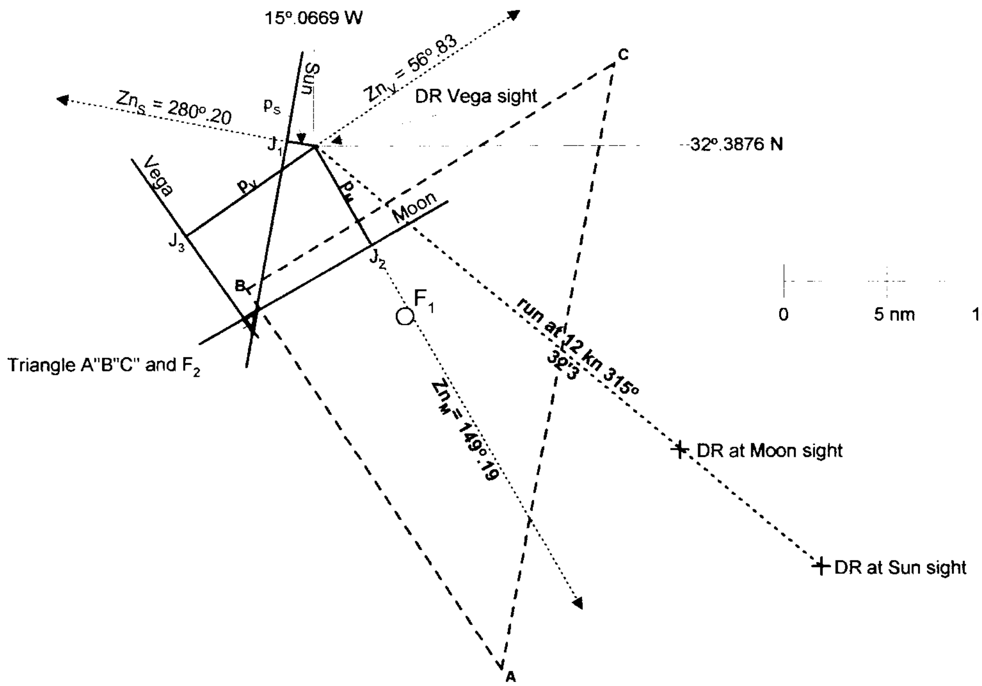
Fitting a linear equation of the form y = ax+b gives:

b = p/CosZn and a = -TanZn --> y = -xTanZn+p/CosZn

or p = yCosZn+xSinZn

The derivation of Y-H's intercept equation is shown with the above figure. A point O (which is initially the DR position, to become the Fix later) is sought so that the distance p to the estimated position in J is smallest, consistent with a similar condition placed on all other intercepts originating in O.

Attachm.-Fig 1: Determining 'cocked hats' and Fixes from multiple sights with different methods.
The Yallop-Hohenkerk Sun-Moon-Vega case



Primary data:

	Sun	Moon	Vega
Time	17h 30m 45s	18h 15m 24s	20h 12m 20s
GHA	82° 5829	358°.7759	287°.7705
Dec	23°.3211 N	3°.3713 N	38°.7668 N
H_o	30°.1507	57°.6765	21°.3722

Course 315°
Speed (kn/hr) 12

Data for $IM_{CH/E}$ only: DR pos. at Vega sight time = 32°.3876 N 15°.0669 W

Derived data:

	Sun	Moon
GHA* (run-on)	82°.9962	359°.0520
Dec* (run-on)	23°.7020 N	3°.6489 N

Other derived data:

DR Moon sight: 32°.1120 N 14°.7410 W
DR Sun sight: 32°0068 N 14°.6168 W

$IM_{CH/M}$ results:

	Sun	Moon	Vega
Zn	280°.20	149°.19	56°.83
Intercept	p_S =1'.25	p_M = 5'.47	p_V = -7'.49

Vertex coordinates:
Sun-Vega (A") = 32°.2342 N 15°.1246 W
Moon-Vega (B") = 32°.2474 N 15°.1348 W
Sun-Moon (C") = 32°.2547 N 15°.1202 W

LSQ results (with primary data and Vertex Program)

	Sun	Moon	Vega
Zn	280°.25	148°.97	56°.76
Intercepts	-0'.33	-0'.23	-0'.25

Vertex coordinates:
Sun-Vega (A*) = 32°.2334 N 15°.1239 W
Moon-Vega (B*) = 32°.2469 N 15°.1344 W
Sun-Moon (C*) = 32°.2502 N 15°.1194 W

Fix F2 = 32°.2459 N 15°.1278 W

GD-UT + K-Z results

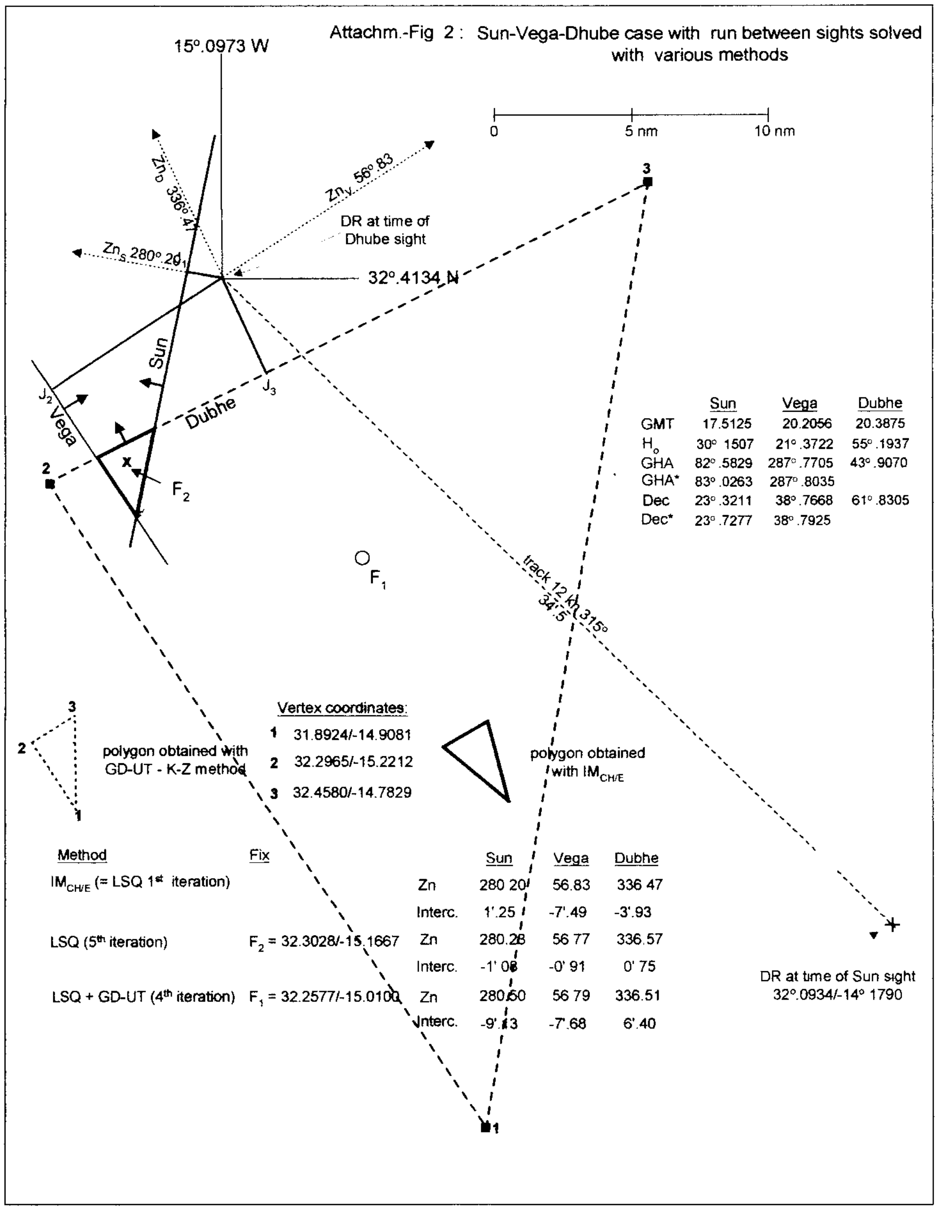
Vertex coordinates:
Sun-Vega (A) = 31°.9252 N 14°.8854 W
Moon-Vega (B) = 32°.2387 N 15°.1280 W
Sun-Moon (C) = 32°.4151 N 14°.7772 W

LSQ + GD-UT results (with derived data, H_o and Vertex Program)

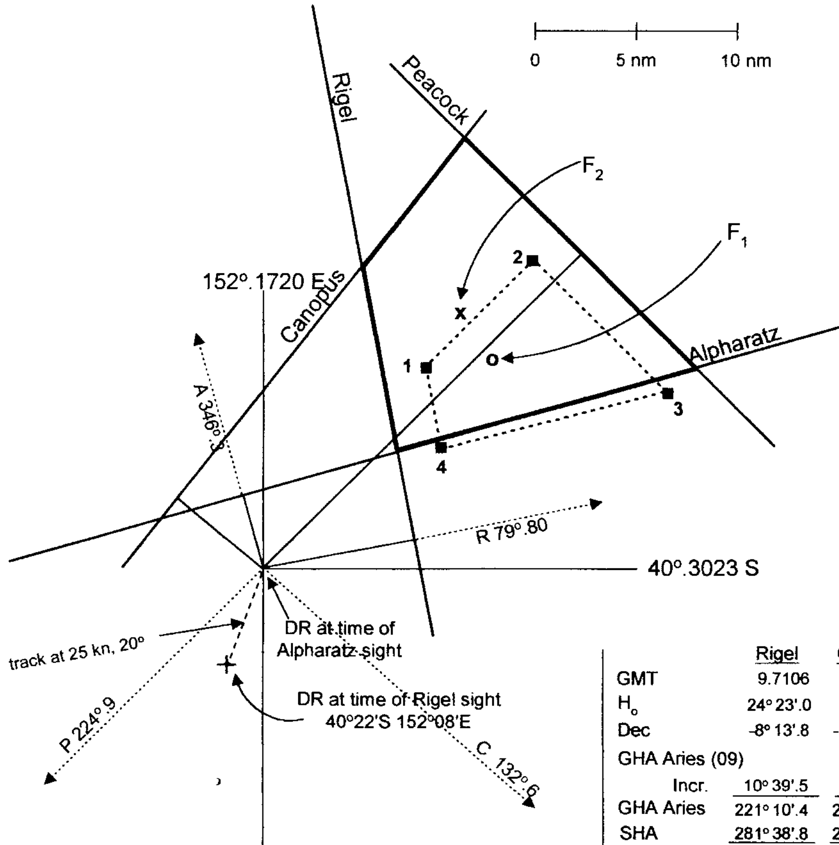
	Sun	Moon	Vega
Zn	280°.50	149°.12	56°.81
Intercepts	-7'.7	-5.'.3	-5.'.8

Vertex coordinates:
Sun-Vega (A') = 31°.9244 N 14°.8850 W
Moon-Vega (B') = 32°.2404 N 15°.1293 W
Sun-Moon (C') = 32°.4189 N 14°.7763 W

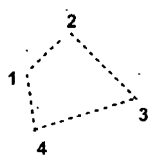
Fix F1 = 32°.2157 N 14°.9746 W


Attachm.-Fig 2 : Sun-Vega-Dhube case with run between sights solved with various methods
15°.0973 W
0
5 nm
10 nm
Zn_D 336°.41
Zn_V 56°.83
Zn_S 280°.20
DR at time of Dhube sight
32°.4134 N
Sun
Vega
Dubhe
J2
J3
F2
F1
X
track 12 kn 315°
34'.5
	Sun	Vega	Dubhe
GMT	17.5125	20.2056	20.3875
Ho	30° 1507	21°.3722	55°.1937
GHA	82°.5829	287°.7705	43°.9070
GHA*	83°.0263	287°.8035	
Dec	23°.3211	38°.7668	61°.8305
Dec*	23°.7277	38°.7925	
polygon obtained with GD-UT - K-Z method
Vertex coordinates:
1 31.8924/-14.9081
2 32.2965/-15.2212
3 32.4580/-14.7829
polygon obtained with IM_CH/E
Method	Fix		Sun	Vega	Dubhe
IM_CH/E (= LSQ 1st iteration)		Zn	280 20	56.83	336 47
		Interc.	1'.25	-7'.49	-3'.93
LSQ (5th iteration)	F2 = 32.3028/-15.1667	Zn	280.28	56 77	336.57
		Interc.	-1' 08	-0' 91	0' 75
LSQ + GD-UT (4th iteration)	F1 = 32.2577/-15.0100	Zn	280.60	56 79	336.51
		Interc.	-9'.13	-7'.68	6'.40
DR at time of Sun sight
32°.0934/-14° 1790

Attachm.-Fig.3: Results of four position solution methods with multiple Star sights and run between sights



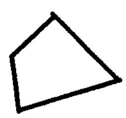
	Rigel	Canopus	Peacock	Alpharatz
GMT	9.7106	9.7467	9.8142	9.9175
H_o	24° 23'.0	35° 19'.8	43° 22'.5	19° 28'.0
Dec	-8° 13'.8	-52° 40'.9	-56° 48'.9	28° 57'.7
GHA Aries (09)	210° 30'.9			
Incr.	10° 39'.5	11° 13'.8	12° 14'.8	13° 48'.0
GHA Aries	221° 10'.4	221° 44'.7	222° 45'.7	224° 18'.9
SHA	281° 38'.8	264° 8'.1	54° 3'.9	358° 12'.5
GHA	142° .8200	125° .8800	276° .8267	222° .5233



polygon obtained with GD-UT - K-Z method

Vertex coordinates:

1	-40.1365/152.3463
2	-40.0444/152.4569
3	-40.1570/152.6049
4	-40.2030/152.3622



polygon obtained with $IM_{CH/E}$

Method	Fix		Rigel	Canopus	Peacock	Alphratz
$IM_{CH/E}$ (= LSQ 1st iteration)		Zn	79.79	132.55	225.00	346.39
		Interc.	7'.72	-5'.35	-22'.07	3'.73
LSQ (3rd iteration)	F_2 = -40.0890/152.3734	Zn	79.75	132.61	224.84	346.19
		Interc.	-3'.63	-3'.49	-6'.50	-6'.49
LSQ + GD-UT	F_1 = -40.1232/152.4128	Zn	79.67	132.54	224.88	346.16
		Interc.	-3'.14	-1'.71	-4'.78	-4'.09

THE
NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION

ISSUE EIGHTY-SIX , WINTER 2005

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a reader forum for the expression of our member opinions and their questions.

ACTIVITIES
By Terry Carraway

A number of members have ordered the 82 (less a few) original copies of The Navigator's Newsletter. We still have a very limited number of the first 21 Issues (less Issue # 19). If you wish to receive the original copies please send an e-mail to navigate1@comcast.net or a letter to: The Navigation Foundation, 12509 White Drive, Silver Spring, Maryland 20904. The price is $25.00 for the Issues with $4.95 postage added. The sorting continues so I ask those who have ordered the 82 Issues to be patient as it is taking more time than expected to sort and mail packets of issues.

This issue of The Newsletter will carry the final part of Member Herman Zevering's article, "Dilemmas in Position Solutions Revisited (A Rejoinder)."

The Spring issue of The Navigator's Newsletter will include his final article "Epilog."

The Foundation still needs letters, articles, cruise logs, at sea experiences and other items of interest for The Navigator's Newsletter. It is time for all members to become aspiring authors. Try your skill at writing with a submission to The Navigation Foundation's Newsletter.

Hone your celestial skills. I read in the newspaper today that the government is seriously considering shutting down the GPS system in a national emergency. The reason stated is the proliferation of the GPS tracking on individual tracking devices on automobiles and other moving objects. The Government is concerned that terrorists will use the system to plant explosives. One must examine the individual tracking device phenomena and draw their own conclusions. One of the main reasons for Admiral Thomas D. Davies, USN to start The Navigation Foundation was to have a ready source of experienced navigators to call on when the GPS had to be shut down because of the threat of enemies using the GPS for targeting. He was the Chief of Naval Development because of his development and the originator of the cruise missile, and the vertical launcher, which used GPS for its flight profile. He was concerned that the Navy would have to resort to traditional navigation for ships and pilots if the GPS system was shut down.

The problem seemed to have dissipated with the fall of the Soviet Union but has resurfaced with the serious threat from the Islamic Terrorist. By placing clandestine GPS tracking devices on Diplomatic, Executive and other official vehicles it would allow the terrorist to have a pattern of travel for these persons and vehicles, thus GPS would have to be shut down. Once shut down all ships and aircraft would have to revert to pre-GPS navigation. Ships would have to use piloting and celestial navigation and planes would have to use VORTAC as their principal means of navigation. A reason for concern.

READERS FORUM
Edited by Terry Carraway

Member Paul J. Adams wrote on September 19, 2004 :

"I am installing another compass on the "Ida K." which requires Deck Magnets, In Aque Meter's instructions it recommends using a "Darla Compass Correction", what is it? I can't find it listed in any catalog or book.

Editor's note: If someone has the answer The Foundation will forward it to member Adams.

Member Jack B. Craven wrote on December 16, 2004:
Terry,
It was with great sadness when I read that Ernest

had passed away. I was working on a letter to him when I received your notice. His e-mail "begonetodogs" was always popping up when he got on line with his computer. About a month ago it caused me to wonder why it had stopped appearing. I met with him a few times in the Neptune Subs to have lunch with him on his way to Galveston. I enjoyed talking to him. He told me that he was having a problem with issue 80 and it had been a big job for me to fix. It would be worth your effort to get a dump of the Navigation Section of his computer before it is eliminated.

I know some ex-Naval Aviators that might like to read the Newsletter and I was about to recommend to Ernest to publish a Membership Form that I could copy and mail to them. Maybe there are other members of the Newsletter that would do the same.

Editors note: The Foundation has had no answer to letters written to Earnes's family. We had requested any material concerning the Navigation Foundation be sent to us.

A copy of The Foundation's brochure has been sent to Member Craven.

Member Ed Hooper wrote on December 7, 2004:

"I have just shined up and calibrated the Zuiho sextant and have used it under simulated "combat conditions." You have to understand, we never sail without racing everybody on the ocean - they don't necessarily know they are racing. If they do then we try to bury them. It is the price I pay for going to sea with old Marine guys. Anyway, the dial-in shade covers work great. I am surprised that this is not an invention that took with other manufacturers. You start by pointing the shade covers, both the mirror and horizon, at the sun and twist in the appropriate darkness. Them, as you bring down the sun, you can easily reach up and the horizon cover to clear without disturbing your sight. Very fast, very user friendly.

Director Roger H. Jones wrote on January 28, 2004:

Charlie Nobles: Greetings and regards. Terry Carraway, with whom I am associated in the Foundation for the Promotion of the Art of Navigation (The navigation Foundation) has forwarded to me some of your e-mail correspondence. I was an early "recruit" by Admiral Tom Davies and Capt. Terry Carraway back in the 1980's when the Foundation was just getting started, and for a number of years was the editor of "The Navigator's Newsletter," as well as a contributor of various articles to that publication. One such contribution was a "text" on celestial theory and practice, which was published in ten successive articles in the Newsletter. It has also been published in the Seven Seas Crusing Association Commodore's Bulletin, and I have used it to teach the subject in various venues both here in the East and also in California. (I am Commodore of SSCA – actually a Rear Commodore now that I am no longer living aboard my sailing vessel, and former Board member of SSCA."

In California I lived at 13900 Panay Way in Marina Del Rey from 1985 until early 1993 and then I lived aboard at the California Yacht Club durning 1993. I left to go cruising on my Hans Christian cutter. I departed the CYC dock at midnight in early February of 1994 bound for Panama.

My "text" is entitled *celestial Navigation – An Armchair Perspective,* and I have had quite favorable feedback about it from mariners in far flung locations. It is addressed to celestial theory and practice using H. O. 249, which I think is understandably the preferred set of sight reduction tables for small boat mariners. It is a boil down of the usual 350 pages of "stuff" that one finds in standard texts , and it presents both the theory and the step-by-step procedure and practice in 50 pages, including a universal sight reduction worksheet that I designed which can accommodate four sights on the front side, and a plotting sheet on the reverse side. Many students of mine have asked me for multiple copies of this worksheet, and I am happy to provide it to them. The monograph is in layman's terms, and have never had trouble teaching the subject to students who are complete novices. It is addressing mainly to the logical starting point, Sun sights, since it is those sights that most small boat navigators favor because of their ease, the availability of the Sun throughout the day and the ancillary procedures such as the LAN shot coupled, with timed shots just before noon and the same exact time interval after meridian passage to produce a very accurate longitude.

If you have any interest in examining *An Armchair Perspective,* I am sure Terry can provide you with a copy at a very, very modest cost. - - - - - I salute your efforts and welcome you as on of the "brethren" who seek to preserve the celestial art in this day and age of black boxes. There are not enough of us these days. But I do get "recruits" from strange quarters. This morning I had a man fixing the air conditioning on my current boat (a Nordic Tug). Like me he is both an airplane pilot and sailor, and he wanted to learn the celestial art, so I will teach him. He has a 45-foot sailing vessel. (Alas, my sailing vessel *"Allidoro",* was sold in 2000 after about 40,000ocean miles, and after a very vexing case of serious bottom blisters.) I am on the little tug now because of a need to stay of the Sun, but I've put 11,000 miles on her in about 3 years. - -

Member George Huxtable wrote:
On Zevering's "Dilemmas", originally posted in NN issue 81.

Herman Zevering's serialized "Rejoinder", as yet incomplete, has given me a bit of a problem. Owing to the quantity and the complexity of its material, I can't claim to have taken it all in, or followed all its twists and turns. And yet, even so, I think I can see the root of the inconsistencies that so trouble him.

These occur whenever he tries to allow for an observer's run between two sights. The traditional way to do this has been to establish a position line, of intercept and azimuth from an observed body, relative to a dead-reckoning (DR) position, and then to transfer that position line, parallel to itself, according to the length and direction of the run.

Zevering does that job quite differently. From a first altitude observation he draws, or calculates, a position circle centred on the observed body at that time. Then, to allow for the run, he transfers the position of that body by the length and direction of the run, creating a new position circle around that new position, with the same radius. That's where the error occurs. Finally, he looks for the intersections of that circle with the corresponding circle around another body.

That method of transferring a circle of position, which he refers to as the "GHA-Dec-updating" technique or sometimes "GD-UT" appears to be Zevering's own invention. At least, I haven't come across it elsewhere, and he has supplied no reference. It first appears in his original paper, in issue 81, just below Fig.4. No justification for the procedure is offered. The trouble is, it doesn't work.

The problem shows up in his fig.4, in issue 81. This shows the geographical position of a body x1 at the centre of a position circle shown by a solid line on which is the observer, at Z', at the moment of taking his first observation. Then the observer moves to a new position Z", through the "run", a distance d, at a course angle a, as the diagram shows. Z" stands on a new, dotted, circle, now centred at x1, with the same radius as before. And the diagram shows that the new centre has been moved through that same amount, a distance d at a course angle a. But on a sphere, it won't be true that shifting the centre of a circle through a certain distance d at a certain course angle a, will cause any arbitrary point on its perimeter to move through that same distance d at that same course angle a. Distance, yes: angle, no! It's because of the way longitude lines converge after they leave the equator. On a flat piece of graph paper, it would indeed apply, but not on the coordinates of a sphere.

It becomes obvious, if you take a ring a few inches in diameter (a thin wrist-bangle, or a wineglass-rim, say) and slide it about on a globe. If you put its centre at a point on the equator, then slide that centre due North, it's clear that some points on the ring are moving across longitude lines with a Westerly component, others with an Easterly component. They can't all move with the same course.

So the basic assumption underlying Zevering's "GHA-Dec-updating" technique is flawed. No wonder it doesn't give the right answers. When he compares it with a more familiar method of allowing for run, referred to as the Altitude-Updating technique, or "AU-T", and finds discrepancies, he concludes (on page 8 of issue 85) that "the rationale of AU-T appears to be flawed". However, it's the other way round.

I should add that in earlier discussions with Zevering, which took place long before the submission of his "rejoinder", I have tried, but failed, to convince him of this error in his method.

I thank member Herbert Prinz for useful discussions.
George Huxtable FRIN. (george@huxtable.u-net.com)
20 Jan 05

+++The ' Two Body Fix ' Re-visited
By George G. Bennett

In issues 37 to 42 of the Navigator's Newsletter considerable attention has been focussed on what has come to be known as the ' two body fix '. In my view, the problem, including the case when sights are not made simultaneously, is capable of a simple and practical solution that does not require anything other than the application of standard spherical trignometrical formulae, some simple conventions for the variables and the normal defin-itions of circular functions (sine, cosine and tangent). If these latter precautions are not taken then it will be found, as most authors have discov-ered, that in addition to the basic data of GHA, declination and altitude for each star, information is required on the position or inter-relationship of the two bodies. For example, in the solution offered by Matthews (Issue 41/42 p.9) one must know where the observer's zenith lies in relation to the great circle connecting the two bodies. Solutions by Dozier, Derickson, A'Hearn & Rossano, Pepperday, Keys *et al* all fall into this category.

In May 1979 I submitted an article to the Naviga-tion journal entitled " General Conventions and Solutions - Their Use in Celestial Navigation " which was published in Issue No.4, Vol.26, Winter 1979/80. In that article I promoted the advantages of adopting general conventions and illustrated it with examples, one of which was the the two body fix. I claim no priority in my exposition of general conventions, which rightly belongs to the German mathematician C.F.Gauss and the American astronomer W.Chauvenet. Unlike Matthews (Issue 41/42 p.3) I do not consider myself a ' co-inven-tor ' but rather a ' disciple ' furthering the work of Gauss & Chauvenet.

When such a generalised system is adopted all problems of celestial navigation are amenable to unambiguous solutions which do not require the navigator to memorise or look up rules when, say, " Latitude and Declination are of the same or opp-osite name ". The system is admirably suited to solutions by calculator / computer.

E.g. Sight Reduction

$$\sin Hc = \sin Lat \sin Dec + \cos Lat \cos Dec \cos LHA \quad (1)$$

$$\tan Z = \frac{-\sin LHA}{\tan Dec \cos Lat - \sin Lat \cos LHA}$$
(2)

Where Hc is the calculated altitude (negative below the horizon), Lat and Dec are the latitude and declination respectively (+ N, -S), LHA is the local hour angle (measured west from the local meridian 0° - 360° and Z is the azimuth measured clockwise from north 0° - 360°). These symbols and conventions, including those used later in this article, are identical to those adopted in the Nautical Almanac.

The solution of azimuth as given by formula (2) may be unfamiliar to navigators. The azimuth is placed in its correct quadrant by considering the signs of the numerator and denominator. The calculator user does not have to concern himself with the problem as the 'to polar' and 'to rect' functions are designed for this purpose, as was stated in my original article and repeated by Pepperday in Issue 39 p. 7.

General Solution of the Two Body Fix

The following is a synopsis of the solution given in my 1979 article. Given the GHA, declination and altitude of each of two bodies the latitude and longitude of the observer can be deduced as follows,

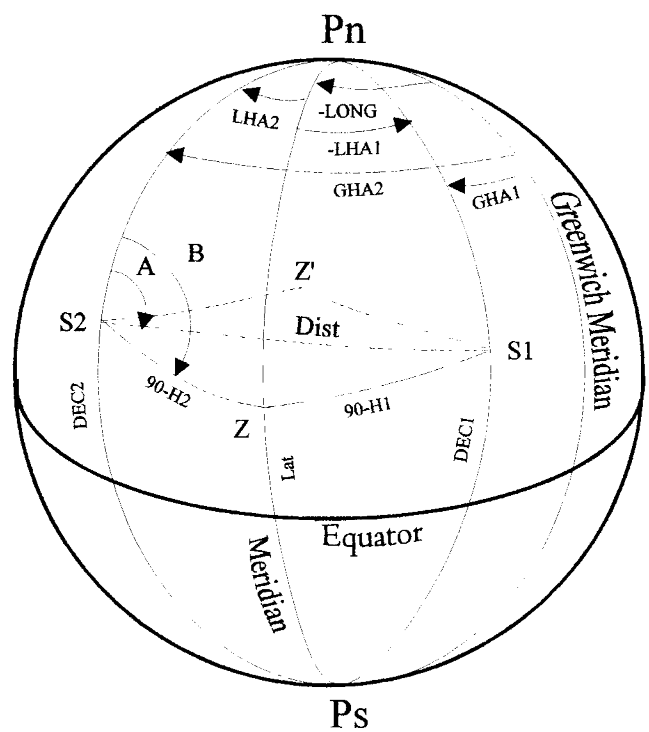


DIAGRAM 1

From Diagram 1

$$\cos Dist = \sin Dec1 \sin Dec2 + \cos Dec1 \cos Dec2 \cos(DGHA) \quad (3)$$

$$\tan A = \frac{\sin(DGHA)}{\tan Dec1 \cos Dec2 - \sin Dec2 \cos(DGHA)} \quad (4$$

where DGHA=GHA2-GHA1

$$\cos(B - A) = \frac{\sin H1 - \sin H2 \cos Dist}{\cos H2 \sin Dist} \quad (5)$$

The solution for (B-A) is ambiguous because of the two possible positions of the zenith Z and Z'. Therefore the two values of (B-A) which result will give two values for B.

$$\sin Lat = \sin H2 \sin Dec2 + \cos H2 \cos Dec2 \cos B \quad (6)$$

Two values of Lat result from the two values of B.

$$\tan LHA2 = \frac{\sin B}{\tan H2 \cos Dec2 - \sin Dec2 \cos B} \quad (7)$$

Two values of LHA2 result from the two values of B as before.
The longitude of the observer's position is then found from

$$Long = LHA2 - GHA2 \quad (8)$$

Likewise two values of Long result from the two values of GHA2.

The aforegoing solution is completely general and it is immaterial in which order the bodies are considered for the solution and their disposition on the celestial sphere. As was seen, two positions result from the data and the decision as to which of the two is correct only presents a difficulty when the bodies are nearly in line (sliding fix).

Non-simultaneous Sights

When the two observations have not been made at the same instant, which is usually the case, the basic data must be modified before the solution can be effected in order to take into account the possibility of a change in the observer's position. This is not a problem peculiar to the two body fix. When one uses the Marcq St Hilaire technique non-simultaneous sights are usually treated in one of two ways.
(1) If the time interval is short or the vessel has only moved over a short distance the observed altitude may be corrected as follows,

$$Hf = Ho - t(V/60)\cos(Z - T) \quad (9)$$

Note that t is the time interval from the time of fix to the time of observation.
By correcting the observed altitude in this way we assume (a) that we are dealing with a first order effect (higher order terms are negligible) and (b) there is no significant difference between the vessel's rhumb line course and a great circle path. It is for these reasons that the application of this formula should be restricted. I even suggested in the original article that the azimuth could be obtained from a star finder - this being simple and of sufficient accuracy for the illustrative example (2.6 miles between sights). Your correspondent, E. Matthews (Issue 41/42 p.3) criticises the application of this method by making an incorrect comparison with formulae that are more appropriate to long runs between sights. One should not condemn a technique when it is used out of context.
(2) If the distance covered between sights is long, then other techniques should be considered. The standard method in sight reduction is to use transferred observations (British nomenclature - double sights). A new DR position based on the vessel's run between sights and the fix obtained from consideration of the second sight and the tranferred azimuth and intercept of the first. This technique is easy to apply both numerically and graphically, the details of which may be found in standard text books on navigation.
Method A
For the two body fix, and this also applies to the Marcq St Hilaire method, a derivation of an altitude correction, from which the simple altitude correction described previously can be made as follows,

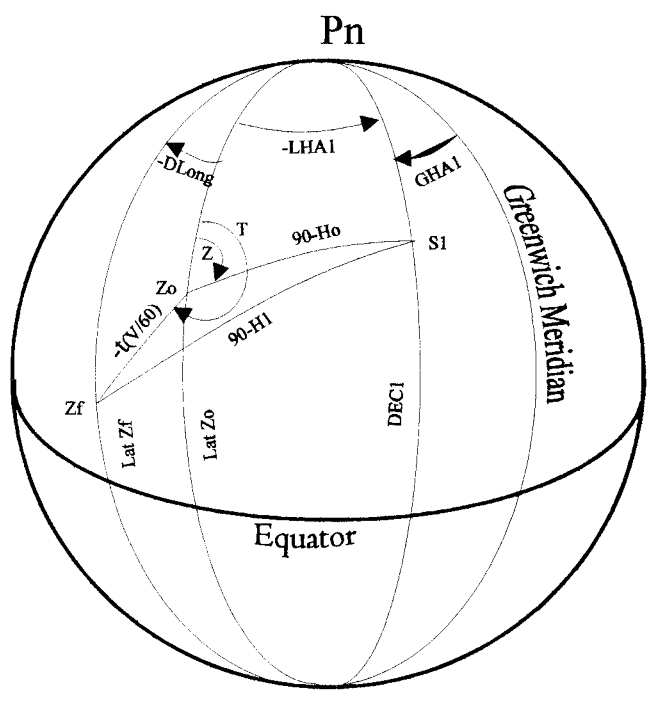


DIAGRAM 2

Zo and Zf show the position of the observer at the times of the first and second sights respectively. If the values of GHA1 and Dec1, obtained at the time of the first observation are retained then all that is required is a new value for H1 to effect the two body fix solution previously given.

In order to treat triangle Zo,Zf,S1 as a spherical triangle the rhumb line course T must be corrected to a great circle course. This may be done either using Table 1 in Bowditch Vol II or numerically as follows,

$$\text{Conversion Angle CA} = \frac{\text{-DLongsinMeanLat}}{2}$$

$$\text{but} \quad Dlong = \frac{-t(V/60)\sin T}{\cos MeanLat} \qquad (10)$$

$$\therefore \quad CA = \frac{t(V/60)\sin T \tan MeanLat}{2} \qquad (11)$$

Where Dlong is LongZf - LongZo and the average of the latitudes of Zo and Zf is taken for Mean Lat.

The formula is a very close approximation to the rigourous one which involves meridional parts. It has also been assumed that the great circle and rhumb line lengths are the same and the conversion angle at either end of the course are equal.

From the cosine formula in triangle Zo,Zf,S1 we obtain

$$\sin H1 = \sin Ho \cos(t(V/60) \\ - \cos Ho \sin(t(v/60)\cos(T + CA - Z) \quad (12)$$

where Z can be calculated from either formula (2) unambiguously or from

$$\cos Z = \frac{\sin Dec1 - \sin LatZo \sin Ho}{\cos LatZo \cos Ho} \qquad (13)$$

or from

$$\sin Z = \frac{-\cos Dec1 \sin LHA}{\cos Ho} \qquad (14)$$

The ambiguity in the solution of Z from its cosine in formula (13) is resolved by considering the size of (GHA1 + Long Zo) i.e. the value of the approximate LHA. Although formula (14) is the simplest of the three, the ambiguity in the solution of Z from its sine is not easily resolved. For ways of accomplishing this the reader is referred to discussions related to the Rust diagram in navigational texts.

After H1 has been found, formulae (3) to (8) can be applied to find the observer's position.

Method B

An alternative solution which is also simple to derive and apply is as follows. If in diagram (2) we shift the observer's zenith Zo to the meridian of Zf through an angle -DLong, see formula (10), and also the star's GHA by the same amount so that

$$GHA1 = GHA + DGHA = GHA + \frac{t(V/60)\sin T}{\cos MeanLat}$$

(15)

the resulting situation will be shown in Diagram 3.

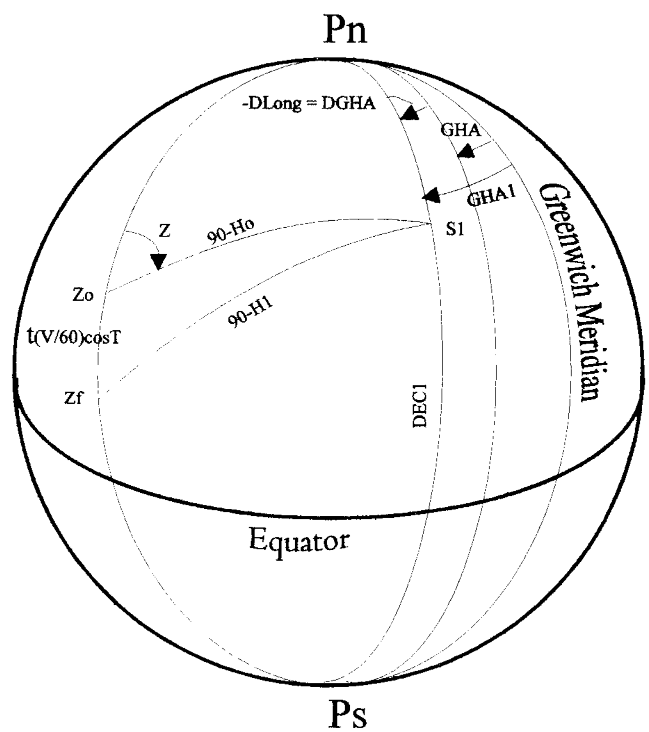


DIAGRAM 3

From the cosine formula in triangle Zf,Zo,S1

$$\sin H1 = \sin Ho \cos(t(V/60)\cos T) \\ - \cos Ho \sin(t(V/60)\cos T)\cos Z$$

(16)

Z may be calculated from either formula (2) or (13). Alternatively, if one substitutes the expression for cosZ from formula (13) in formuula

(16), then

$$\sin H1 = \sin Ho \cos(t(V/60)\cos T)$$

$$-\frac{\sin(t(V/60)\cos T)(\sin Dec1 - \sin LatZo \sin Ho)}{\cos LatZo}$$

(17)

Illustrative Example

Approximate position at the time of the first observation N54°, W46°. Based on a course of 205° and a speed of 20 knots the position at the time of the second observation is N52° 27', W47° 12'.

Body	GMT of obs'n	Altitude*	GHA	Dec.
1	0H 10M 50S	62°24.5'	39°17.6'	N26°44.2'
2	5 17 26	69 24.7	80 38.4	N51 29.4

* Corrected for index, dip and refraction.

Find the observer's position at the time of the second observation.

Method A

Z (formula (2)) with LHA=353°17.6'	167.038°
Mean Latitude	N53°14'
CA (formula (11))	0.482°
H1 (formula (12))	63°43.4'
Position of fix (formulae ((3) to(8))	N52°22.4' W 46°58.5'

Method B

GHA1(formula(15))**	40°29.8'
H1(formula(17))	63°55.3'
Position of fix (formulae (3) to(8))	N52°21.4' W46°58.9'

** Mean latitude as before

Small variations in the value of Z will be obtained depending upon which of formulae (2), (13) or (14) is used. This will result in small variations in the position of fix. If high accuracy is sought the solution may be repeated using the improved estimates of the position of fix in the solution.

Conclusion

It has been shown that the two body fix, including an allowance for run between sights, can be solved in a relatively straightforward way. The solutions offered involve some minor approximations which would be masked by uncertainties in the observed data, when one considers unknown errors of helming, current, leeway, windage, to name but a few that would be present after a long run.

In extreme circumstances, altitudes of 88° etc as cited by your correspondent E. Matthews in Issue 41/42 p.8, most methods will exhibit inaccuracies in position brought about slight differences between the values of the true and estimated positions. However, an iteration of the solution should rectify this problem when the refined values of position are used in the solution.

I consider the technique inferior to that of the Marcq St Hilaire method, which has been almost universally adopted. Any number of bodies can be considered simultaneously, even a single position line may be of invaluable assistance in certain circumstances. The number of reduction methods that has been devised using logarithms, calculator/computer, tabular and graphical methods attest to its popularity. If one chooses to navigate using the two body fix technique, then my view is that there is no logical justification for this self-imposed restriction.

My interest in the method stemmed from a desire to popularise general conventions and the two body fix readily demonstrated their advantages.

I have heard it argued that with the two body fix a navigator need not know his position at all. This surely is a proposition that any self-respecting navigator will reject. It would be absurd to suggest that one could be in such a situation. In an extreme case two applications of the Marcq St Hilaire technique will converge to give an acceptable fix.

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MEMBER HERMAN ZEVERINGS, "DILEMMAS IN POSITION SOLUTIONS REVISITED (A REJOINDER), PART 3. *EDITORS NOTE: ALL COMMENTS, CRITICISM AND INSIGHTS WILL BE GREATLY APPRECIATED.*

1 Subsequent references relate to Vol II and III of an old edition of the ANM (1938) which were donated to me.

1 For the algebraic or K-Z Method, see K. Herman Zevering – The K-Z Position Solution for the Double Sight, European Journal of Navigation, Vol 1-3, Dec 2003, p43-49. Unfortunately, many typographical errors occurred in this publication.

1 See ANM Ch. IV "The Mercator Chart" – "Procedure when the Altitude is Large": "When two observations of this kind are taken, two position circles may be drawn, and the observer's position is at one of their two points of intersection….If the observer is in a ship and there is run between sights, the first position circle must be transferred for the run. This can be done by transferring the geographical position and then drawing the circle".

1 ANM Vol III, Ch X "The Astronomical Position Line" (Fig 62). An example is given in the case of simultaneous sights of Polaris and Capella. In connection with the "Star Altitude Curves" the ANM mentions: "If there is an appreciable interval between the sights, two adjustments are necessary: the first altitude curve must be run on the distance covered by a ship or aircraft during the interval, and it must also be shifted to the right through a distance equivalent to the translation of the curve itself during the interval, this second distance being measured on the horizontal time-scale". The horizontal time scale is in this case Local Sidereal Time, which together with the Greenwich ST establishes longitude. The star altitude curves approach is therefore identical to the approach followed in ANM's Large Alt case. In both instances the 'translation of the curve' is found, i.e finding the GHA-Dec of a moving GP, before the data are run on.

1 One of CelestNav's screens provides 'Std deviation' and 'mean sq intcpt', which is perhaps calculated as $\sqrt{(\Sigma p_i^2)}/n$ where p_i is an intercept and n the number of sights. If a further iteration does not significantly improve these two measures the program may be stopped for it has achieved a sufficiently accurate final position solution.

1 I didn't explore this, but perhaps with certain arbitrary initial position assumptions (see section 3.1), A*B*C* will begin to deviate significantly from A"B"C".

1 Op. cit., p 42

1 Op. cit., p 139

1 The statistics for the Sun-Moon-Vega-Dubhe case are σ = 1'.4, a = 2'.8, b = 2'.1 compared to σ = 0'.5, a = 1'.1, b = 0'.8 for Sun-Moon-Vega.

1 Op. cit., p 42

1 As mentioned in relation to the Polaris-Mirfak-Venus sketch, the conclusion that the resulting 'cocked hat' is solely because the sights are not 'run on', is simply misleading ("..the cocked hat disappears"). This is misleading in so far as in Chapter XIII in Vol III "Errors in Position Lines" the ANM is at pains to show that "the position lines obtained from three astronomical observations (which for simplicity are considered to be taken simultaneously) are no more likely to pass through a common point than three terrestrial position lines are likely to pass through one…." (see "The Cocked Hat Formed by Astronomical Position Lines"). Perhaps because the ANM says nothing about the simultaneous double sight, in M. Blewitt's Celestial Navigation for Yachtsmen (op. cit.) one finds no discussion of the relevance of the intersection of the PL of the Sun and of the Moon shown in the author's Fig 28. M. Blewitt's work oddly only deals with simultaneous sights involving more than two sights. The whole issue of working sights and plotting the results in the sight-run-sight situation is not covered. In fact, the Sun and Moon sights in Blewitt's example are almost 2 minutes apart in GMT. This is of course not much on a traditional sailing yacht in average conditions, but significant on a fast-moving vessel.

1 R. Miranda – "Navigation: Miscellaneous Tips", in Multihulls, Jan/Feb 1992, p 36. The article promoted the author's "workbooks" on celestial navigation.

1 Op. cit., p 34, Fig 28. Incidentally, the plot appears to be wrongly drawn in this booklet as the special longitudes of the sights do not match the longitude scale and the Assumed Positions are wrongly named, as the Ass Position Moon is furthest to the West. There is typically no discussion or explanation of the relevance of the intersection of the two PLs.

1 ~~The conclusion that larger run distances will produce larger deviations seems to be borne out only when the Yallop-Hohenkerk Sun and Vega sight data are included. The Sun's GHA and Dec are correctly derived from the published coefficients but the combination of its Zn (280°.2), Dec (23°.3) and Lat of the observer (32°.4) appear to be anomalous. Also, the Dep between~~ ~~GHA_{Sun} and GHA_{Vega} (136°.9) is much greater than $Zd_{Sun}+Zd_{Vega}$ (110°.1).~~

1 In my LSQ program, true azimuth is calculated in a different (traditional) way than by Yallop-Hohenkerk (see op. cit. top p xix) but the two methods are equivalent.

1 Lat_{DR1} appears to be so chosen in Keys' example (op. cit., p 140-141) that the MA (Meridian Angle) is bounded by what I call the Meridian Difference obtained with K-Z (in this case MD11a), i.e the absolute smallest angle between the $Long_{GP}$ and the $Long_{observer}$. At 47°.3084 N and 13°.1170 W (the assumed $Long_{DR1}$), the MD and MA are practically the same (MD11a =3.0158, MA 3.0155). When Lat_{DR1} ∞ approx. Lat 47.42 N, CosMA becomes greater than unity and there is no possible solution. The Lat_{DR1} at 47°.33 is apparently chosen so as to lie between 47°.3084 N and 47°.4200 N. Perhaps Keys manipulated his example so as to give a result to be expected when applying the IM.

1 In the pre-electronic era, this part of the exercise could be accomplished by means of the 'Blackburne Tables'. These Tables computed the 'hour angle' (=MD) to find $Long_c$, given the known variables GHA, H_o, Dec and Lat_{DR}.

1 $LHA*_1 = MD_1$ + d'Long for sights bearing W and $LHA*_1$ = 360° - MD_1 + d'Long for sights bearing E, where d'Long is positive if E and negative if W (see Keys, op. cit., p 140). Using Keys figures (GHA_1 = 15°.260; $Long_{DR1}$ = - 13°.117; $Long_{DR2}$ = -12° .353; MD_1 = 2°.703), |d'Long| = 13°.117-12°.353 = 0°.764 → $MD*_1$ = 2°.703 + 0°.764 = 3°.467. As mentioned, it is unnecessary to actually calculate $Long_{c,1}$ from MD_1: $MD_1 = GHA_1+Long_{c,1}$ or $Long_{c,1}$ = 2°.703 - 15°.260 = -12°.557, so that $MD*_1 = GHA_1 + Long_{c,1}$ + d'Long = 15°.260 - 12°.557 + 0°.764 = also 3°.467.

The end of part 3, K. Herman Zevering's "Dilemmas in Position Solutions Revisited (A Rejoinder)

MEMBER ZEVERING'S EPILOGUE

TO BE CONCLUDED IN FUTURE ISSUES OF THE NAVIGATOR'S NEWSLETTER

POSITION SOLUTION DIFFERENCES IN THE SIGHT-RUN-SIGHT CASE (EPILOGUE)

BY K. HERMAN ZEVERING

In "Rejoinder" (addendum NN 83)[i], I pointed out that the methods of transferring the position line or circle of an earlier sight with respectively IM/LSQ and A-UT do not produce position solutions that are mathematically equivalent to those obtained with GD-UT[ii] using the same data and are therefore not valid in general terms. The argument for GD-UT as the correct method is simply difficult to reject. This method has in fact been introduced in the ANM but only for a case in which in the pre-electronic era the position circles could be drawn on the chart.

This "Epilogue" represents a final statement on the various issues covered in "Dilemmas" (NN81) and "Rejoinder":

Vindication of GD-UT (Sections 1 and 2)
The demise of A-UT (Section 3)
Possible reconciliation of error theories (Section 4)

1 Critique Regarding The GD-UT Method

This critique by George Huxtable was conveyed to me by email.

Issue A: The Large-Alt case in the ANM is a special case – Is it really?

Huxtable comments:
"Yes, under some circumstances, when you shift a position circle over the globe, every point on the periphery of that circle will move approximately through the same course and distance as its centre does. Those special circumstances are spelled out in the ANM:

- The radius of the circle must be small
- The observer and the body must be in reasonably low latitudes.

The example on pages 33-35 of the ANM (Vol III) has been chosen with those points in mind".

Reply:
I believe that the wrong reasons are given for the special treatment in the ANM of the Large-Alt case. The reasons are in my opinion the following:

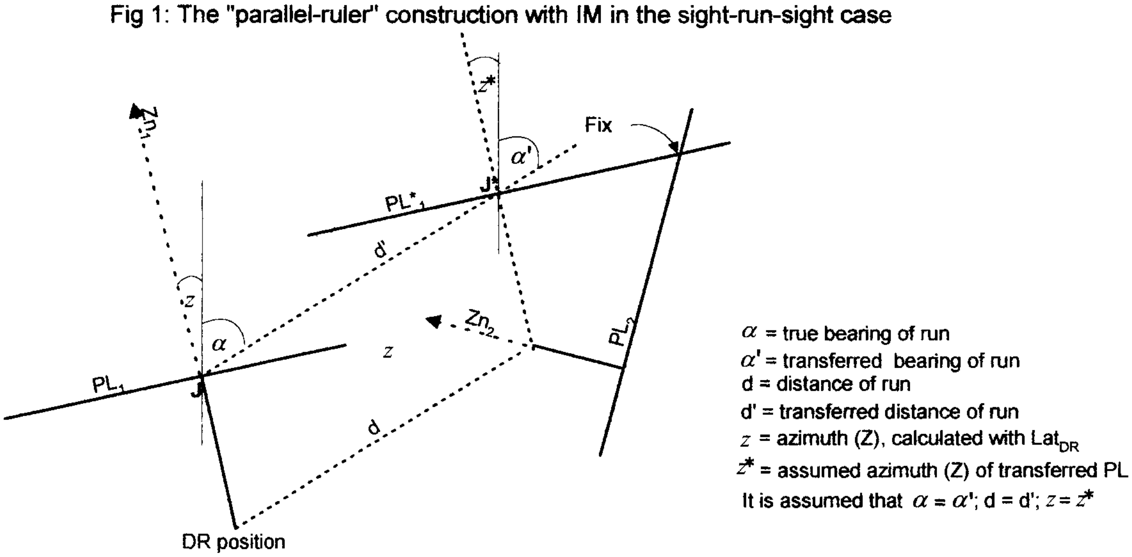
1. In any other case, the sea chart will disallow this construction method. It cannot be overemphasized that the pre-electronic approach required constructions on the chart.
2. In the Large-Alt case, a straight line on the chart can no longer represent the position circle. I will argue below that this is in fact a trivial concern.

The ANM mentions: "Only when the altitude is so large that the position circle can be drawn on the chart as a circle are these assumptions (viz. constant azimuth around "J"; intercept coincides with Zd; straight rhumbline PL) inadmissible"[iii].

I contend that in the sight-run-sight case these assumptions are generally inadmissible and particularly so in cases where zenith distance is large. Implicit is a fourth and most crucial assumption, namely that the displacement represented by the transfer of a position circle's GP would translate in general in equal displacement of an observer's position on its circumference or periphery. This assumption is equally inadmissible, but I will argue below that it is least violated in the Large-Alt case. The assumptions in the ANM are there to justify the assumed initial position approach and the chart work accompanying the IM[iv]. There can hardly be any doubt that the authors of the ANM were well aware of the correct manner of transferring an earlier sight's position circle, but resort to it only when this is feasible in practical chart work[v].

In Fig 1 I reproduce a figure that already appeared in "Rejoinder" to show that the above assumptions support what I call the 'parallel-ruler' transfer of J to J*.

Fig 1: The "parallel-ruler" construction with IM in the sight-run-sight case



The ANM's particular concern in the Large-Alt case is that the 'straight-line' (PL) assumption is substantially violated. The underlying idea here is simply that the point of intersection of the straight PL_1 and PL_2 sections drawn from respectively J_1* and J_2 is naturally different from the point of intersection of position circle segments drawn from these points. In the Large-Alt case analyzed in "Rejoinder" I have shown that the 'straight-line' assumption in the sight-run-sight case hardly affects the position solutions with the different methods. In this particular case the runs were short, but I will show in Section 2 that the effect of run distance on the distance *ZZ** is insignificant when H_0 is large, regardless of azimuth. All relationships on the globe are mathematically defined by spherical trigonometry. It would therefore also not make sense to expect that a certain solution method only holds for part of the globe, or only for that part where chart dimensions are no longer a restricting factor.

Issue B: The direction from Z to Z* is not the same as the direction of transfer as GD-UT presumes. GD-UT is therefore flawed.

<u>Huxtable comments</u>:
"This is not obvious with a 'small' circle but the point Z' (1st DR) does not move to Z" (2nd DR or EP) in the direction of the course. In your fig.4 in NN81 you have presumed that this applies to a position circle of arbitrary size centred at some arbitrary latitude. You have taken an arbitrary point Z' on that circle, and presumed that if the circle is

transferred along a course **a** ("true course bearing") by a distance **d** then that point on the circle moves also along a course **a** through a distance **d** to Z". This is what I question and I insist that it is wrong! The distance, yes! The course, no! Fig 4 in NN 81 shows the centre of the circle (X_1) being transferred by an amount <u>d</u> in a direction <u>a</u>. Is <u>a</u> intended to be identical to **a**, and if not, where is the relation between them to be found? Similarly for <u>d</u> and **d**, which I suspect should indeed be identical. Although the length **d** will be the same for every point on the periphery of that circle, and identical to <u>d</u>, the direction of motion of those points, **a**, will, it seems to me, differ from each other and differ from the "true course bearing" of the vessel, which is <u>a</u>.

It seems to me that when the circle is transferred, every point on its periphery will move with a different initial course, different from the course of the vessel, in which case the change in Dec and the change in GHA would differ for all those points on the periphery. For instance if the position circle is moved due North, Z' will move to a new position Z" (2nd DR or EP). Z' will move so as to cross lines of both latitude and longitude. Not only the latitude but also the longitude of Z" will differ from those of Z', even though there was zero change in the longitude of the centre. This implies that the true course of the motion of Z must differ from the true course of the motion of the centre, which was due North. Try moving a (non-small) circle northward from the equator on a globe. Will every point on that circle be moved with the same course, or not? I concur, however, that the amount of that motion, **d**, will be exactly the same as the motion of the centre.

Perhaps the discrepancies you find between the LSQ method and <u>your own</u> are the result of a weakness in transferring a position circle by <u>your</u> (my underlining) GHA-Dec-updating method, not the other way round.

<u>Reply</u>:

<u>Remark on notation</u>
A prior remark here is that in Fig 4 in "Dilemmas" the points Z' and Z", respectively denoting the initial and transferred observer's position do not represent 1st and 2nd DR positions as assumed by Huxtable. In terms of the IM, the points Z' and Z" would be respectively J and J*, the estimated positions after allowing for the intercept (see Fig 1). But this will not affect the argument. I will indicate these positions now throughout as Z and Z*. The GP of the earlier sight is X and its transferred position X*. The distance (d) corresponds to the length (arc) XX*. The bearing from X to X* is α and the corresponding bearing from Z to Z* is ά. The azimuth angles at the points Z and Z* are indicated as *Z* and *Z**.

In Fig 4 of "Dilemmas" the displacements were labelled differently, i.e <u>a</u> and <u>d</u> versus **a** and **d**, indicating that I didn't presume for a moment that they were the same. Huxtable's observation actually supports the fact that the 'parallel-ruler' transfer cannot reflect the displacement of the GP, which causes the discrepancies with transfer methods other than GD-UT. The aim of the parallel-ruler transfer is obviously from the estimated observer's position to simulate the transfer of the earlier sight's position circle. The degree to which this simulation fails depends on a combination of sextant altitude, azimuth and run distance.

With the "Due North" (or due South) model, Huxtable has in fact intuitively hit upon the only model available to numerically evaluate the relative movement of centre and periphery, which indicates that $Z \neq Z^*$ and XX* ≠ ZZ* to varying degrees. Contrary to his hunch, also the distances at respectively X and Z will not remain the same! The difference between α (bearing at X) and ά (bearing at Z) can of course not be evaluated with the 'Due North' model and unfortunately it appears impossible to obtain an independent measure of ά. However, it is logical to expect that also $\alpha \neq$ ά[vi].

The parallel-ruler approach is only a convenient terrestrial analogy, hiding the fact that any method of transfer in the sight-run-sight case must consider how the earlier sight's position circle with the initial observer's position on it moves relative to the next sight's position circle. This is a case where the chicken comes first, i.e the run translates at the GP of the earlier sight, not at the place where your boat is supposed to be. The only thing that remains constant is the length of the position circle's radius or zenith distance.

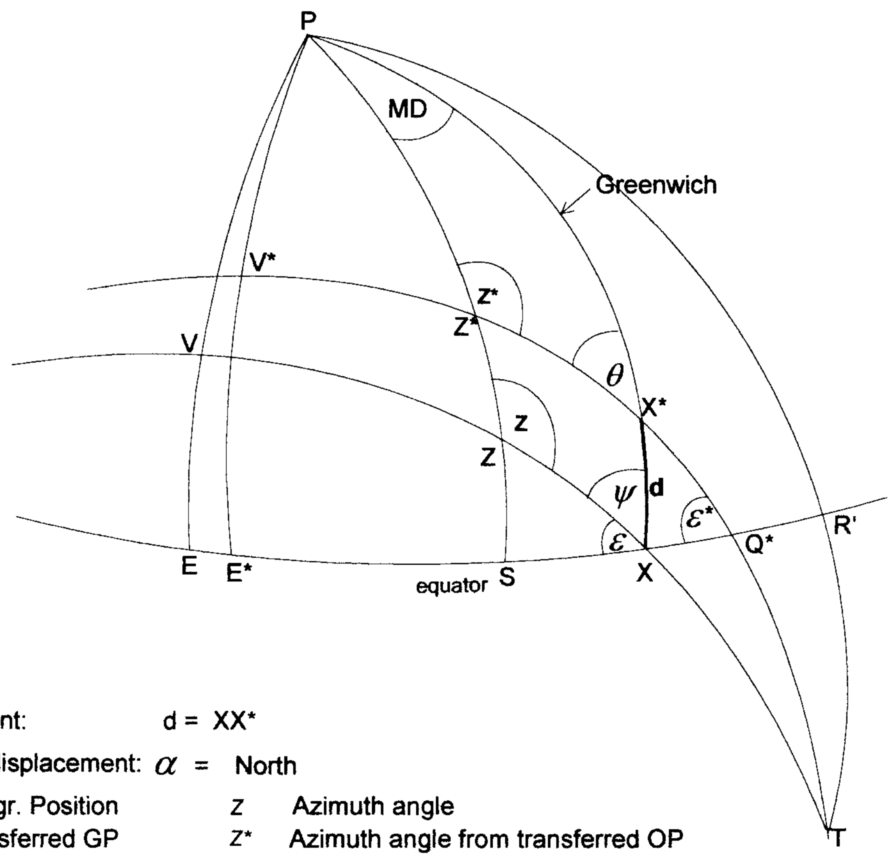
The parallel-ruler approach can also not account for the possibility that the parallel great circles through X and Z and X* and Z* have their intersection point (T) between the GP and the observer's position. In this case the position of Z* relative to Z will be reversed compared to the movement from X to X*.

I will support the case for GD-UT in more detail in Section 2, but in concluding my reply at this point I maintain that the 'weakness' is not in GD-UT but rather the other way round in the IM/LSQ methods which rely on the convenient parallel-ruler concepts mentioned before.

2 The GD-UT Method

To come to an understanding of GD-UT, consider the "due North" case sketched in Figure 2. The position circle is for convenience centred exactly on the equator at the Greenwich meridian. When the circle is moved due North, X is moved along its meridian to X* and Z along its own meridian to Z*. No longitude is "crossed" and the circle remains defined by its radius (=Zd). The point pairs X and Z and X* and Z* lie respectively on what I call 'parallel' great circles[vii].

Fig 2: Due North displacement case



Displacement: d = XX*

Bearing of displacement: α = North

X	Geogr. Position	z	Azimuth angle
X*	Transferred GP	z*	Azimuth angle from transferred OP
Z	Observer's position	V	Vertex of gr. circle TXZV
Z*	Transferred OP	V*	Vertex of gr. circle Q*X*Z*V*
		T	Gr. circle Intersection point

The initial and transferred great circle could only be really parallel, i.e equidistant everywhere as implied in the parallel-ruler construction, if the transferred great circle were a 'small circle', i.e one that does not have the Earth's centre as centre. But X* and Z* cannot lie on a small circle because X*Z* (= Zd) is defined as a great circle segment. In the Large-Alt case, the transferred great circle comes closest to being virtually parallel.

The effect of varying assumptions regarding altitude, azimuth and distance can be explored with the case shown in Fig 2. The due North model is indicated in worked detail in Annex-Table 1. Azimuth is being varied between $0° < Z < 180°$, thereby staying in those quadrants of the position circle where Z =

Zn[viii] The results of the analysis are in Table 1.

The effect of different combinations of *Z*, H_o and run distance (d) on the position of the great circle through the transferred points X* and Z* relative to the great circle through X and Z is indicated with the following parameters:

- Difference in distance[ix], i.e |ZZ*-XX*| = Δ_1 (in n.m)
- Difference in azimuth, i.e |*Z* *- *Z*| = Δ_2 (in degrees)
  Parameters defining the two parallel great circles:
- The angles with the equator = ε and ε*
- The angles with the Greenwich meridian = ψ and θ

A first major conclusion is that the differences in distance (Δ_1) vary from insignificant to approaching 0° to becoming very large: Other conclusions that may be gleaned from Table 1 are:

1. When *Z* approaches 90°, the differences in distance (Δ_1) and azimuth (Δ_2) are largest. When H_o is small (say 5°) the largest differences occur when *Z* is around 88° – 89° (not shown in Table 1).
2. When *Z* decreases from 90° toward 0° or increases from 90° toward 180° the differences in distance (Δ_1) and azimuth (Δ_2) generally decrease from significant to insignificant, approaching zero[x].
3. When H_o decreases from large (say 89°.5) to small (say 5°), Δ_1 increases. How substantial the increase is depends on azimuth and on run distance. The larger the run distance, the larger Δ_1.becomes. For instance at *Z* = 40° and H_o = 5°, Δ_1 increases from 0'.9 at a run distance of 3 miles to 18'.1 at a run distance of 60 miles. At *Z* = 40° and H_o = 89°5, the effect of run distance is negligible and Δ_1 itself remains negligible.

These conclusions to my mind are further confirmation that applying IM/LSQ in the sight-run-sight case will produce deviations in the position of the transferred PL that will significantly influence the position solution with these methods, depending on a combination of azimuth, sextant altitude and distance. Most revealing is that in the Large-Alt case (H_o = 89°,5), i.e when the position circle is small, the quadrangle XZZ*X* is virtually a plane parallelogram, regardless of azimuth and run distance. The IM parallel-ruler approach is in fact best suited to the Large-Alt case!

Table 2.1: Due-North cases compared -GHA = 0° Dec = 0°; α =360° (due N)

	d	3'			30'			60'		
Z	H_o	5°	60°	89°.5	5°	60°	89°.5	5°	60°	89°.5
	Δ_1	0'.01	0'.0029	0'.0000	0'.11	0'.03	0'.0000	0'.03	0'.06	0'.0001
	Δ_2	0.0000	0.0000	0.0000	0.0002	0.0002	0.0002	0.0008	0.0008	0.0008
175°	ε	89.56	85.67	85.0002	89.56	85.67	85.0000	89.56	85.89	85.0002
	ε*	89.57	85.67	85.0002	89.61	85.69	85.0010	89.65	85.71	85.0025
	ψ	0.44	4.3329	4.9998	0.43	4.33	4.9998	0.44	4.33	4.9998
	θ	0.43	4.3307	4.9998	0.39	4.31	4.9992	0.35	4.29	4.9983
	Δ_1	0'.91	0'.17	0'.0001	9'.07	1'.71	0'.0011	18'.15	3'.4972	0'.0034
	Δ_2	0.0000	0.0000	0.0000	0.0018	0.0018	0.0018	0.0073	0.0073	0.0073
140°	ε	85.82	53.99	50.0001	85.82	53.99	50.0011	85.82	53.99	50.0011
	ε*	85.86	54.01	50.0014	86.23	54.17	50.0075	86.65	54.35	50.02
	ψ	4.18	36.0052	39.9989	4.18	36.01	39.9989	4.18	36.0052	39.9989
	θ	4.14	35.9882	39.9986	3.77	35.83	39.9943	3.35	35.66	39.9860
'	Δ_1	12'.50	0'.45	0'.0002	126'.46	4'.89	0'.0075	255'.67	10'.60	0'.03
	Δ_2	0.0001	0.0001	0.0001	0.0124	0.01	0.0124	0.0494	0.0494	0.0494
100°	ε	63.70	11.51	10.0004	63.70	11.51	10.0004	63.70	11.51	10.0004
	ε*	63.95	11.54	10.0011	66.26	11.82	10.03	68.87	12.17	10.11
	ψ	26.30	78.49	79.9996	26.30	78.49	79.9996	26.30	78.49	79.9996
	θ	26.05	78.46	79.9991	23.74	78.19	79.9830	21.14	77.87	79.9417

	Δ_1	65'.71	2'.20	0'.0263	634'.84	21'.96	0'.26	1296'.39	43'.92	0'.53
	Δ_2	0.0500	0.0500	0.0500	0.50	0.50	0.50	1.0000	1.0000	1.0000
→90°	ε	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	ε^*	1.15	0.1000	0.0710	11.42	1.0000	0.71	22.63	1.9998	1.42
	ψ	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000
	θ	88.85	89.91	89.95	78.59	84.13	89.50	67.39	88.27	88.99
	Δ_1	2'.87	1'.27	0'.0261	28'.69	12'.68	0'.26	57'.38	25'.36	0'.52
	Δ_2	0.0500	0.0500	0.0500	0.50	0.50	0.50	1.0000	1.0000	1.0000
→90°	ε	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
	ε^*	0.0500	0.058	0.0704	0.5005	0.58	0.70	1.0010	1.15	1.41
	ψ	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000	90.0000
	θ	90.0022	90.03	90.05	90.02	90.29	90.50	90.04	90.58	90.99
	Δ_1	12'.47	0'.44	0'.0000	123'.09	4'.05	0'.0053	242'.23	7'.24	0'.02
	Δ_2	0.0001	0..0001	0.0001	0.0124	0.01	0.0127	0.0494	0.0494	0.0494
80°	ε	63.70	11.51	10.0004	63.70	11.51	10.0084	63.70	11.51	10.0004
	ε^*	63.44	11.48	10.0002	61.20	11.25	10.0208	58.77	11.04	10.09
	ψ	153.70	101.51	100.0004	153.70	101.51	100.0004	153.70	101.51	100.0004
	θ	153.44	101.48	100.0001	151.20	101.24	100.0084	148.76	100.9991	100.04
	Δ_1	0'.91	0'.17	0'.0000	9'.05	1'.65	0'.0001	18'.07	3'.22	0'.0015
	Δ_2	0.0000	0.0000	0.0000	0.0018	0.0018	0.0018	0.0073	0.0023	0.0073
40°	ε	85.82	53.9948	50.0011	85.82	53.99	50.0011	85.82	53.99	50.0011
	ε^*	85.78	53.9778	50.0008	85.40	53.83	50.0019	85.99	53.67	50.0101
	ψ	175.82	143.99	140.0011	175.82	143.99	140.0011	175.82	143.99	140.0011
	θ	175.78	143.98	140.0008	175.40	143.83	140.0001	174.98	143.66	140.0028
	Δ_1	0'.01	0'.0028	0'.0000	0'.11	0'.03	0'.0000	0'.23	0'06	0'.0000
	Δ_2	0.0000	0.0000	0.0000	0.0002	0.0002	0.0002	0.0008	0.0008	0.0008
5°	ε	89.57	85.67	85.0002	89.56	85.67	85.0002	89.56	85.67	85.0002
	ε^*	89.56	85.66	85.0002	89.52	85.65	85.0002	89.48	85.62	85.0000
	ψ	179.5631	175.6671	175.0002	179.56	175.67	175.0002	179.56	175.67	175.0002
	θ	179.5588	175.6649	175.0002	179.52	175.65	175.0000	179.48	175.62	175.0002

The due North model cannot be applied when the course bearing deviates from North or South because the angle θ, the angle of cut of the transferred great circle with the meridian through X* (see Fig 2), cannot be independently calculated.

A final remark is, it is unnecessary to use the rhumbline formulas to determine Dec* and GHA* of the transferred earlier sight. From ΔXPX* ($\angle$PXX* = α) and using the data of G. Keys Sun-run-Sun case:

Cosα = [SinDec*-SinDecCos(d/60)]/CosDecSin(d/60)
SinDec* = CosαCosDecSin(d/60)+SinDecCos(d/60) = 0.3415
Dec* **= 19.9672**
Dec* = Dec+(d/60)Cosα **= 19.9680**
From ΔPXX*:
Cosβ = [Cos(d/60)-SinDecSinDec*]/CosDecCosDec* = 0.99995385
β = 0.5504
or with Sine rule:
Sinβ =(Sin(d/60)Sinα/CosDec* = 0.0096
β = 0.5504
GHA* = GHA-β **= 14.7096**
GHA* = GHA - (d/60)Sinα/Cos[½(Dec+Dec*)] **= 14.7097**

The differences in Dec* and GHA* obtained with either the rhumbline formulas or the fundamental formula (Cosine Formula) are negligible and either method may be used.

3: The faulty rationale of A-UT

This rationale is illustrated with the sketch in Fig 3. The position estimated from the DR would be in J, transferred to J*. The actual position is in Z*, the intersection of PC^*_1, the transferred earlier sight's PC, with PC_2. If plane geometry would apply, the run distance (= d) laid out at the same course angle α from any point on the circumference of the first position circle (PC_1) would lie on the transferred position circle (PC^*_1). In other words in plane geometry the points J*', J*, Z*, J*'' would all lie on the transferred circle. In spherical trigonometry this 'parallel-ruler' analogy does not hold, i.e the points J*', J*, Z*, J*'' would lie on the transferred position circle but the distances J'J*', JJ*, ZZ*, J''J*'' and the bearings at J', J, Z, J'' would differ from respectively d and α.

For reasons given in Section 2, logical and in fact also conventional would be to assume that the locus of the transferred position circle can be found by moving its centre X (=GP) to X* for the magnitude and direction of the displacement (d and α) and by projecting the circle from X* with its given radius (Zd = $90^o - H_o$ = XZ = X*Z*). This of course is what GD-UT does.

But as indicated in Fig 3, with A-UT this logic is sidestepped. The point J* is seen as the intersection of the transferred position circle (PC^*_1) and a concentric circle with radius XJ* drawn from X. The reasoning appears to be that if J* and Z* may be assumed to be close enough, the distance XJ* and XZ* would be about the same, so that J* and Z* would lie approximately on a concentric circle with centre X and radius XJ*. A-UT also subscribes to the parallel-ruler analogy, so that it is assumed that JJ* = d and $\alpha' = \alpha$. We will see shortly that the more XJ* and XZ* differ in actual measurement the larger the discrepancies in position solution between A-UT and GD-UT.

In reality the concentric circle with radius XZ* is unlikely to be coincident with the one with radius XJ* because the estimated position J is uncertain. Of course, the concentric circles with radius XZ* or XJ* will also not be coincident with the transferred position circle. Underlying A-UT is therefore the assumption that these differences in locus will have an insignificant effect on position solution but this is not borne out by analysis.

TO BE CONTINUED IN NEWSLETTER NUMBER 87 SPRING 2005

THE NAVIGATOR'S NEWSLETTER

FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION ISSUE EIGHTY-SEVEN SPRING 2005

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review gooks on the subject and maintain a reader forum for the expression of our member opinions and their questions.

ACTIVITIES

By Terry Carraway

There has been considerable interest in acquiring the back issues of The Navigator's Newsletter. If you have ordered the set please be patient as the packaging and mailing has to wait because of my additional duties as editor, administrator, and office boy.

With summer approaching it is time to order your charts. Service from the FAA (which now is the organization who mails the chats) has been excellent. Your order can be filled in less than a week. Order by telephone at 301-622-6448 or FAX to the same number. Order by e-mail to: navigate1@comcast.net or my snail mail to: The Navigation Foundation, 12509 White Drive, Silver Spring, Maryland 20904. Using this address will get your order to me sooner than the P. O. Box as that mail is only picked up every two weeks.

The past 12 months has be sad ones for the Officials. Directors and wonderful people who have worked with us for many years. First came the shock of learning of the accidental death of Ernest Brown. He had been a director since the early beginning of The Foundation and editor for many years. His knowledge of navigation and having been a professional editor provided a wonderful Newsletter. Second came the death of Louise Christopher. Mrs. Christopher was former secretary to U. S. Senator Milton Young of North Dakota for 23 years. Later she worked for a lobbying firm and when she retired she opened a word processing service in her home. She began typing the submissions to the newsletter from its beginning. Her ability to read the many handwritten notes and letters with great accuracy was amazing.

READERS FORUM

Edited by Terry Carraway

Member Paul J. Adams requested information on installing Deck Magnets for his Aqua Meter Compass.

Member Paul J. Adams requested information on installing Deck Magnets for his Aqua Meter Compass.

Member Harvey Malakoff responded by telephone with the following: Information on installing Deck Magnets for a "Darra Compass Correction" can be found on page 16 of the pamphlet "Choosing and Using A Marine Compass", 1975 Ed.. Published by Aqua Meter.

Member Leslie J. Finch wrote on 3 March 2005:

"I would like to get a copy of "How to Rename Your Boat." I renamed my boat sometime ago. I haven't noticed any unusual misfortune, but I feel I am on the edge and pushing the envelope. I didn't use my sextant much last year. I had cataract in my sextant and shooting eye. I had it taken care of and celebrated by taking a moon sight at the ranger station at Smith Point. It reduced unusually well. (The ranger station is about 200 ft. from N 40 deg.- 44', W 72 deg. - 52' and has nearly a 180 degree view of the Atlantic to the South and some of Great

South Bay to the WNW. There is enough open water on the Bay to see the horizon or edge of the world as we call it.

Next week we are going to Albuquerque, N. M. to see our son graduate from his last Para-rescue school and become an Air Force P. J.. He is an extraordinary young man. I'll take along my sextant and artificial horizon as I do on such adventures."

Member Jeffrey E. Thompson wrote on 22 March 2005:

"Dear Capt. Carraway,

I have two requests of you when times allow.

1. I wish to order the Government Issue of 2005 Nautical Almanac, but have never have through our Foundation – So please advise me of procedures and costs, etc.
2. If it's not improper & space will permit in our Newsletter; please pass on to our members my desire to obtain a surplus U. S. Navy Mark II or III sextant. I am a military history buff as well

As a novice Celestial Navigator. Parties can contact me Via E-mail at RAVEN28@OTELCO.NET or by telephone at: 205-429-4232.

Member George Huxtable wrote on 16 March 2005:

"Dear Terry,

Thanks for sending the contribution from George Bennett. I have the following comments to make about it, which you are welcome to publish if you wish. Or not, as you prefer."

George

The following comments on George Bennett's contribution, "The Two Body Fix' Re-visited", may be helpful to readers.

1. After equation (8), the text reads, "Likewise two values of Long result from the two values of GHA2", but should really be, values of Long result from the two values of LHA2".

2. In equation (9), a quantity T has been introduced without explanation. T represents the true course that the vessel has followed, in the "run" between the two sights.

3. Bennett defines most of the sign conventions that he uses, but not that for geographic longitude. Without saying so, he has chosen to define longitudes as positive Eastwards: that is, measured in the opposite sense to his hour angles which increase westwards. There are many respectable precedents for the use of that convention, just as there are the opposite "West-is-positive" convention (such as Meeus' Astronomical Algorithms). Not that one convention is right and the other wrong (though my own preference is the same as that of Meeus). But it helps the reader's understanding, to be clear about which is being used.

4. Bennett writes- "When such a generalized system is adopted all problems of celestial navigation are amenable to unambiguous solutions…", but then he goes on to deal with the "two body fix", which by its naturehas inevitably two possible solutions, the two intersections of the position circles that surround the two bodies. The observer will be at one such intersection, not the other, but Bennett's method on its own does nothing to tell him which in the case of a two body fix, the "unambiguous solution" that Bennett claims for his method has not been achieved. True, from a rough knowledge of where he is, the choice of the correct position will normally be quite obvious, but the ambiguity in the solution remains.

George Huxtable

Contact George Huxtable by email aat george@huxtable.u-net.com.by phone at 01865 820222 (from outside the UK +44 1865 820222) or by mail at : 1 Sandy Lane, Southmoor, Abington, Oxon OX13 5HK, UK

Dear Terry,

Another note from me, should you wish to print it.

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Navigator's Newsletter printed a note from me on page 3, issue 86, which attempted to identify the source of inconsistencies which have so troubled

Herman Zevering in his series of papers which started in issue 81.

That letter included the following-

"The problem shows up in his fig.4, in issue 81. This shows the geographical position of a body x1 at the centre of a position circle shown by a solid line on which is the observer, at Z', at the moment of taking his first observation. Then the observer moves to a new position Z", through the "run", a distance d, at a course angle a, as the diagram shows. Z" stands on a new, dotted, circle, now centred at x1(underlined), with the same radius as before. And the diagram shows that the new centre has been moved through that same amount, a distance d at a course angle a.

But on a sphere, it won't be true that shifting the centre of a circle through a certain distance d at a certain course angle a, will cause any arbitrary point on its perimeter to move through that same distance d at that same course angle a. Distance, yes: angle, no! It's because of the way longitude lines converge after they leave the equator. On a flat piece of graph paper, it would indeed apply, but not on the coordinates of a sphere."

Sorry to say, there was a silly error in that second paragraph. Where I wrote "Distance, yes: angle, no!", that was wrong. What I should have written was that for points on the perimeter of such a circle, NEITHER the distances moved through, NOR the course-angles, are the same as for the point at the centre of that circle. Herman Zevering correctly spotted my error, when he wrote (referring to, and quoting, an earlier email of mine which he received directly, not via NN) on page 11 of NN 86 "contrary to his hunch, also the distances at X and Z will not remain the same!". I thank him for that insight, which of course is correct.

However, my comment about distance was no more than a regrettable "aside"; it doesn't affect, at all, the weakness that I have pointed out in Zevering's diagram 4 on page 11 of NN 81.

Perhaps I can demonstrate the error inherent in Zevering's procedure with a numerical example, which I will make as simple as I possibly can.

Imagine a moment T, near Greenwich noon, and near the equinox, when the GHA and declination of the Sun were both exactly zero, at position X. X is at dec = 0, GHA = 0, or its geographic position is at lat = 0, long = 0, somewhere in the Gulf of Guinea.

Imagine three vessels, A, B, and C.
A is at lat = 60N, long = 0
B is at lat = 45N, long = 45E
C is at lat = 0 , long = 60E

We will assume there is sea for them to float in at these places, even if there really isn't.

If you work it out, all three ships are exactly 60 degrees, or 3600 nautical miles, great circle distance, from that Sun geographical position X. If each navigator measured the true Sun altitude at that moment T, it would be exactly 30 degrees in each case. So that position circle, radius 60 degrees, centred on lat = 0, long = 0, defines the position of any vessel which measured the Sun's altitude to be 30 degrees at that moment T. I think we can all agree about that.

Now assume that each of these vessels is steaming due North at exactly 10 knots, for the next 6 hours. At the end of that time, the latitude of each will have increased by 1 degree North, and the longitude will be unaltered. We can write the new positions as

A* is at lat = 61N, long = 0
B* is at lat = 46N, long = 45E
C* is at lat = 1N , long = 60E

I think all will agree so far.

Now, if we adopt the Zevering procedure, we have to transfer the centre of the position circle, from its original position at (0, 0) according to the motion of the vessel, using his formulae on page 11 of NN81, as follows-

$Dec^* = Dec + \Sigma d'Lat/60$ and

$GHA^* = GHA - (\Sigma dep/60/\cos(1/2Dec^* + 1/2Dec)$.

For a 60-mile Northward shift for each vessel, we find that in each case the appropriate change of Dec is +1 degree North, and zero change in GHA.
So the new transferred position X* is centred at 1 degree N, 0 degrees East. Now we get to the

interesting bit. Calculate the new great-circle distances between this transferred position X* and the three final positions of the vessels, at A*, B*, C*.

It's obvious that the distance X* A* must be exactly 60 degrees, just as XA was before. And if we calculate X* C*, we get 59.989 degrees, almost exactly the same as the previous value for XC of 60 degrees.
The surprise comes when we calculate X* B*, the great-circle distance between positions (1, 0) and (46, 45). This comes to 59.756 degrees, nearly 15 arc-minutes less than before, and nearly 15 arc-minutes less than the distances from X* to A* and from X* to C*. This 15 minute discrepancy has arisen as a result of imposing a shift of only 60 miles.

If X* was indeed the centre of a position circle, which included all vessels that measured a Sun altitude of 30 degrees at time T, and then steamed North through 60 miles, then the distance from any such vessel to X* would be the same; that being the definition of a circle.

But it's clear, from those calculated distances, that X* is NOT the centre of such a position circle, and it's also clear that the three new vessel positions A* B* and C* are not even on a circle at all. That's why the Zevering procedure is bound to fail. It assumes that the transferred position circle defines a locus which includes all such vessels, and looks for its intersections with another circle. But that assumption is wrong.

In figure 4 of NN 81, it's the dotted circle which is supposed to be the locus of the transferred positions, and which is shown intersecting with another circle at position Z". But if that dotted "circle" turns out to be not a circle at all, then the procedure fails.

George Huxtable.

======End of Copy of email sent to Terry Carraway on 2 May 05=====

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Member Herman Zevering wrote:

On Huxtable's comments in NN Issue 86 regarding Zevering's initial "Dilemmas" and later "Rejoinder".

I am not at all surprised that these two papers have given Huxtable a bit of a problem. I hope that my last paper in this series, "Epilogue" (yet to be published in the NN), will provide more convincing arguments, although they will not necessarily be more simple. "Epilogue" will include verbatim comments I received quite a while ago from George Huxtable by email and among other things I will address the various problems he presumes there exist with GD-UT, with random versus systematic error, and much more.

I should perhaps say that for someone set in his belief that celestial navigation is a closed book he knows all the conventional inside out offs, I imagine my contributions pose a bit of a challenge. For example, in "Rejoinder" I asked why Huxtable believes that with three sights there is according to him only a 25% chance that the fix will lie inside the cocked hat triangle. I address this statement fully in "Epilogue", which will show that this belief is in fact erroneous and based on the analogy of terrestrial sights discussed in the ANM, which is not applicable to celestial sights. This in itself is basically just as arguments in the field of celestial navigation go. However, Huxtable conveyed to me that "nav classes" are usually incorrectly told that the fix lies inside the cocked hat, whereas this is generally a correct assumption, barring certain anomalous configurations Huxtable wouldn't know about. So I am inclined to predict that the disagreements will increase because the papers I contributed will inevitably make major inroads into various conventionally held beliefs in celestial navigation.

Coming back to the problem that appears to vex Huxtable the most, I would say that the traditional transfer method basically tries to do the same thing with the parallel ruler on the chart as GD-UT does programmatically. Let's not loose sight of the similarity in method or at least of the objectives of the two methods, which are the same. In the sight-run-sight situation, the traditional method also moves the position circle, as represented by the position line of an earlier sight, according to the distance (**d**) and course (α) of the observer's movement. An important point is that the traditional method likewise does not tamper with the observed altitude of the earlier sight (like for instance A-UT does), because it represents the zenith distance or radius of this sight. In the German beer mug lid analogy of a position circle I mention later, the radius of the lid remains constant. So I think there is largely similarity between the traditional proxy transfer method and GD-UT.

However, the traditional method has to assume for simplicity, because it is after all just a construction-based proxy method dating back to a pre-electronic era, that the transfer can be realized sufficiently accurately by moving the earlier position line parallel to itself according to **d** and α from an estimated position "J" on the position circle's circumference. At least this is one way of doing the transfer, but other methods will achieve the same thing.

What I have been trying to explain to Huxtable (and will explain again in "Epilogue") is the basic fallacy underlying the traditional 'parallel ruler' method of transfer in that it assumes that moving a point like "J" on a position circle's circumference according to **d** and α is equivalent to moving the GP and hence the entire position circle according to **d** and α. This is after all the objective of any transfer method, namely to move the earlier position circle in a mathematically correct way so as to be able to ascertain its intersection(s) with the later sight's position circle. This is where the error occurs with the traditional method, which is that it does not move the earlier position circle in a mathematically correct way, although in certain configurations and usually when the displacement distance is very small it will yield acceptable approximations. This is the reason that a significant difference in position solution may result when using the traditional proxy method.

I have also been trying to explain Fig 4 in "Dilemmas", which Huxtable for some reason continues, almost *ad nauseam*, to regard as proof that GD-UT is false and all other methods true. In Fig 4 of "Dilemmas", which was in fact intended as a conceptual aid only, the displacement of the GP of the earlier sight and the displacement of point Z' on the position circle are in fact labelled differently, i.e **a** and **d** versus **a** and **d**, indicating that I didn't presume for a moment that they were the same as Huxtable appears to claim. This is in fact the crux of the matter, namely that indeed in spherical trigonometry they can mathematically not be the same and I think that Huxtable agrees with this now. His *wrist-bangle and wineglass-rim* thought experiment still convinces him of "distance, yes: angle no!" but he has now also agreed in his latest email to Terry Carraway and myself that it should be "distance, no and angle also no!". I believe I can prove this mathematically in "Epilogue", i.e that distance does not remain identical. So in fact we seem now to be in basic agreement about the principles involved. Our differences stem from the fact that I want to discard the use of the traditional transfer technique in favour of GD-UT if an electronic programming medium is available. It is perhaps true that I was the first to put GD-UT into practice in solving non-simultaneous sights, but I have subsequently found (as reported in "Rejoinder") that GD-UT is actually fully supported in the ANM, another point on which Huxtable vehemently disagrees (but I think incorrectly so), as we will see when "Epilogue" appears.

What seems to be the correct method for Huxtable may be likened to dragging a position circle like the curved lid of a giant German beer mug from point "J" behind a boat across a stretch of ocean. Instead, I would say just forget about the boat. The observer has moved through the equivalent of great circle track as determined by **d** and α relative to the GP of the earlier body and this requires that its GP must be moved accordingly.

A final comment I would like to make is that to my mind this is the first time there is clear evidence that other NN members than just George Huxtable (namely Herbert Prinz) are apparently actively considering and even debating my papers, although not through the forum presented by NN. I would in fact be very interested to hear what comments the NN membership have regarding my contributions, rather than just from one source.

Herman Zevering, khzevering@optusnet.com.au,
May 11, 2005.

A Response to G.G. Bennett's "The Two-Body Fix Revisited"

by Herman Zevering

The reason for Bennett's NN Issue 44 article (The 'Two-Body Fix' Revisited) is apparently the criticism by a certain E. Matthews in earlier NN Issues, whose contributions I haven't read. However, the argument seems to be that for larger run distances a triangle like S1-Zo-Zf (Bennett's Diagram 2) cannot be treated as a spherical triangle because ZoZf is a rhumbline. The reason for wanting this article re-published in the NN is apparently to contribute to the "current discussion", presumably in my contributions (Dilemmas, Rejoinder and Epilogue).

Let me first state that the real shortcomings of A-UT, whether it is Bennett's "standard method" used in his 1979 General Conventions article, his methods A and B or other versions, such as applied by G. Keys have as far as I am concerned been diagnosed in my "Rejoinder" and "Epilogue". All A-UT versions are at best only proxy methods, giving a comparable position solution to the one obtained with GD-UT (GHA-Dec Updating Technique) in some configurations, but not in others. In other words they have no general validity. I will demonstrate this again later using the numerical example in the Issue 44 article.

Another general point is that Bennett makes it seem as if the A-UT method he used in his 1979 General Conventions article, in that article called "standard method employed in sight reduction", is a kind of short-distance Marcq St Hilaire technique. The long-distance Marcq St Hilaire method in sight reduction would then be "to use transferred observations (British nomenclature for double sights)". Let me state the following to put this in a proper perspective:

a. Unlike the Intercept Method (IM), the double sight method, which was unknown to M St Hilaire or has at least nothing to do with the method he introduced, does not require any knowledge of an assumed (DR) position. This is in fact the interesting aspect or bonus of this solution method. Applied to pairs of multiple sights the method can determine the vertices of a cocked hat polygon without any reference to assumed (DR) position. If it is a non-simultaneous sights case, only the data pertinent to the run between sights are additional data, whereas the DR position at the time of the 1st sight is immaterial.

b. A-UT, whether it is Bennett's or some other version, is a technique that is not used with the IM at all. The aim of adjusting altitude with A-UT is to reduce the non-simultaneous situation to an equivalent simultaneous one to which the double sight method can be applied. The problem is the surrogate altitude introduced with A-UT. Not only is its rationale deficient, but it also nullifies the advantage mentioned under a. of not requiring assumed 'data'.

c. "Transferred observations" is not British nomenclature for double sights. The IM-based transfer technique can be applied to any number of sights. There is simply no link between the IM-based transfer technique or its nomenclature for that matter with the double sight method.

d. The fix or observed position obtained with the double sight, which is one point of intersection of two position circles, does not indicate the actual (estimated) position, unless there are absolutely no random and/or systematic errors in the observations. Three or more sights will normally show that the "double sight" only determines a vertex of a cocked hat polygon.

e. None of the above methods, including GD-UT, applied to three or more sights will yield a calculated fix (observed position). The traditional approach to finding a fix is to apply certain ad hoc constructions, for example Bennett's "eyeball least squares"[i].

f. The only method that can provide a calculated fix with three or more sights is the LSQ method a la Yallop-Hohenkerk, provided in the sight-run-sight case the IM-based transfer technique used by these authors in combination with LSQ is not used. With the fix obtained with LSQ it is assumed that all error is random. If there is systematic error, the LSQ fix (including Bennett's "eyeball LSQ" for whatever it is worth) cannot determine the fix and additional methods are required (see my Epilogue).

In returning to the rest of Bennett's Issue 44 article I will number and title my comments for easier reference.

1 The effect of the approximation of a great-circle track by a rhumbline track

Although this appears to be the gist of E. Matthews criticism, it nevertheless appears to me that the approximation of a great circle track by a rhumbline track, generally known as "great circle sailing", will have a negligible effect on the position solution with Bennett's A-UT versions in the context of the relatively short distances that are generally involved.

In the example in Bennett's Issue 44 article the distance covered is some 102 miles. Nonetheless when the cosine formula is applied to triangle P-Zo-Zf (see Bennett's Diagram 2), the distance <u>ZoZf</u> found (= d') is nearly the same as d = tV:

Cos(d'/60) = Cos(d'Long)Cos(LatZo)Cos(LatZf)+Sin(LatZo)Sin(LatZf) ..(i)
Cos(d'/60) = 0.99956
d'/60 = 1.70327
d' =102'.1963
d = tV = time diff x kn/hr = 5.1100 x 20 = 102'.2000

The difference between d and d' is 0'.0037 or 7 m. Noted is that t is the time between two sights, not the "time interval from the time of fix to the time of observation" (which fix? which observation?). If the triangle P-Zo-Zf is treated as a spherical triangle, the great circle through Zo and Zf is determined by the coordinates of these two points and the question is then what is the great-circle distance from Zo to Zf and what is the bearing of Zf from Zo. The distance d' is given by (i) and the bearing α' follows from:

Cosα' = [SinLatZf - SinLatZoCos(d'/60)]/[CosLatZoSin(d'/60)] ..(ii)
Cosα' = -0.90271
α' = 154.51686
True T = T* (say) = 360 – 154.51686 = 205.4831

The difference between the course bearing T* and T in Bennett's numerical example is therefore 205.48314 – 205 = $0^{\circ}.48314$.

When d' and T* are used to define Bennett's H1, the surrogate altitude:

SinH1 = SinHoCos(d'/60)+CosHoSin(d'/60)Cos(Zn -T*) .. (iii)
SinH1 = 0.89666
H1 = 63.72266 or 63° 43'.4

The same result is obtained with Bennett's formulas (11) and (12).

Using the conventional cosine formula as in (i), (ii) and (iii) has the advantage of avoiding speculation about what Formula (11) determining the so-called "conversion angle" actually accomplishes, such as: "The formula is a very close approximation to the rigorous one which involves meridional parts. It has also been assumed that the great circle and rhumb line lengths are the same and the conversion angle at either end of the course are equal".

It has in my opinion little to do with greater, let alone “high” accuracy or for that matter with an approximation of some more rigorous formula. As long as Formulas (10) and (11) yield the same result as the cosine formula applied in (i), (ii) and (iii), they are sufficiently 'rigorous'. Except for the (negligible) effect of the ellipsoidal shape of the Earth, it can hardly get more rigorous than applying the cosine formula to a spherical triangle. What has happened is no more than defining the sides and angles of a substitute spherical triangle P-Zo-Zf, which only fully shares d’Long, LatZo and LatZf with the original (part-rhumbline) triangle P-Zo-Zf.

Another worked example may further illustrate the equivalence of the approach with (i), (ii) and (iii) and with Bennett’s formulas (10), (11) and (12). In this numerical example I only changed the course from 205° to 25°.

time diff	tV = d	course	d'Lat	d’Long	Initial Lat	New Lat	Initial Long
5.1100	102'.2000	25°	1.5437	1.2480	54	55.5437	-46
New Long				Dep			
-44.7521				0.7199			

Dec	26.7367
GHA	39.2933
X	-0.45314
Y	0.10430
TanA	-0.20230
A	-11.43685
Zn	168.5631

CA -0°.5097 ..(11)

SinH1 = SinHoCos(d/60)+CosHoSin(d/60)Cos(T+CA-Zn) ...(12)

SinH1	0.87473
H1	**61.0132**
Cos(d'/60)	0.99956 (i)
d'/60	1.7033
d'	102.1959
Cosα	0.91002 (ii)
α = T*	24.4918
SinH1	0.87473 (iii)
H1	**61.0132**

As is seen, CA is negative and the adjusted course angle with Bennett’s Method A is 25° - 0°.5097 = 24°.4903.

2 Negative distance?

Although this is perhaps a minor point, to get Bennett’s results with Formulas (9), (11) and (12) in the Issue 44 article, the reader must substitute negative values for tV (=d), otherwise the formulas do not give the right answers. For instance, if a positive value for d is used, CA will turn out negative with the numerical example in the Issue 44 article: ½(102.2/60)Sin205Tan½(54+52.54) = -0.482.

Diagram 2 indicates that both d’Long and t(V/60) are to be taken as negative quantities. What has happened here is in my opinion a simple substitution error which affects Formula (11). The substitution should proceed as follows:

CA = -½d’LongSinMeanLat
d’Long = (d/60)SinT/CosMeanLat ...(10), so that substitution gives
CA = -½(d/60)SinTanMeanLat = 0.482 (with Bennett’s numerical example) ..(11)

Because of this substitution error, the result obtained with Formula (11) has the wrong sign and to correct this it is apparently assumed that the run distance must be negative, which is of course impossible. As a result of this faux pas with the algebraic sign in Formula (11), Formula (12) appears to be manipulated to accommodate the odd negative distance. But Formula (12) is actually in all cases simply:

SinH1 = SinHoCos(d/60)+CosHoSin(d/60)Cos(T+CA-Zn)

where distance is a positive quantity as it should be. The assumption that distance must be negative then finally also affects Formula (9). This formula should simply be:

Hf = Ho + (d/60)Cos(Z-T) …(9)

3 Cos(Zn-T) and Cos(T-Zn)

This is also a minor point, but it deserves mentioning. In Bennett's 1979 article the difference between azimuth (i.e Zn) and course angle was indicated as ΔA. It makes of course no difference to the outcome of (iii) or formulas (9) and (12) for that matter, whether the difference between azimuth and course is defined as Zn-T or T-Zn, because Cos(Zn-T) = Cos(T-Zn). In formula (9) the difference is given as Cos(Z-T), in Formula (12) it is Cos(T-Z).

4 Z in Bennett's Formulas is Zn, except in Formula (2)

It is also important to remind readers that Z in Bennett's formulas is not azimuth angle but true azimuth (Zn)[ii].

There is a small problem in using formula (13) in the Issue 44 article. As it stands it would give the wrong Z and Zn or might even produce an error message. This formula only works if for H_o is substituted H_c (calculated altitude). However, formula (2) is foolproof, provided Z is not understood as being necessarily the same as Z in Formula (12). TanZ in formula (2) is in fact equivalent to TanA given in Yallop-Hohenkerk's "Compact Data etc. 1986". The necessary conditional statements have to be applied to determine Zn from A.[iii]

5 The short-distance 1979 "standard method" and the long-distance Method A

The standard method employed in the 1979 article is, according to Bennett's statement in the Issue 44 article, applicable only when "the time interval is short or the vessel has only moved over a short distance". Needless to say the *time interval* is irrelevant if the vessel is stationary; it is only the vessel's movement that counts. The formula for the standard method is given as formula (9) in the Issue 44 article, except that the minus sign in the right-hand side should be + as mentioned earlier. The 1979 article's method is apparently a short-cut method only.

When the distance is small, the result Hf is practically the same as the surrogate altitude H1 computed with formula (12), but omitting the so-called "conversion angle (CA)" because according to Bennett this latter adjustment is only necessary for long distances:

CosΔA = Cos(Zn -T) = [Cos(S1Zf)-Cos(d/60)SinHo]/Sin(d/60)CosHo
CosΔA = [SinH1-Cos(d/60)SinHo]/Sin(d/60)CosHo
SinH1 = CosΔASin(d/60)CosHo+Cos(d/60)SinHo ….(v)

With A-UT, the length S1Zf is treated as a surrogate zenith distance of a new (larger) position circle, so that S1Zf is taken to be 90 - H1, in which H1 is the surrogate altitude. In the short distance case of the 1979 article, Bennett's formula (9) and (v) give the same result:

Ho	10.2850
t (hr)	0.3672
V (kn/hr)	7
d = tV	2'.5706
d/60	$0^{o}.0428$
ΔA = 55-243	-188
CosΔA	-0.990268
Hf = Ho+ (d/60) CosΔA	10.2426 with Formula (9)

The same case analyzed with (v):

SinH1	0.177816
H1	10.2426 with (v)

When the Issue 44 article's numerical case is analyzed with Bennett's short-cut "standard method" of 1979:

ΔA = Zn-T = 167.038-205	-37.9620
CosΔA	0.788419
t	5.1100
V	20
(d/60)CosΔA	1.3429
Ho	62.4083
Hf = Ho+ (d/60)CosΔA	63.7513 (63^{o} 45'.08) with Formula (9)

When applying (v):

SinH1	0.896734
H1	63.7320 (63^{o} 43'.92) with (v)

In other words, in the long-distance case Formula (9) obtains Hf = 63^{o} 45'.08 and method (v), which is Formula (12) without the CA correction obtains H1 = 63^{o} 43'.92, a difference of 1'.16 in altitude. This could perhaps be taken as proof that the "standard method" of 1979 does not hold for large displacement distances.

However, H1 calculated with (v) differs only 0'.5 in altitude from Bennett's Method A result and a more important point is actually whether applying H1 obtained with Methods A and B rather than H1 obtained with (v) makes much difference for the position solution. In fact the differences in position solution are rather insignificant, at least in this particular case[iv]:

Difference in Lat compared to Method A = 0'.6
Difference in Lat compared to Method B = 0'.4
Difference in Long compared to Method A = 0'.2
Difference in Long compared to Method B = 0'.2

Bennett makes it look as if E. Matthews critique is valid and that, of course, one has to use a different method when the displacement distance is large. In my opinion just using formula (v) in all cases appears sufficient. Method A and Method B are hardly worth the fuss, especially not if one believes as Bennett does that the approximations would in any case be "masked by uncertainties in the observed data".

6 A-UT requires an assumed (DR) position

In the 1979 article, taking an azimuth bearing was considered an "elementary precaution" and if you hadn't done it you could use a star finder to determine approximate azimuth. This approach has been bypassed in the Issue 44 article. Method A simply calculates azimuth (Zn).

In the 1979 article, with the short-cut method the assumed (DR) position seemingly didn't play any role in deriving the position solution. This is indeed the attractive aspect of the double sight method that it does not require an assumed position. As pointed out in my Epilogue, adopting a (approximate) value for azimuth (Zn), however, implicitly defines an assumed position at the time of the 1st sight. In the Issue 44 article an explicit initial (DR) position (at the time of the 1st sight) is introduced as part of Method A, with which Zn is then calculated. This is quite an about face and it is probably the reason why Bennett now calls the idea that "a navigator need not know his position with the two body fix" absurd, whereas in 1979 he was apparently satisfied that A-UT in combination with his double-sight method did not need an assumed position, only approximate azimuth.

Nonetheless, Method A is not very sensitive to variation in the assumed initial (DR) position. This is demonstrated in Annex 2, where I assumed a $Lat_{DR} \sim Long_{DR}$ that differs a full 1° (53° N and 45° W) from the position adopted in the Issue 44 article's numerical example. The (absolute) difference in position solution caused by assuming a substantially different DR position is 1'.9 for Lat and 0'.6 for Long. This relative insensitivity of Bennett's A-UT versions to variations in assumed (DR) position at the time of the 1st sight, at least in some configurations, might have actually been seen as a vindication of the method and of his original advocacy of using an approximate azimuth value.

To my mind, Bennett could have defended his A-UT version in general and against the criticism of E. Matthews by pointing out that:

- The effect of an assumed (DR) position on the final position solution is negligible. An approximate initial position (at the time of the 1st sight), or else an approximate azimuth from observation or from a star finder will do.

- The effect of using rhumbline (run) distance versus great-circle distance is also negligible.

The only concession should have been to substitute formula (v) for his original short-cut method, Formula (9).

7 A-UT as proxy method

The crux is, however, when the position solution obtained with the A-UT versions are compared to the position solution obtained with GD-UT, the differences can be significant. Run distance could be one of the factors affecting these differences. For example, A-UT and GD-UT applied to Bennett's 1979 case yield virtually the same position solution (see Epilogue). But this is not so when comparing the position solutions in the Issue 44 article's case (see Annex 3):

	Diff with Method A	Diff with Method B
Lat	5'.4	4'.4
Long	1'.8	1'.4

It demonstrates my earlier contention that the A-UT versions can produce significant differences in position solution. This is simply because of their basically faulty rationale, one that is masked when the run distance is short.

8 A recap of a few points about GD-UT versus A-UT

I should recap a few points about GD-UT versus A-UT. The GD-UT method is basically indicated in the ANM:

"If the observer is in a ship and there is a run between sights, the first position circle must be transferred for the run. This can be done by transferring the geographical position and then drawing the circle"(Vol II, p 43).

Noted is that allowing for the run in the worked example given in the ANM (Vol II, p 43-45), involving three successive Sun sights, is by using the rhumbline version of GD-UT. This particular case has been analyzed in my "Rejoinder" and "Epilogue". In the pre-electronic past the method could only be applied (constructed) in the Large-Alt case when the position circles are small enough to be drawn on the chart.

Needless to say, if one is prepared to use what I call the traditional IM-based 'parallel ruler' transfer method, which of course plays no role in A-UT, its basic idea should be understood properly, which is that the transferred Position Line (PL) is supposed to represent the transferred position circle of the earlier sight. The traditional transfer method is therefore a surrogate method for doing this, but unlike all A-UT versions, it is still premised on the correct idea that the one property about the position circle that does not change is its zenith distance or radius. The rationale of tampering with the radius of the 1st sight's position circle and constructing another circle with an inflated (surrogate) radius as A-UT does is simply hard to understand and incorrect. What's more, the method is also unnecessary and may give significantly wrong results.

The problem with the traditional IM-based transfer method is the assumption that transferring a point (Z) on the circle over a distance d and course α is equivalent to moving the GP of the sight according to d and α, a proposition which is simply not generally valid, regardless of the question of rhumbline versus great-circle distance, which like with Bennett's A-UT versions is basically an irrelevant issue.

9 The great-circle and rhumbline version of GD-UT

With GD-UT, the run distance d at true course α is automatically interpreted as a great-circle distance with initial true bearing α. It is a case where the great circle through the GP of the 1st sight is determined by one point on it (the GP or X_1) and the angle at which it cuts the meridian through X1, which is α or 360^o-α. Applied to the data of the Issue 44 article, we have (β is the angle at the pole between the meridians through X_1 and X^*_1):

SinDec*	CosαCosDecSin(d/60)+SinDecCos(d/60)
SinDec*	0.425633
Dec*	25.1907 (cosine formula)
Dec* = Dec+(d/60)Cosα	25.1929 (rhumbline equation)
Difference	**0'.13**
Cosβ	[Cos(d/60)-SinDecSinDec*]/CosDecCosDec*
Cosβ	0.999904
β	0.7954 (cosine formula)
Sinβ	Sin(d/60)Sin(360-α)/CosDec* = -Sin(d/60)Sinα/CosDec*
Sinβ	0.013882
β	0.7954 (sine rule)
β with 4-part formula: SinDecSinα = CosDec/Tan(d/60)+Sinα/Tanβ	
Tanβ = -Sinα/[(CosDec/Tan(d/60)-SinDecCosα]	
Tanβ	0.013884
β	0.7954 (with 4-part formula)
GHA* = GHA+β	40.0888 GHA* calculated with β
GHA* = GHA-(d/60)Sinα/Cos(½(Dec+Dec*)	
	40.0940 GHA* calculated with rhumbline equation.
Difference	**0'.32**

The entirely correct formulas for finding Dec* and GHA* (the transferred coordinates of the 1st sight's GP), is to find Dec* with the cosine formula and then angle β. GHA* = GHA+β. However, when applying the rhumbline equations the results are practically the same. This was already pointed out in my Epilogue. The distance the vessel moved in this case is no less than 102'.2 nautical miles, yet the differences calculated with the great-circle and rhumbline formulas are negligible, 0'.13 (237 m) in Dec* and 0'.32 (583 m) in GHA*. In other words, GD-UT is not really dependent on rhumbline computations, but the rhumbline equations are just easier to apply with negligible effect.

10 A few final points

These points are mainly to set the record straight regarding some authors referred to in Bennett's Issue 44 article. I reject as inappropriate the reference to Keys (assuming that it is Gerry Keys) in Bennett's Issue 44 article as being among authors whose double sight methods require knowledge of "where the observer's zenith lies in relation to the great circle connecting the two bodies". Gerry Keys' geometric solution method of 1982 requires no such assumptions and as a geometric solution like Bennett's is more elegant and from a programmatic viewpoint also a much easier handled and straightforward one. Just consult Keys' expose of the solution in his 1982 book (p 135-138) to be convinced. Bennett's 1979 solution method, said to derive from Gauss and Chauvenet, is inefficient, to say the least. It is inefficient to use anything else than the cosine approach for obtaining a geometric solution of the problem. While $\text{Cos}(GHA_1\text{-}GHA_2)$ is unambiguous and equal to $\text{Cos}(GHA_2\text{-}GHA_1)$, the ambiguity arising from the application of the sine function to these differences as with Bennett's method causes programmatic problems which need to be doctored, leading to special sub-rules in the middle of the program, switching from a rectangular to polar function for certain but not all equations, etc.

Pepperday's writings on the double-sight method should certainly not be put at par with Gerry Keys' 1982 contribution. Pepperday, a disciple of Bennett like Bennett proclaims to be one of Gauss and Chauvenet, simply tried to emulate his mentor's double sight solution method, at least in one article from his hand I know of[v].

There is finally a point in the Conclusion of Bennett's Issue 44 article where he is simply wrong and that is his opposition to the idea that with the double sight reduction a "navigator need not know his position at all". Bennett calls this absurd, a "proposition that any self-respecting navigator will reject". Nonetheless, the proposition is absolutely correct. To apply the double sight method in a sight-run-sight situation with GD-UT requires only the run data (distance and course) and the observed GHA, Dec and H_o of the two sights. There is also no need to know (calculated or observed) azimuth to find the fix. Azimuth is simply irrelevant and a by-product. As it cannot be observed to a sufficient degree of accuracy but only calculated, it is not a datum. The assumed (DR) position, including azimuth that can be calculated from it, is therefore simply redundant (pseudo) 'data'.

While the run data may be inaccurate, the more important point is that the sight reduction methods themselves shouldn't introduce inaccuracies of their own, like A-UT and this is the crux of the whole argument.

With all running fix methods other than GD-UT, run distance appears to be a contributory factor affecting the relative accuracy of the position solution compared to GD-UT's. However, the runs don't need to be kept short to avoid the rather illusory effect of rhumbline versus great circle distance, but to avoid introducing significant inaccuracies. Unfortunately, navigators continue to be told and shown in worked examples in various manuals that it doesn't matter if long distances between sights are covered[vi]. The reason why I think runs should be kept relatively short when using GD-UT is only to minimize the effect of (inaccurately known) current set and leeway, random errors in helming, to mention just a few likely sources of error.

11 What about Bennett's Method B?

I mainly concentrated on Bennett's Method A, but Bennett's "Method B" lo and behold is almost halfway there by considering that the updated GHA of the earlier sight equals GHA1 = GHA - (d/60)SinT/CosMeanLat (15)[vii]. If this approach is extended to the other GP coordinate so that Dec1 = Dec + (d/60)CosT and MeanDec is substituted for MeanLat, Bennett has in fact hit upon the GD-UT method, so that navigators will be finally able to retire A-UT to the back of the nav table where it belongs.

Annex 1: Analysis of Bennett's A-UT Method A

For Body 1:

time diff	tV = d	course	d'Lat	d'Long	Initial Lat	New Lat	Initial Long
5.1100	102'.2000	205°	-1.5437	-1.2480	54	52.4563	-46

New Long
-47.20251

(i) Cos(d'/60) = Cosd'LongCosLatZoCosLatZf+SinLatZoSinLatZf
(ii) Cosa' = [SinatZf-SinLatZoCos(d'/60)]/CosLatZoSin(d'/60)

(i)	Cos(d'/60)	0.999558	
	d'/60	1.7033	
	d'	102.1963	
(ii)	Cosa'	-0.902712	
	a'	154.5169	
	T*	205.4831	
Form (13)	CosZ	-0.981174	LHA 353.2933
Wrong	Z = Zn	168.864817	

With quadrantal formula:

X	-0.453137	
Y	0.104300	
TanA	***-0.230173***	
A	-12.9622	

Correct	Zn	**167.0378**
Form (2)	TanZ	***-0.230173*** (This is in fact TanA)
	SinHc	0.885318
	Hc	62.2907
	Using Hc in Bennett's formula (13)	
	Cos Z	-0.974518
Correct	Z = Zn	**167.0378**
(iii)	SinH1	0.896662
	H1	63.7227 or 63° 43'.4

Application of K-Z double sight method with H1

	Body 1		Body 2
GHA1	39.2933	GHA2	80.6400
Dec1	26.7367	Dec2	51.4900
H1	**63.7227**	Ho,2	69.4117

Lat1	52.3734	Lat1 selected: 0'.0 (diff in Lat with Method A);
Lat2	32.7802	1'.0 (diff in Lat between Method A and Method B)
CosMD1,1a	0.9910	7.6821 (MD1,1a)
CosMD1,1b	0.8323	33.6646 (MD1,1b)
CosMD2,1a	0.8698	29.5674 (MD2,1a)

CosMD2,1b   0.9789   11.7793 (MD2,1b)

Group 1 (selected)

Long1 46.9754 GHA1+MD1,1a   Long1 selected: 0'.0 (diff in Long with Method A);
       31.6112 GHA1-MD1,1a   0'.4 (diff in Long between Method A and Method B)
       114.3046 GHA2+MD1,1b
       46.9754 GHA2-MD1.1b
       Long1 selected is a Long W

Group 2

Long2 68.8607 GHA1+MD2,1a
       9.7259 GHA1-MD2,1a
       92.4193 GHA2+MD2,1b
       68.8607 GHA2-MD2,1b

CosZ	-0.9630	0.1913
Z	164.3558	78.9692
Zn	164.3558	281.0308
LHA	352.3179	33.6646
	LHA>180	LHA<180
	Zn = Z	Zn = 360-Z

NB The zero difference in Lat and Long shows the equivalence of Bennett's geometric double sight method and the algebraic-trigonometric K-Z method I applied in the analysis.

Annex 2: Method A with variation in assumed initial DR position

For Body 1:

time diff	tV = d	course	d'Lat	d'Long	Initial Lat	New Lat	Initial Long
5.1100	102'.2000	205°	-1.5437	-1.1753	53	51.4563	-45

New Long
-46.1752

(i) Cos(d'/60) = Cosd'LongCosLatZoCosLatZf+SinLatZoSinLatZf
(ii) Cosa' = [SinatZf-SinLatZoCos(d'/60)]/CosLatZoSin(d'/60)

(i)	Cos(d'/60)	0.999558
	d'/60	1.7033
	d'	102.1965
(ii)	Cosa'	-0.902841
	a'	154.5340
	T*	205.4660

Form (13)	CosZ		-0.925292 LHA 354.2933
Wrong	Z = Zn		157.712465
	X	-0.438963	
	Y	0.088804	
	TanA	***-0.202305***	
	A	-11.4369	
Correct	Zn		**168.5631**
Form (2)	TanZ		***-0.202305*** This is TanA
	SinHc		0.894106
	Hc		63.3938
	Using Hc in Bennett's formula (13)		
	Cos Z		-0.980144

Correct	Z	**168.5631**
(iii)	SinH1	0.896888
	H1	63.7520 or 63° 45'.12

Application of K-Z double sight method with H1

	Body 1		Body 2
GHA1	39.2933	GHA2	80.6400
Dec1	26.7367	Dec2	51.4900
H1	**63.7520**	Ho,2	69.4117

Lat1	**52.3412** (selected)		1'.9 diff in Lat with base case Method A;
Lat2	32.7921		0'.9 diff in Lat with base case Method B
CosMD1,1a		0.9910	7.6924 (MD1,1a)
CosMD1,1b		0.8324	33.6542 (MD1,1b)
CosMD2,1a		0.8701	29.5310 (MD2,1a)
CosMD2,1b		0.9788	11.8157 (MD2,1b)

Group 1 (selected)

Long1	46.9858 GHA1+MD1,1a	0'.6 diff in Long with base case Method A
	31.6009 GHA1-MD1,1a	0'.2 diff in Long with base case Method B
	114.2942 GHA2+MD1,1b	
	46.9858 GHA2-MD1.1b	
	Selected Long is a Long W	

Group 2

Long2	68.8243 GHA1+MD2,1a	
	9.7623 GHA1-MD2,1a	
	92.4557 GHA2+MD2,1b	
	68.8243 GHA2-MD2,1b	
CosZ	-0.9628	0.1927
Z	164.3177	78.8900
Zn	164.3177	281.1100
LHA	352.3076	33.6542
	LHA>180	LHA<180
	Zn = Z	Zn = 360-Z

Annex 3: A-UT compared to GD-UT

For Body 1:

time diff	distance	course	d'Lat	d'Long	Initial Dec	New Dec	Initial GHA	New GHA
5.1100	02'.2000	205°	-1.5437	-1.8007	26.7367	25.1929	39.2933	40.0940

	Body 1		Body 2
GHA*1	40.0940	GHA2	80.6400
Dec*1	25.1929	Dec2	51.4900
Ho,1	62.4083	Ho,2	69.4117

Lat1	**52.2829 (selected)**		5'.4 diff in Lat with Method A;
Lat2	32.2494		4'.4 diff in Lat with Method B
cosMD1,1a	0.9927	6.9106 (MD1,1a)	
cosMD1,1b	0.8326	33.6354 (MD1,1b)	

cosMD2,1a	0.8613	30.5385 (MD2,1a)
cosMD2,1b	0.9848	10.0075 (MD2,1b)

Group 1(selected)

Long1	47.0046	(W)GHA1+MD1,1a	1'.8 diff in Long with Method A;
	33.1834	GHA1-MD1,1a	1'.4 diff in Long with Method B
	114.2754	GHA2+MD1,1b	
	47.0046	(W)GHA2-MD1.1b	

Group 2

Long2	70.6325	GHA1+MD2,1a
	9.5555	GHA1-MD2,1a
	90.6475	GHA2+MD2,1b
	70.6325	GHA2-MD2,1b

CosZ	-0.9720	0.1951
Z	166.4044	78.7467
Zn	166.4044	281.2533
LHA	353.0894	33.6354
	LHA>180	LHA<180
	Zn = Z	Zn = 360-Z

---

i See "The Complete On-Board Navigator (2003-2007)", p21

ii 'True' doesn't mean non-magnetic as is sometimes assumed. In relation to azimuth, 'true' means that the azimuth angle (Z), which lies between 0° and 180° is corrected for actual compass bearing of the celestial body (Zn). This is of course true compass bearing. So if you were by any chance applying Bennett's "standard (A-UT) method" on the high seas, which required a (approximate) bearing on the earlier sighted body, the bearing should be corrected for magnetic variation. The approximate bearing is then approximate Zn.

iii In Yallop-Hohenkerk: X = $CosLat_{DR}$SinDec-$SinLat_{DR}$CosDecCosLHA and Y = -CosDecSinLHA, so that TanA = Y/X = TanZ in the formula Bennett gives at (2) in the Issue 44 article. The conditional statement to find Zn from A in spreadsheet notation is: IF(X<0,A+180,IF(X>0#and#Y<0,A+360,A)). Formula (2) is also given in G. Keys 1982 book, called "azimuth in quadrantal notation" (p 123). Keys' Z_Q = Tan^{-1}(Y/X) is the same as Bennett's Z = Tan^{-1}(Y/X). In both instances Zn is to be found by using a P→ R function, so that Zn = θ. The origin of Keys' and Bennett's quadrantal formula is probably the Compact Data Bulletins of the Royal Greenwich Observatory, but I could be mistaken here.

iv The differences are in absolute terms

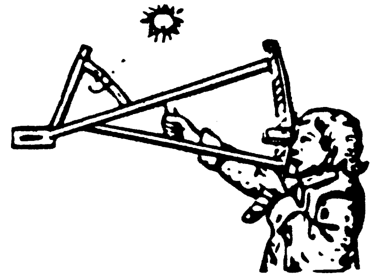
v See M. Pepperday, "The two-body problem at sea", UK J of Nav. (Forum), Vol 45. In this rather stark article written with rather unjustified aplomb, Pepperday basically attempts to discredit the two-body solution method. By Pepperday's own admission, his two-body program created from his old surveyor notes kept 'crashing' during a (fictitious) trip at sea from Gladstone to Noumea, even though his mentor, G.G. Bennett whose 1979 article was mentioned in Pepperday's bibliography, managed to successfully use the two-body method during his own trip from Noumea to Newcastle on board the yacht Onya of Gosford. Pepperday sided with "all right-thinking people" in favour of the Intercept Method, to which he had obviously little theoretical nor practical exposure at the time, for instance thinking that "the intercepts from multiple sights should all be the same..". Pepperday might have written more valuable later contributions, perhaps correcting his earlier views, of which I am not aware.

vi This includes examples in various manuals in which it is not only suggested that there is no urgency in making observations (taking sights) but that the navigator can with impunity run on his sights to any point along the run, even to a point in time well after the last sight was taken. It is the fallacy of the traditional 'parallel ruler' method of sight transfer that is mostly uncritically supporting this approach to sight planning: just shove the PL of a sight parallel to itself along any run distance. Besides the fact that the 'parallel ruler' method, like A-UT has no general validity, the traditional 'running fix' therefore also overlooks the chance of increased error in the run data with larger run distances.

vii Formula (15) in the Issue 44 article is actually stated as GHA1 = GHA + (tV/60)SinT/CosMeanLat, but t(V/60) has presumably to be taken as a negative quantity as with all Bennett's other formulas. There is therefore still a problem with the algebraic sign. As already pointed out in my "Dilemmas", the entire expression (d/60)Sinα/CosMeanDec (my own notation) or any similar rhumbline expression must bear a negative sign because GHA is always expressed positively in a westerly direction.

THE FINAL SEGMENT OF MEMBER HERMAN ZEVERING'S "EPIL0GUE" WILL BE PRINTED IN NEWSLETTER NUMBER 88, SUMMER 2005

THE NAVIGATOR'S NEWSLETTER



FOUNDATION FOR THE PROMOTION OF THE ART OF NAVIGATION ISSUE EIGHTY-EIGHT SUMMER 2005

This letter is published to keep members up to date on the activities of the Foundation, provide useful notes on navigation techniques, review books on the subject and maintain a reader forum for the expression of our members opinions and their questions.

ACTIVITIES

By Terry Carraway

Once again we must apologize for the long delay in getting this issue of The Newsletter to you. It has been a bad year for The Foundation with the loss of so many good friends and people who were vital to The Foundation. We believe we have turned the corner as noted below.

We now have some good news for our members. The Navigation Foundation has a new professional writer and editor, Dr. David Burch. Dr. Burch has accepted our plea to be the new editor. With Dr. Burch on board as editor look for some changes in contents and format. The Navigation Foundation has mostly concentrated on celestial navigation over the past 23 years. We have explored almost every facet of this ancient art using some of the most foremost experts. Rear Admiral Thomas D. Davies, founder of The Navigation Foundation and an expert on celestial navigation. Director Ernest Brown, a professional editor of Bowditch for many years; Director, Commander John Luykx, an expert on sextants, chronometers and celestial navigation and The very first Director after The Navigation Foundation was started, Director Roger Jones an expert and teacher of celestial navigation. We believe it is time to investigate some of the modern navigation systems. With our new approach we hope we can attract some new young navigators who are interested in current navigational techniques. We will still have the expertise to answer any questions on celestial you may have.

This issue will have the conclusion of Mr. Herman Zevering's articles. We thank all members who wrote commenting on these articles.

For all members who ordered the back 82 issues of The Navigator's Newsletter offered during our (house Cleaning) again I must ask you to be patient. I will get issues 44 – 53 in the mail as soon as possible. You have not been forgotten.

READERS FORUM

Edited by Terry Carraway

Member Gayle Stone wrote on October 13, 2005:

"Foundation Staff", I am seeking assistance or collaboration with a member regarding "Moon/Upper Limb" reductions. Preferably someone that has worked with or is familiar wit, Leonard Gray's "100 Problems in Celestial Navigation".

I thought I had successfully completed all his problems with UL some time ago except for the occasional fault of neglecting to take 30 minute subtraction for UL Apparent Altitude Correction.

I thought I had successfully completed all his problems with UL some time ago except for the occasional fault of neglecting to take 30 minute subtraction for UL Apparent Altitude Correction. That error is easily analyzed since the intercept is about 30 Minutes (NM) off the mark. I have also worked my own sights of Sun/Moon UL , such as the opportunity offered in daylight here on March 19, 2005 (Approx. Lat. 25-40, Long. 080-09). This met with great success, FIX to (known) DR, within 1 NM.

On occasion I re-visited all facets of navigation such as, storm evasion vis a vis our hurricanes this year, tide, currents, et al. In returning to Mr. Gray's book for exercise recently, I am consistently abut 15 (fifteen) minutes off with Moon UL, LOP's and can't understand why. Although I am H. O. 229 oriented, I thought maybe working them with H. O. 249 would reveal my error but to no avail. One of the problems in the book creates a Sun advance to later UL Moon sights and I hit tht one on the mark. I see no difference in my reduction procedures, maybe just an error in plotting?

Leonard states that his book is not without some errors so as a check for this possibility, I cross check everything with my CELESTICOMP-V and using his sight UT and Hs, it agrees with his FIX'es.

In a quandary.
Gayle Stone

E-mail Gayle Stone at: steglesto@bellsouth.net

Member Dr. David Burch wrote on October 8, 2005:

Hi Terry,

It was also indeed a pleasure to meet you after all these years. Thank you again for driving over and hosting this very enjoyable meeting.

If I may say so, I would not be so harsh in depicting the content of the recent newsletters, I am sure tht members appreciate the very fine job you and Roger and others have done on all of them, and these publications – even the very detailed ones – are treasured to me as well as to all members, which is why I am willing to work hard to help preserve them and to carry on the tradition.

I think adding new content is just our joint recognition that "the art of navigation" evolves, and the Foundation can evolve with it. Celestial navigation should certainly remain a primary focus, but we can expand on it with latest technologies as well as revitalizing some of the developmental work from the last two centuries. I look forward to sharing content from ideas in my mind on this topic . . some of which I have done in one form or another that we can adapt . . . most of which has not been "published" except in our training materials.

I am particularly interested in Matthew Henson photos you mentioned. What a story. I think it could be quite a contribution from the Foundation to preserve and publish these if possible. I will find the books I have by and about Henson to see if they are duplicates. I also work with some very talented photographers and digital artists who could help us with a presentation of them if it might be possible. Please keep me posted.

I think it would also be wonderful to ask Roger to write up his meeting with Henson as part of the presentation… or at least and article if the photos do not work out.

Thanks again for the lunch meeting and many thanks for the invitation to work on the Newsletter. I hope I can do as well as you have.
Best regards,
David

Member Captain Warren G. Leback wrote on July 15, 2005:

Being a member of the Foundation, I read with interest those articles dealing with Celestial Navigation.

I graduated from The United States Merchant Marine Academy Class of 1994. We were taught the basics of Celestial Navigation becoming thoroughly grounded in Time and Spherical Trigonometry. Then it was on to methods of solving Lines of Positions and Latitude using the four methods that were in use at that time.

-Bowditch (American Practical Navigator)
-Marcqi St. Hilaire
-H.O. 208 Driesenstock
-H.O. 211 Ageton

Each one and improvement over the one proceeding it, and of course easier to solve and less time consuming.

The Hydrographic Office issued H.O. 214, which if I recall, correctly was contained in four (4) volumes which permitted you to solve the navigation problems quicker and more accurately. When a set was delivered to my ship the "Santa Ana" (Grace Line). I noted the set was compiled by the Workers Progress Administration (WPA). It was long after becoming adept in their use that I could not praise the QPA enough in making the navigation of our ship more efficient.

It is sad today to see the graduates of The Maritime Academy and Naval Academy not being thoroughly grounded in the basics of Celestial Navigation. The powers that be say that with electronic navigation equipment, celestial navigation is not necessary. Tell me what happens when the lights go out - - and they can.

Captain Warren G. Leback

Member Captain Warren G. Leback wrote on July 15, 2005;

As a member of the Foundation, I am sending a copy of an article I have written on "Lifeboat Sextant, in World War II."

Having served on a Grace Line C-2 in 1944-1947, we had been issued a "Lifeboat Sextant." It was plastic with the appropriate instructions on its use.

I found one E-bay and that led me to write the article. The article may be of interest to the members of the Foundation.

World War II
The Lifeboat Sextant

In late 1943 the Maritime Commission through the War Shipping Administration began to furnish as part of the lifeboat equipment, a Lifeboat Sextant. I am sure there are many of us who remember being trained in its use. More importantly there are probably still alive those who had to use it after their vessels were sunk.

The lifeboat sextant was stored in a more or less watertight box clearly marked as property of the Maritime Commission. Besides the sextant, the box contained

One (1) pair of six (6) inch parallel ruler

One (1) pair of dividers

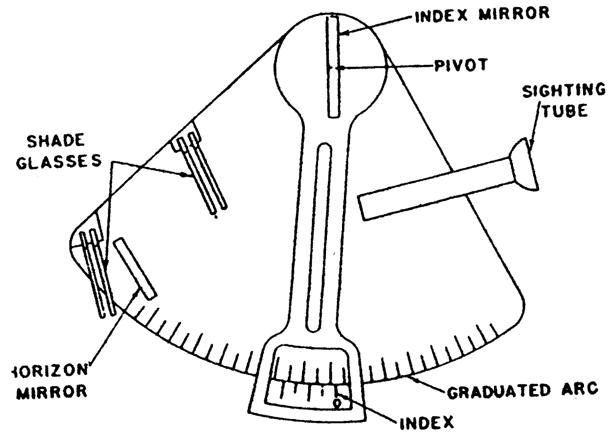
Two (2) pencils

One (1) eraser

One (1) note pad

One (1) instruction book

The sextant was constructed out of ribbed gray plastic with two folding handles on the back. In lieu of a telescope, a sighting tube was fitted. An adjustable vernier scale was fitted over the arc. The index arm in addition to the vernier scale carried the index mirror. Two sets of shade glasses were fitted to the arc, one set to reduce sun glare and one set to reduce horizon glare. The horizon mirror was split so as to show the horizon and the reflected image of the sun or star. The sextant is shown below.



The instruction book was straightforward, concise and written for the novice. The inside of the front piece provided a Check Off List. On several ships I served on the List was reproduced and posted on the bridge, in chart room and copies given to each officer.

The book contained instructions, data, and pertinent comments, however the most important instructions covered

- Latitude from Noon altitude of the Sun

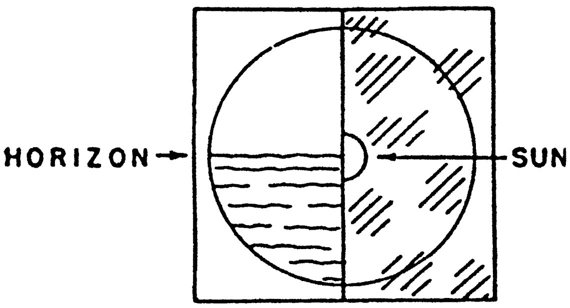
-Latitude by observation of Polaris

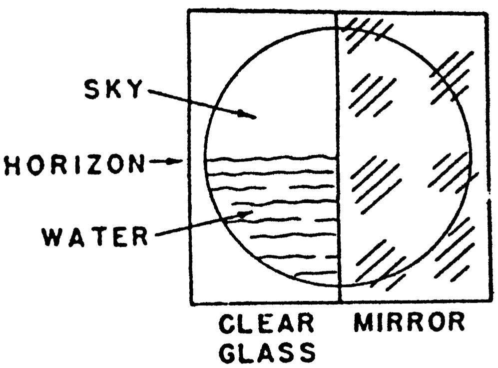
-Line of Position from observation of the Sun to determine longitude

-Position by observation of two or more stars

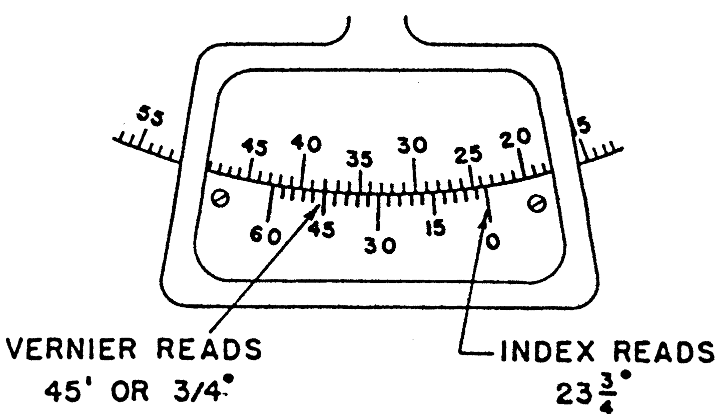
If by chance you forgot the Chronometer or your watch and the Time Zone difference east or west of Greenwich, Lines of Position for Longitude Position could not be worked. Latitude from observations of the sun's highest altitude and the Pole Star could be determined without Greenwich Civil Time to observe the zenith. Bear in mind one could always "run the Latitude down" and reach land.

The basic instruction on how to use the sextant was simple and straightforward. The sextant is held in the right hand by the handles on the back of the Arc. Estimate by eye, the altitude of the sun or star. An easy method is to look directly overhead then by eye divide the arc into 15 degree segments (total of six segments). Adjust the pivot to the estimated altitude adjusting the pivot until the sun or star is reflected in the horizon mirror. Remember the sun's equator is adjusted to the horizon line. A star is adjusted to the horizon line. This is shown below.

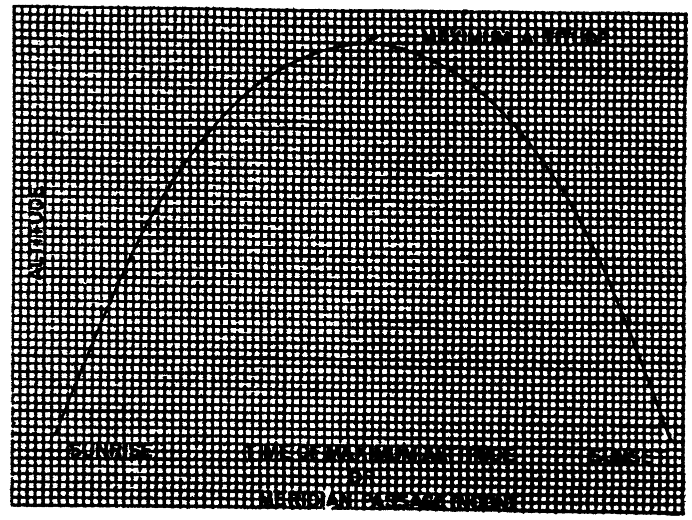




The altitude in degrees is read off the Arc. The minutes are read off the vernier as shown below.



To determine Latitude from the noon local time altitude of the sun. It was recommended the observer take a series of observations of the sun is taken prior to and after the sun reaches the zenith. The observed altitude of the sun or pole star is the latitude of the observer. These observations should be plotted on the graphs provided to insure a correct observation is obtained. This is shown above.

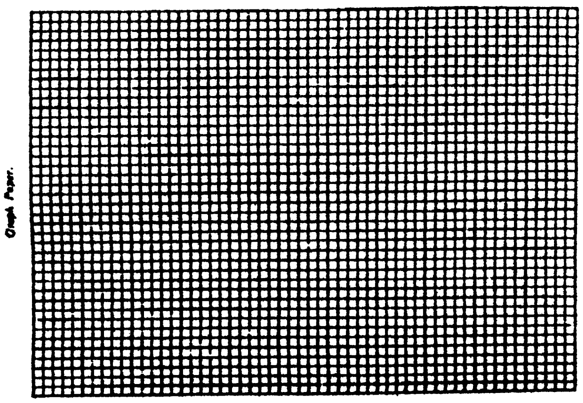


Latitude can be obtained from observing the Polaris's (Pole Star) altitude north of 10 degrees North Latitude. With a one degree error or less the altitude of Polaris equals the observer's Latitude.
Longitude is determined by observing the altitude of the sun or star if the observer knows the correct Greenwich Civil Time at the time of observation. If GCT is not known then Longitude can not be determined. There were several examples of determining Longitude, which requires considerable practice on the part of the novice navigator.
The instruction book provided a simple method of determining direction. Sailing instructions were provided such as how to determine speed of the drifting, rowing or sailing. It also provided the novice on how to determine direction using a compass. All lifeboats had as part of their equipment "Pilot Charts". These charts contained a wealth of information to assist in navigation. It recommended the novice navigator study the charts carefully.
A star chart was included in the book giving the principal stars. This chart provided for star identification. It was useful in determining a rough estimate of the Lifeboat's position.
Included were the following tables

- Table I – Calendar for 1944 and 1945.
- Table II – Declination of the Sun by month and day of month.
- Table III – Correction to Sun's Declination at Time of Meridian Passage.
- Table IV – GHA (Greenwich Hour Angle) of the Sun by month and day.
- Table V – Correction to GHA.
- Table VI – GHA by month and day.

- Table VII – Listing of 24 stars giving order of magnitude, their Declination and Sidereal Hour Angle.
- Table VIII – Bearing from North when Rising or Setting for Sun or Stars by month and Latitude.
- Table XI – Altitude and Azimuth by Latitude increments.

Plotting Sheets, Graph Paper and scratch pad were provided. The Plotting Sheet is shown below.



There was a check-off list plus some suggestions when abandoning ship. These were

- Your lifeboat should contain for navigation
  - Charts
  - Compass
  - Sextant
  - Radio
- If time permits you should take the following
  - Chronometers, watches, charts and sextants from Chart Room
  - Know the error of the Chronometer and your own watch.
  - Date, time abandoning ship.
  - Last known position of vessel.

The instruction was as before stated straight forward and concise. It however lacked a paragraph on Dead Reckoning and Plane Sailing.

Vessels running in Convoy in the North Atlantic and when abandoning ship crews were generally picked-up by the Convoy Escorts and Designated Rescue Ships. Vessels sailing in the South Atlantic, Indian and Pacific Oceans generally sailed by themselves. Hence the Sextant and its Navigation Book were useful. I sailed in the Pacific we ran by ourselves except for the invasion of Guadacanal and Okinawa. I sailed with two Skippers whose Standing Orders were to post on the Bridge and in the Chart Room at the change of each Watch the following:

- Ship's position
- Nearest Landfall, bearing and distance.
- Greenwich Mean Time
- Ship's course and speed.

A small roll of charts of the area were readily available when abandoning ship.
I am sure many of the Merchant Marine Veterans remember the Lifeboat Sextant. There are occasions on the Internet where Lifeboat Sextants are listed for sale. The current prices range in area of $150 per Sextant. It would be a souvenir from when we were young and sailing in harm's way..
Captain Warren G. Leback.

Member J. David Smith wrote in July 2005:
Thanks for all you good work during this bad year.
David

Member William S. Clarke wrote in July 2005:
I enjoy your publication, I just wish I understood the basic principles better.
Bill Clarke

Editors note: With a new editor and a different content I believe our Newsletter will be much better and with more educational and informative articles.

Member Bruce M. Lane wrote:
Dear Mr. Carraway, Thank you for the copy of "Celestial Navigation an Armchair Perspective" that was sent May 4. Enclosed is a check to cover the cost. I'm sorry it took so long to send the check
Also enclosed is a duplicate set of "Celestial Navigation" that was sent May 21. Perhaps was sent as a result of confusion with the remaining back issues of The Navigator's Newsletter. So far I have received back issues 84-86, inclusive (I suggest this only in an effort to resolve any confusion; there is no rush at all)

Thank you for your help in this matter.
Bruce M. Lane

BOOK REVIEW

By Roger H. Jones

RADAR FOR MARINERS

By David Burch. Copyright 2005

Internal Marine/McGraw Hill
P.O. Box 220
Camden, ME 04843

In his newest book, *Radar for Mariners,* David Burch continues with his long-standing tradition of offering to his readers new and compelling insights into the many facets of marine navigation. That is one of David's hallmarks: he not only selects topics that are timely and of central importance to the over-all field of marine navigation, but he also has consistently brought to his audience refreshing and very well conceptualized treatment of his subjects. *Radar for Mariners* is anything but a mere rehash of an old topic. It is an exceptionally authoritative, masterfully complete, and up-to-date statement of the "state of the art" of marine radar. Included also with this 248 page, conveniently sized, book is a CD ROM for Windows (explained in brief below).

David's stated goal is to *"teach safe, efficient use of radar for small-craft navigation in any condition of visibility."* He focuses on the environment of vessels less than 80 feet in length, but his new book should be invaluable also to those who seek to learn the use of radar aboard large ships. He approaches his subject not only with the environment of motor vessels in mind, but also the sometimes special environment of sailing vessels which may be well heeled over sailing to windward. *Experienced navigators (whether small-craft skipper or sea captain) will often single out radar as the most important electronic navigation instrument.* Burch makes and supports this bold statement, and he does so in this day and age of GPS. It is a statement with which this Reviewer and blue water sailor thoroughly agrees. Pay greater heed and far more respect to your radar, all ye slaves to GPS!

The book is divided into two main parts: Part I – Working Knowledge of Radar; and Part 2 – Beyond the Basics. There are six chapters in Part 1, and seven chapters in Part 2. The Appendix includes a Glossary, a List of Abbreviations, and References. The CD is inserted into a sleeve inside the back cover. "How Radar Works," "Operation and Training "Interpreting the Radar Screen," "Radar for Position Navigation," Radar Piloting," and "Radar for Collision Avoidance" are the topics covered in Part 1. They are covered well indeed, and in <u>understandable layman's detail</u>. They are presented in a manner that makes the lengthy and confusing "User's Manual" for my own RayMarine on-board radar (in my Nordic Tug) cringe in embarrassment. More than one call to RayMarine's technical support staff might have been avoided by me had I first read David's new book.

David Burch's professionally-rendered illustrations are equally understandable. Each of the many illustrations is addressed to a specific point, and the reader is not asked to wade into a complex and confusing, multi-purpose visual presentation. The illustrations include actual radar screens. The many intricacies of Gain, Pulse Length, Echo Trails, Precipitation Clutter, Sea Clutter and many other phenomena that are often just by-passed by radar users now emerge with a clarity that is startling. Readers, your intuitive use of your radar will become learned use of it and all of its capabilities, many of which you have no doubt overlooked to date.

Part 2's chapters deal with: "Installation, Specifications, and Performance," "Special Controls and Features," "False Echoes and Interference," "Advanced Navigation and Piloting," "Radar and the Navigation Rules," and "Looking Ahead." David's readers will learn things about the Navigation Rules in relation to radar that most small craft mariners probably do not know, and his digital age readers will be grateful for the many insights into new radar features that enable coupling with personal on-board computers, near-term future developments in GPS collision avoidance systems, and the current digital age trends that will further enhance radar usage. Again, the illustrations in Part 2 are profuse and they are presented with outstanding clarity.

The CD-ROM contains several products intended to enhance the study of radar and also to introduce the reader to the Starpath Radar Trainer simulator. Starpath Navigation is a David Burch proprietary publishing and training enterprise, and the Starpath Radar Trainer is an excellent supplement to *Radar for Mariners*. Purchasers of the book receive a free trial version of the Starpath Trainer with a trial period that begins the day the program is run for the first time, and ends after 30 days or five sessions, which ever comes first. It is worthy of note that the Starpath Radar Trainer PC simulator has been recognized throughout the marine navigation world as probably the most effective means now available for mastering the fundamentals of radar navigation and collision avoidance.

All ye salty slaves to GPS, get this book! Keep it aboard. Make it a centerpiece in your shipboard library. Open you minds to all the things that you never knew about radar. Take Burch along with you on you coastal and ocean voyages. He has been there before you, and it is his vast experience which has given him the insights and the skill to set forth on the printed page the encyclopedic knowledge of radar which is his gift to you.

Roger H. Jones, Port Orange, FL., June-05

New marine books

The following book titles are available through The Navigation Foundation. Order by Fax, telephone number 301-622-6448, the Internet to: navigatae1@comcast.net or my "Snail Mail " to: The Navigation Foundation, 12509 Whited Drive, Silver Spring, Maryland 20904. When you receive you book do not pay the invoice usually enclosed with the book. You will be billed by The Navigation Foundation, this will give you your 20% discount.

Knots, Bends and Hitches for Mariners

The Boatowner' Guide TO GMDSS and Marine Radio.

Don Casey's Complete Illustrated Sailboat Maintenance Manual.

First Shot.

The Hal Roth Seafaring Trilogy

Seaworthy.

Good Boat keeping

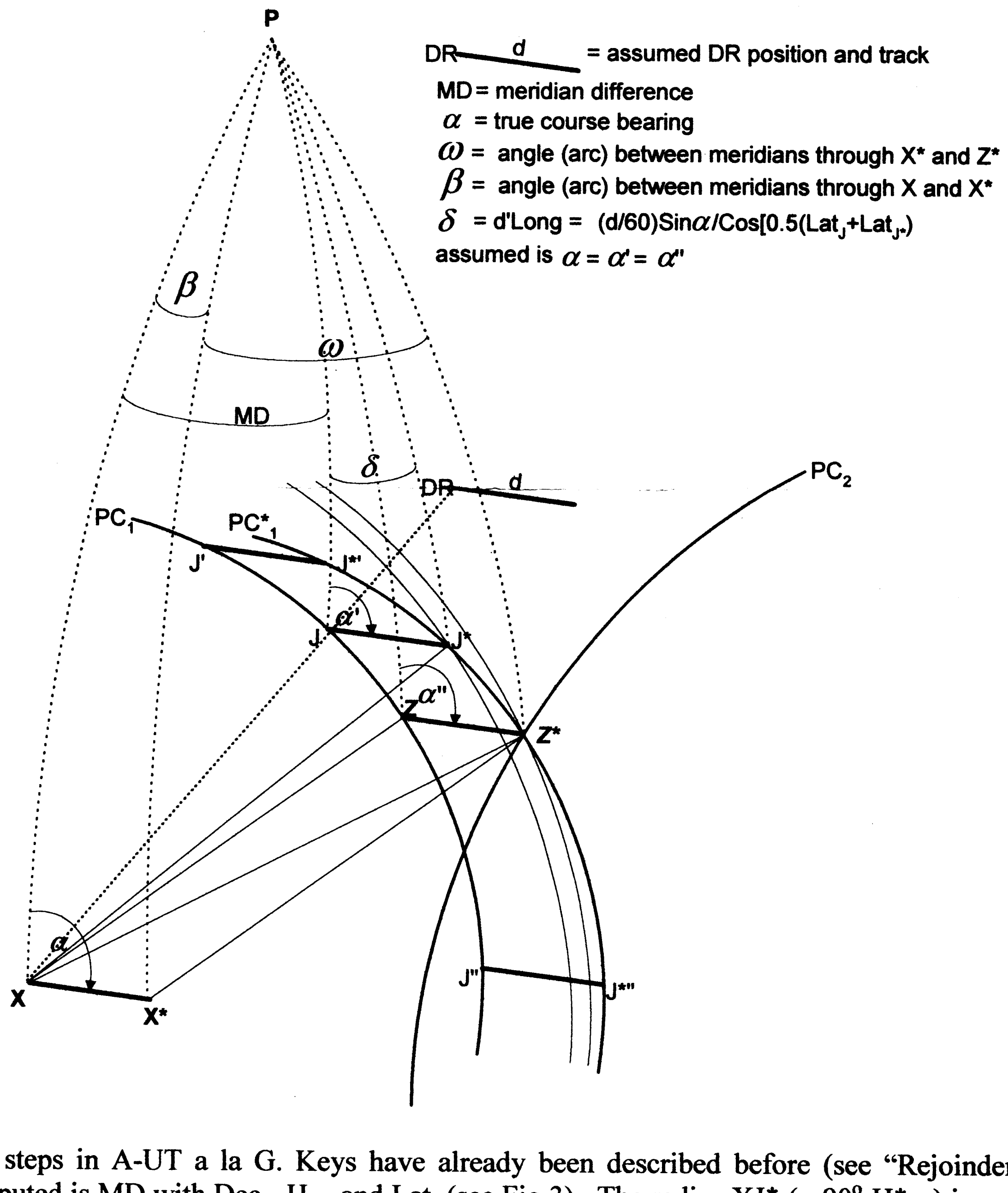
Coastal Crusing Under Power.

The Complete Guide to Metal Boats.

Fix It and Sail.

THE CONCLUSION OF MEMBER HERMAN ZEVERING'S EPILOGUE

Fig 3: A-UT and GD-UT in the sight-run-sight case



The steps in A-UT a la G. Keys have already been described before (see "Rejoinder", Section 3.7). First computed is MD with Dec_1, $H_{o,1}$ and Lat_1 (see Fig 3). The radius XJ* (= 90°-$H^*_{o,1}$) is computed next, from MD ± δ, Dec_1 and Lat_{J^*}.[i] In applying the geometric or the K-Z double sight solution method, $H^*_{o,1}$ is then substituted for $H_{o,1}$.

In the version of A-UT by G.G Bennett as exemplified in "General Conventions"[ii], it is assumed that the approximate true azimuth at J is known from observation or from a Star Finder. The distance (arc) XJ* (=90°-$H^*_{o,1}$) is then computed from the spherical triangle XJJ*[iii].

Besides the fact that a simple sketch of the constructions involved show that A-UT from the viewpoint of general validity make no sense, the possible distortions caused by A-UT have simply remained uninvestigated. The technique may be known in Surveyors' circles but is nowhere supported in the ANM.

Table 3.1 demonstrates that with the A-UT version of G. Keys, the greater the difference between XZ* and XJ* (Fig 3) the greater the discrepancy in position solution obtained with respectively GD-UT and A-UT.

Table 3.1: The effect of using A-UT (Keys' method) on position solution

	Sun-Vega (Y-H)	Sun-Sun (G. Keys)
ω	68°.1128	2°.4623
β	0°.4153	0°.5503
XZ* with GD-UT	60°.3539	27°.6758
$H^*_{o,1}$ with A-UT	30°.5918	62°.3130
XJ* with A-UT	59°.4082	27°.6870
|XZ* - XJ*|	56'.74	0'.67
	GD-UT:	
Lat_{Fix}	31°.9252	47°.4402
$Long_{Fix}$	-14°.8854	-12°.2474
	A-UT:	
$Latt_{Fix}$	32°.2329	47°.4513
$Long_{Fix}$	-15°.1235	-12°.2460
Difference in d'Lat	18'.46	0'.67
Difference in Dep	16'.86	0'.06

Notes to Table 3.1
The cases are found in "Rejoinder", Tables 8 and 10
Cosβ= [Cos(d/60)-SinDecSinDec*]/CosDecCosDec*
CosXZ* =
Cos(ω±β)CosDecCosLat_{Z*}+SinDecSinLat_{Z*}
ω+β if course bears W; ω-β if course bears E
Lat_{Z*}~$Long_{Z*}$ = Lat_{Fix}~$Long_{Fix}$

As shown in Table 3.1, large differences in position solution tend to correspond to large differences between XZ* and XJ*. In the Y-H Sun-Vega case the difference in position is some 17 miles and the difference between XZ* and XJ* (see Fig 3) is 57 miles. In the Sun-Sun case of G. Keys, the difference in position is less than a mile while the difference between XZ* and XJ* is also less than a mile.

Table 3.2: Comparison of A-UT and GD-UT results with Bennett's data

	A-UT +K-Z method G.G Bennett		A-UT+K-Z method G.Keys		GD-UT+K-Z	
	Sun		Moon			
GHA	140.3100		263.8083			
Dec	22.7333		-2.5967			
H_o	10.2850		26.3333			
Lat_{Fix}	29.7187 S		29.6349 S		29.7180 S	
$Long_{Fix}$	157.1522 E		157.1743 E		157.1523 E	
Difference (1)	negligible		d'Lat 5'.0 Dep 1'.1			
Difference (2)	d'Lat 5'.0 Dep 1'.2					
	Sun	Moon	Sun	Moon	Sun	Moon
Z	56.2672	77.0368	56.2669	77.0903	56.2585	77.0372
Zn	56.2672	282.9632	56.2669	282.9097	56.2585	282.9628
LHA	297.4622	60.9605	297.4843	60.9827	297.5037	60.9607
time diff (hr) = 0.3672; d =2'.5706; α = 243°						
	Zn	55.00	MD	60.9125	d'Lat	-1'.17

	Zn-α	-188.00	CosZ	0.5736	Dep	-2'.29
	dCos(Zn-α)	-2'.5455	Z	55.0000	Dec_{Sun}	22.7333
	$H*_{o,1}$	**10.2426**	$SinH*_{o,1}$	0.1789	$Dec*_{Sun}$	22.7139
			$H*_{o,1}$	**10.3051**	GHA_{Sun}	140.3100
			Lat_{DR1}	-31.6874	$GHA*_{Sun}$	140.3513
			$Long_{DR1}$	158.7775		
			Lat_{DR2}	-31.7068		
			$Long_{DR2}$	158.7326		
			dCosα	-1'.17		
			$d'Long_{DR}$	-2'.69		
	A-UT +K-Z method G.G Bennett		A-UT+K-Z method G.Keys		GD-UT+K-Z	
Lat_{Fix} $Long_{Fix}$	29.6888 S 157.1601 E		29.6349 S 157.1743 E		29.7180 S 157.1523 E	
Difference (1)	d'Lat 0'.4 Dep 1'.8		d'Lat 1'.1 Dep 5'.0			
Difference (2)	d'Lat 0'.7 Dep 3'.2					
	Sun	Moon	Sun	Moon	Sun	Moon
Z	56.2671	77.0559	56.2669	77.0903	56.2585	77.0372
Zn	123.7329	257.0552	123.7331	257.0903	123.7415	257.0372
LHA	297.4701	60.9684	297.4843	60.9827	297.5037	60.9607
time diff (hr) = 0.3672; d =2'.5706; α = 243°						
	Zn	125.00	MD	60.9125	d'Lat	-1'.17
	Zn-α	-118.00	CosZ	0.5736	Dep	-2'.29
	dCos(Zn-α)	-1'.2068	Z	55.0000	Dec_{Sun}	22.7333
	$H*_{o,1}$	**10.2649**	$SinH*_{o,1}$	0.1789	$Dec*_{Sun}$	22.7139
			$H*_{o,1}$	**10.3051**	GHA_{Sun}	140.3100
			Lat_{DR1}	-31.6874	$GHA*_{Sun}$	140.3513
			$Long_{DR1}$	158.7775		
			Lat_{DR2}	-31.7068		
			$Long_{DR2}$	158.7326		
			dCosα	-1'.17		
			$d'Long_{DR}$	-2'.69		

Note to Table 3.2: (1) Difference with GD-UT results; (2) Difference between A-UT (Bennett) and A-UT (Keys)

Bennett's A-UT version seemingly operates irrespective of any assumed (DR) position. To develop methods that are free from the assumed position odium is indeed the main goal of multiple sight reduction algorithms. But there is a catch here. MD, Lat_Z and $Long_Z$ (or Lat_{DR} and $Long_{DR}$) are automatically determined once Zn is somehow established[iv].

The difference in position solution obtained with the two A-UT versions compared to GD-UT is negligible in the case of Bennet's version and 5'.0 in d'Lat and 1'.1 in Dep in respect of Keys' version (see Table 3.2). The A-UT methods also do not obtain the same position solutions and in this example differ in d'Lat by 5'.0 and in Dep by 1'.2. The A-UT versions are evidently not based on an identical interpretation of the properties of the triangle PXJ* (see Fig 3).

Table 3.3 compares the results of Bennett's A-UT and GD-UT for two cases already analyzed in "Rejoinder" (Tables 9 and 6 respectively). In the ANM Moon-Sun case the discrepancy in position solution is d'Lat 1'.7, Dep 0'.5 and in the Y-H Moon-Vega case 0'.5, 0'.3. The differences are moderate and correspond to the differences between XJ* and XZ* which are also moderate (see Table 3.3).

I conclude therefore that the A-UT methods have no general validity. With due respect to their authors, it is about time they are discarded from the mariner's celestial navigation kit.

Table 3.3: Comparison of results with A-UT (Bennett's method) and GD-UT for the ANM Moon-run-Sun and Y-H Moon-Vega cases

	A-UT + K-Z method G.G. Bennett		GD-UT + K-Z		A-UT + K-Z method G.G. Bennett		GD-UT + K-Z	
	(ANM Moon-Sun case)				(Y-H Moon-Vega case)			
LatFix	50.4842 N		50.5117 N		32.2467 N		32.2387 N	
LongFix	13.8454		13.8323 W		15.1342 W		15.1280 W	
Difference	d'Lat 1'.7 Dep 0'.5				d'Lat 0'.5 Dep 0'.3			
ω	6°.3791				16°.0760			
β	0°.5417				0°.2761			
XZ* (GD-UT)	72°.7351				32°.6922			
XJ* (A-UT)	72°.7086				32°.7017			
|XZ* - XJ*|	1.6				0'.6			
	Moon	Sun	Moon	Sun	Moon	Vega	Moon	Vega
Z	174.32	106.76	173.80	106.78	148.64	56.76	148.88	56.76
Zn	174.32	106.76	173.80	106.78	148.64	56.76	148.88	56.76
LHA	354.15	295.39	353.62	295.35	343.64	272.64	343.92	272.64
	Zn≅173*				Zn≅149			
time diff hr	2.6736				1.9489			
d	32'.1				23'.9			
α	70				315			
Zn-a	103				-166			
dCos(Zn-α)	-7.2172				-22'.6920			
$H_{o,1}$	17.4117				57.6765			
$H^*_{o,1}$	17.2914				57.2983			

*Given as "true bearing" in ANM Vol II, p 192

4 Towards a reconciliation of error theories

In "Dilemmas" and "Rejoinder" were attempts to reconcile traditional error theory with LSQ error theory. Next to the question of how to allow for the run between sights, the other most complex one is how to interpret and use the triangulation implied in the multiple sight.

4.1 The 1 in 4 Probability Issue

George Huxtable also elaborated on his earlier comments in Issue 82 regarding the error issues, especially on his assertion of the 1 in 4 probability that the fix will lie outside the cocked hat (see Box 1). I will address these comments first, but my arguments will become clear in what is to follow in Sections 4.2 and 4.3.

Box 1: Huxtable's comments on error issues

1 The one-in four probability of the true position falling within a cocked hat depends only on statistical logic and rests on two assumptions:

a. The errors are entirely random ones and there are no systematic ones remaining that have not been fully allowed for, in which case, an intercept is equally likely to be "toward" as it is "away".

b. The probability of an intercept being exactly zero is small enough to neglect.

The simplest case to consider is of 3 stars, 1, 2, and 3, spaced 120 degrees apart. From a stationary vessel at a precisely known position, we determine the intercept of each star. Because of waves, there is a random disturbance of our observations, which will displace each of the three intercepts. Each one is equally likely to be displaced toward (T) as away (A). There are 8 combinations, all equally likely:

	Star 1	Star2	Star 3		Star 1	Star 2	Star 3
1	T	T	T	5	A	A	A
2	T	T	A	6	A	A	T
3	T	A	T	7	A	T	A
4	T	A	A	8	A	T	T

Of these 8 possibles, in only 1 and 5 will the true position be embraced within the triangle, which gives a 1 in 4 likelihood or a 25% chance. Three times out of four, some other combination will occur, which will mean that the true position is outside an edge or a corner. The same argument can be applied just as well to three compass bearings of landmarks. This conclusion of a 25% probability is so contrary to the expectation of most mariners that they often find it hard to accept. Many have been taught in their nav classes that it is certain that they must be somewhere within the triangle, and to be safe they should assume a position within the triangle that is nearest to a presumed danger. Nothing could be more complacent!

2 I think perhaps you can check the general truth of what I am saying by getting a least-squares program to draw an error-ellipse around a cocked hat at 25% probability level, rather than the usual 95%. I predict that the resulting ellipse will cover very much the same area as does the triangle itself, because in

both cases the probability of the true position lying within is just 25%.

I believe the argument embraces several aspects. The first aspect is the (random) chance of obtaining a particular combination of T and A sights from an assumed position. With three sights this is 1 in 8 or 12½%. The distribution of the sights in azimuth and the fix will remain identical if the azimuth of each sight would be reversed (rotated) 180°, which would also reverse the sign of the corresponding intercept. As we will see later such a rotation would also reverse the sign of any permissible systematic error. Hence, a combination of sights with the same characteristics (distribution of sights; location of fix) will have a 25% chance. With three sights there are therefore four pairs in which each combination has identical characteristics: ATT+TAA; TTT+AAA; TAT+ATA; AAT+TTA. Assuming that the cocked hat triangle formed is in general of an irregular shape, the desirable pair is the one where the distribution in azimuth > 180°, because the random error margin (confidence ellipse) will tend to be smallest, while any allowance for systematic error would reduce the error margin without affecting the fix. Such an allowance for systematic error, if it could be inferred or estimated (see below), could in fact significantly reduce the random error margin.

Important is therefore sight planning, with the object of obtaining three evenly distributed sights so that all three azimuth bearings (Zn) are enclosed by an angle > 180°. Even though the opportunities may not present themselves to achieve this, sight planning would greatly increase the chance of getting the right combination[v].

The second aspect is the interpretation of the confidence interval or error margin of a fix obtainable from a given combination of sights. A first point to Huxtable's comments is that the 1 in 4 probability simply cannot be argued with the example of the stationary vessel and the assumptions a and b[vi]. However, the quintessence of his argument is I believe about the confidence interval or error margin of a fix.

At face value, Huxtable's interpretation of the error margin seems to be in line with LSQ error theory. For instance, if LSQ would be applied to the Yallop-Hohenkerk Sun-Moon-Vega case (see "Rejoinder", Attachm.-Fig 1) at the 25% probability level, indeed the confidence ellipse would approximately envelop the cocked hat area[vii], as predicted by Huxtable. The conclusion that there is therefore a 75% chance that the fix will lie outside the cocked hat is nevertheless incorrect, as already indicated in "Rejoinder". I believe that this conclusion is influenced by the error theory for terrestrial (compass) bearings on which I will say some more below.

The ellipse can indeed be drawn at a fraction or multiple (k) of the estimated standard deviation σ but I maintain that its interpretation is similar to the one for say a 'normal' or Gaussian error distribution. In this distribution, 68% of the observations will lie within the range $\pm\sigma$ from the mean, and 95% within $\pm 2\sigma$. More extreme values will lie beyond $\pm 2\sigma$. If you had to rely on an extreme value, you would take, say, mean $\pm 2\sigma$. There is only a 2½% chance that a value still larger than $+2\sigma$ or smaller than -2σ will be encountered. A similar interpretation applies to the confidence ellipses that can be drawn at various k-values. The majority of the observed positions would fall within the cocked hat, with the Fix as central tendency. However, to be on the safe side in the presence of a danger, you would have to consider that more extreme deviations might occur although their probability is very marginal. In other words, the error zone is basically a worst-case scenario under special circumstances, when the navigator needs to put himself at the position of "greatest disadvantage".

There is finally the aspect of the relevance of the fix itself. The fix remains the most relevant orientation available to the navigator. Celestial navigation is about obtaining fixes.

Is there an analogy with terrestrial compass bearings? The terrestrial case is not really applicable to celestial sights[viii]. To start with mere random error first (refer to Fig 4), there is only a 1 in 4 chance that the fix will lie within the plotted cocked hat and a 75% chance that the true fix will physically lie outside the cocked hat.

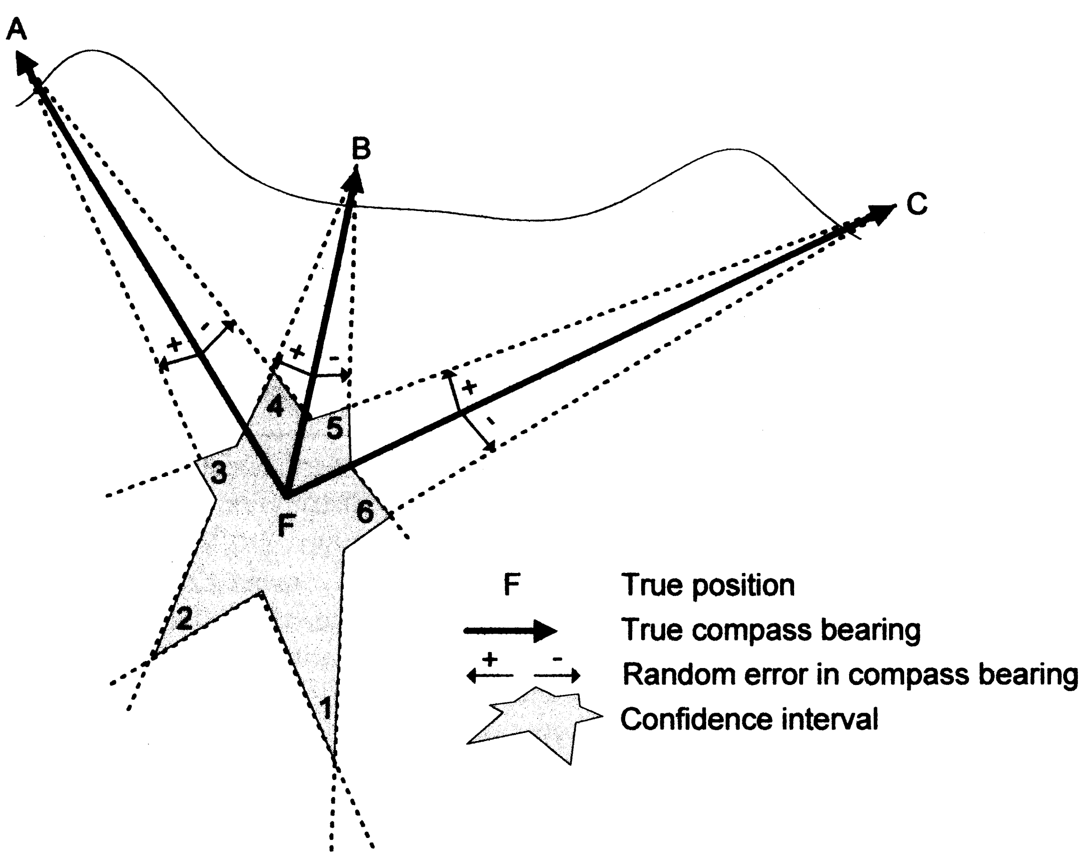
There is simply no comparison with the celestial case[ix]. Also, in the celestial case an overall error margin can be calculated (with LSQ) without assigning any values to either random or systematic error. In the terrestrial case, without assigning such values no conclusions can be drawn at all about the relative (in)accuracy of the fix. In the terrestrial case, if there is systematic error only, the true position can be found, provided the systematic error is given a definite value[x].

4.2 A possible reconciliation of error theories

When talking about cocked hats and errors the picture should be clear. If there is no error, the PLs do not form a cocked hat but intersect in one point! Imagine a DR position with 'true' intercepts so that all PLs intersect in one point. This point is the fix. Each intercept is then entirely a correction for the (wrong) DR position. In other words, intercepts should not be confused for observation errors! The errors only increase or decrease the 'true' intercepts and it is these deviations that form the cocked hat. All error theory is based on the idea that if there were no error at all, the position lines must intersect in one point.

The error margin question begins with the PL of one sight, followed by the 'error parallelogram' with two sights (for which LSQ cannot determine the error margin)[xi] and the cocked hat conundrum with more sights: "the navigator would take for his position that point which would place him at the greatest disadvantage" [xii].

Fig 4: Confidence interval for three terrestrial compass bearings



In simple terms, observation error theory in celestial navigation is based on the (correct) idea that random error as well as systematic error will displace the PL (or position circle segment) parallel to itself[xiii]. Systematic error means an error that is equal in magnitude and sign and one that will affect all sights equally. Random error causes a variation in the observations that can be expressed in terms of standard deviation.

A valid criticism of the LSQ approach is to my mind that systematic error, if present, forms a non-random error component, i.e random error is residual when systematic error is subtracted from total error. It means that if systematic error is present but not allowed for, the confidence ellipse and thus the error margin would be exaggerated. Also, the actual locus (centre) and/or size of the LSQ confidence ellipse may differ from the ellipse projected with this method when systematic error is not allowed for. The basis for this argument is that systematic error in statistical significance theory translates as 'bias'. The authors of the LSQ method did not consider this aspect and all error is treated as random. Yallop-Hohenkerk do recognize the "effect of systematic error on the final calculated position" but think that it is minimized when the Zn are equally spaced and pay no further attention to it.

With the error theory in the ANM on the other hand, errors may be random[xiv] or systematic. You can only allow for systematic error and only if you know it or can give a definite value to it. The drawback of this approach is that even if the cocked hat polygon could or should be corrected (adjusted) for systematic error the approach provides no means of dealing with any residual random error. This is perhaps one reason why the ANM does not pursue its bisector theory in the case of more than three sights: in an irregular n-polygon ($n > 3$) the bisectors would not intersect in one point (see Fig 6b-top).

A general misunderstanding regarding the bisector approach found in the ANM needs to be cleared up. The bisector construction is in fact merely a by-product of the method of allowing for unidirectional systematic error (e_s), whereby each PL is moved the same distance in the direction (+ or -) of the error. In a 'consistent' cocked hat triangle suspected of systematic error, e_s is allowed for by moving each PL the same distance parallel to itself in the appropriate direction. With all Zn pointing 'in', e_s must have a positive value, if pointing 'out', a negative one (see Box 2).

Box 2: <u>Determining appropriate direction by the sign of the intercept and of e_s</u>

p = + (toward)
p = - (away)

e_s = +
p would increase - direction Zn, away from DR position
p would decrease - direction Zn, towards DR position

e_s = -
p would decrease - direction opposite to Zn, towards the DR position
p would increase - direction opposite to Zn, away from the DR position

In a cocked hat triangle with all Zn 'in' (case 1), e_s if it exists can only be positive; a negative e_s would make all PL displacements outward unbounded or indeterminate. In this case random error is maximum. In a cocked hat triangle with all Zn 'out' (case 2), e_s can only be negative; a positive e_s would make all PL displacements outward unbounded or indeterminate. In this case random error is also maximum.

This may be visualized with triangle ABC in Fig 6a, where the Zn directions lie along DR-J_1, DR-J_2, and DR-J_3 respectively. If T_{J1} and A_{J1} etc. indicate a Zn respectively 'toward' and 'away', case 1 is satisfied with $A_{J3}T_{J2}T_{J1}$. The respective p's are respectively -, +, +; $+e_s$ would move all PLs inward. If e_s is maximum, the fix happens to be at the intersection of the bisectors and random error is zero, but residual random error remains if it is not maximum. To find the fix, run LSQ for the residual random error. All intercepts extending from the fix will become negative (after the 2nd iteration). $-e_s$ would move all PLs outward but e_s would be indeterminate. So a case can be made only for $+e_s$.

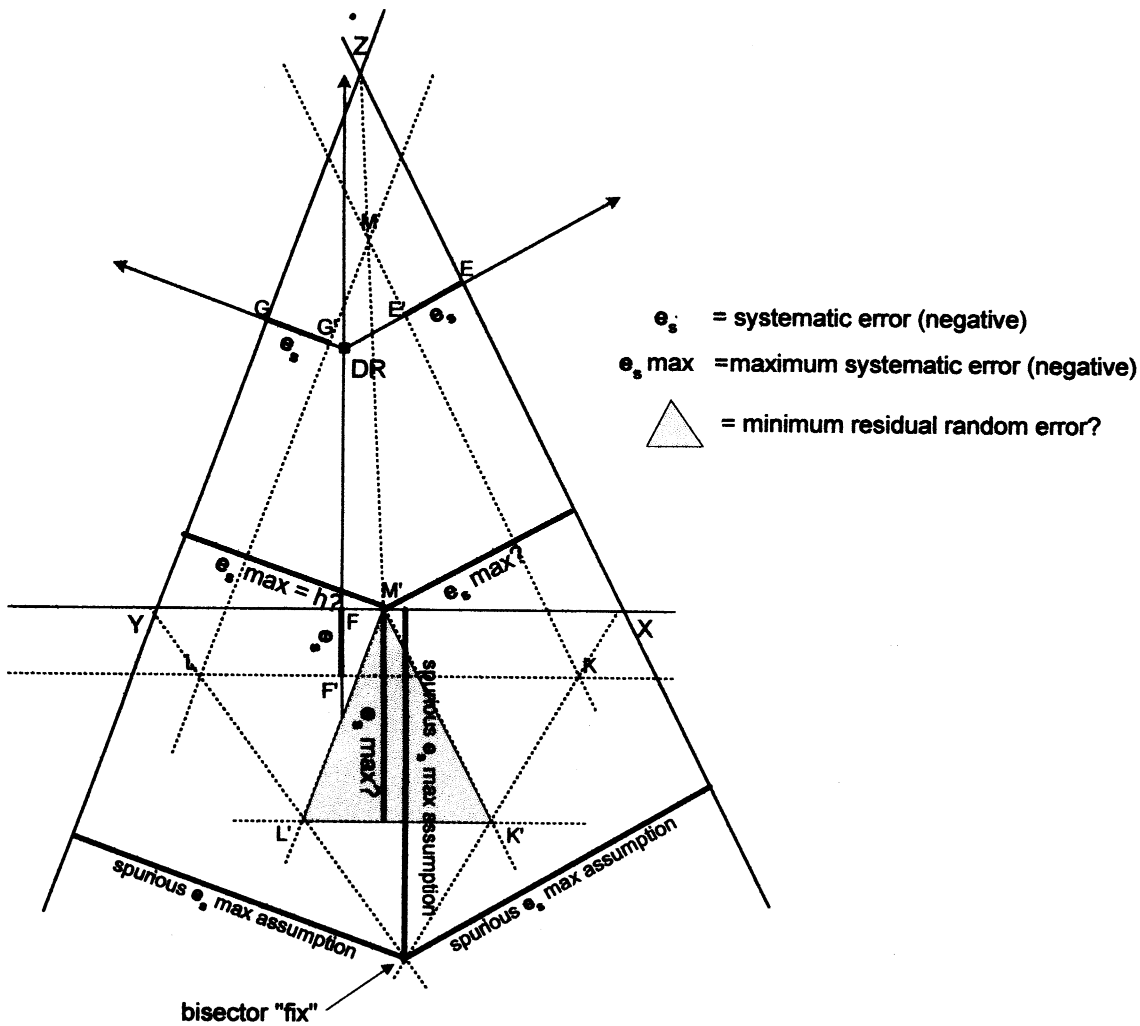
Case 2 is satisfied with $T_{J3}A_{J2}A_{J1}$. The respective p's are respectively +, -, -; $-e_s$ would move all PLs inward; $+e_s$ would move all PLs outward but e_s would be indeterminate, so a case can be made only for $-e_s$.

The bisector intersection determines a fix inside the consistent cocked hat because this happens to be the point of intersection of the PLs, shifted to reflect maximum systematic error (e_s max).

I believe, with Fig 92 (Vol III, p 190) the ANM lost sight of the underlying e_s max principle. This figure depicts an inconsistent cocked hat, two Zn 'out' and one 'in', reproduced in Fig 5[xv]. What has happened here is that the bisector construction applicable in the case of the consistent cocked hat triangle is simply extended to the inconsistent cocked hat triangle. To put the (bisector) fix where it is (see Fig 5) implies an e_s max that is highly implausible, if not spurious. No argument is proffered why a correction of this magnitude should be made.

Unfortunately, the bisector construction became established as a method of finding the fix and navigators began to plot lines half way between position lines to find a (approximate) point of intersection, without realizing the principle underlying the error theory[xvi].

Fig 5: Systematic and random error and the 'inconsistent' cocked hat (the case in the ANM, Vol III, p 190, Fig 92)



If the systematic error theory is pursued logically, the assumption that e_s = -EE' (see Fig 5) reduces residual random error, which is now represented by the triangle KLM.

Fig 6a: Systematic and random error with three consistent sights

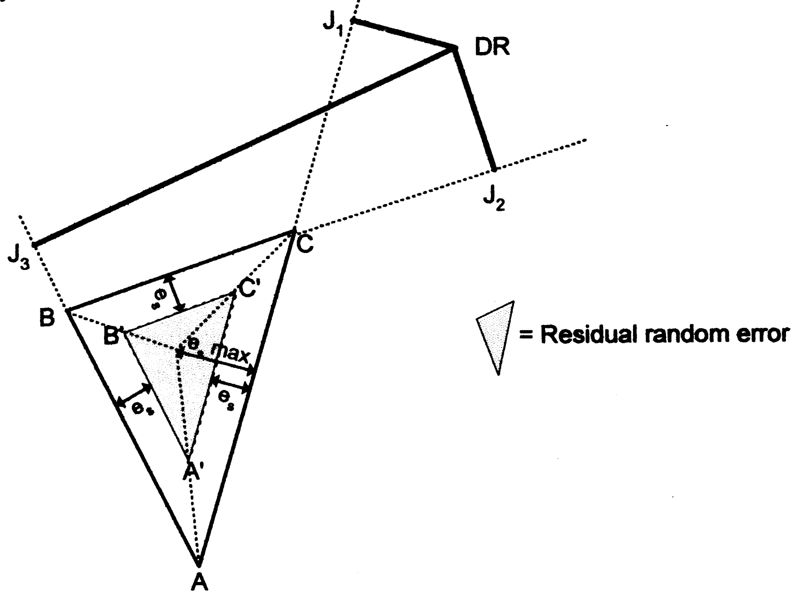
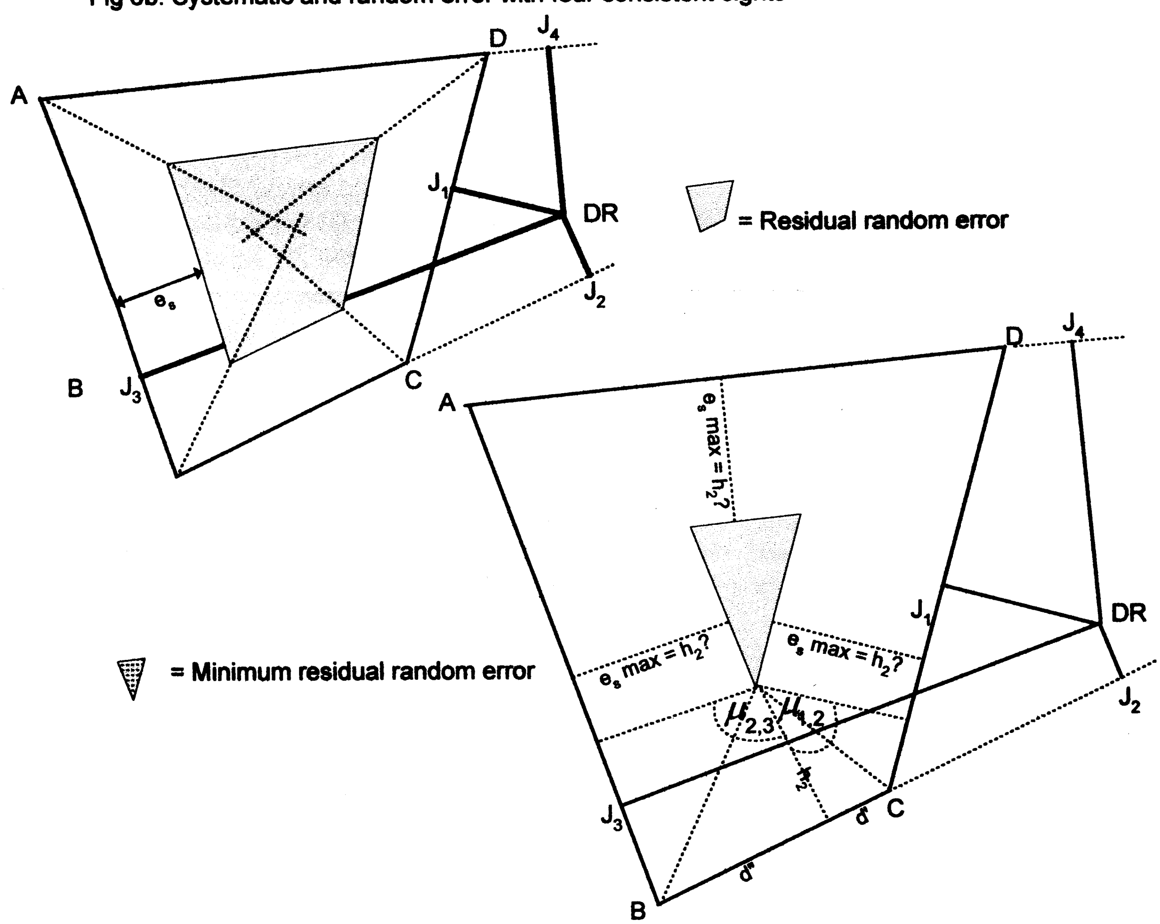


Fig 6b: Systematic and random error with four consistent sights



This triangle is simply the result of the negative e_s allowed for. The PL through X and Y is displaced outward because the intercept DR-F is negative and e_s is negative (see Box 2). To find the fix and the error margin, run LSQ for the triangle KLM! The error e_s cannot be positive because it would be indeterminate.

Is there a maximum permissible e_s? In the case of the consistent n-polygon (n=3; see Fig 6a) it appears that systematic error, if present, is expected to have certain internal limitations, i.e PLs cannot be expected to shift so as to “cross over” and move indeterminately in opposing directions. Another consideration is certainly that LSQ tends to determine a fix inside the cocked hat polygon, even if it is inconsistent, and it is therefore doubtful whether e_s could be much greater than the largest intercept extending from the fix as found with LSQ[xvii].

A possible approach would be (see Fig 5) to take e_s max = -h as limiting value. If e_s would be < -h (i.e > h in absolute terms) the systematic error would become indeterminate and therefore meaningless. Only e_s max can be removed. The resulting residual random error is represented by the triangle M'K'L'. To find the fix and the error margin, run LSQ for the triangle K'L'M'. The fix would lie in the triangle K'L' M'.

The reconciliation of the two approaches, the LSQ approach to random error and the ANM one to systematic error could therefore in general lie in first applying a correction for systematic error, followed by applying LSQ to the residual random error. As the size of the systematic error (e_s) is generally unknown, e_s max may be substituted as discussed in connection with Fig 5. I will explore some of the ramifications of such a compromise theory shortly. A main consideration is not whether various assumptions about possible error are right but how to give the navigator a number of options when considering a vessel’s position. What if the error margin is exaggerated due to a systematic error factor? It is not necessarily advantageous or possible under all circumstances to follow a worst-case scenario. The algorithms needed to vary assumptions can all be programmed relatively easily.

To conclude this subsection it is necessary to elucidate a few other concepts first. One is the terms 'consistent sights' and 'inconsistent sights' in the case of three or more sights. It does not mean that all three sights must be either ‘towards' (T) or ‘away' (A), which is only a reference to the sign of the intercepts[xviii]. But indeed, as noted by Huxtable in the case of three sights, if the sights are taken at random only two out of eight possible combinations[xix] of intercept signs will result in a 'consistent' cocked hat. As indicated already, with three sights this is achieved only when the Zn are equally distributed around the compass, i.e all Zn would be enclosed by a 'total angle' >180^o. In all of the six remaining combinations, the 'total angle' of the three Zn would be < 180^o.

For three sights, if the desired combination is achieved the resulting cocked hat will be consistent. The situation could look as in Fig 6a. In all other cases it will look like in Fig 5. The application of LSQ to the original cocked hat triangle may exaggerate the confidence ellipse in all cases if any systematic error is present. The 'consistent' case for four sights is shown in Fig 6b.

The chance of obtaining a consistent cocked hat with four sights appears to be only 2 out of 16 or 12½%[xx]. However, there is a chance with four sights that 8 out of 16 combinations are 'semi consistent', i.e three of the four sights all point 'in' or 'out'. Half of these may form useful 'consistent' cocked hat triangles. There is generally a better than 1 in 3 chance with four sights of obtaining either a consistent cocked hat quadrangle or triangle[xxi] if sights are not planned. If sights are planned, however, the chance is likely to be greater. With three sights the consistency of the resulting configuration can be predicted from the (approximate) azimuths of the sights. With four or more sights, however, the consistency is no longer predictable from the azimuths, i.e the 'total azimuth angle' is no longer indicative of the resulting configuration of intersecting PLs. A plot is needed, even if just a rough one, by computing and plotting the intercepts of the sights to find the location of each PL.

4.3 Allowing for maximum systematic error

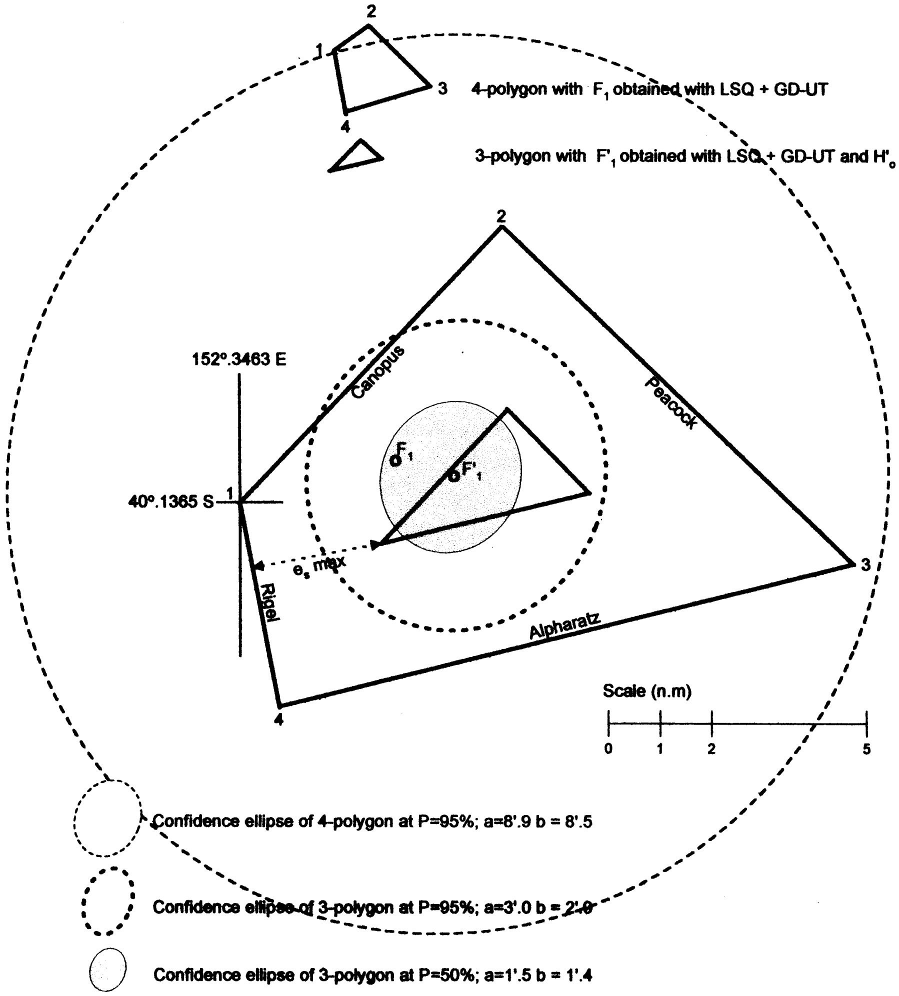
In $p = H_o - H_c$ it is clear that a deck watch error affects both H_o (parallax, semi-diameter) and H_c (Dec, GHA). The time factor also influences the calculation of azimuth. If the time factor is ignored[xxii], systematic error only affects H_o; e_s is either positive (+) or negative (-), so that $p = H_o \pm e_s - H_c$. How do we allow for systematic error and find the fix and confidence interval? This is obviously done by adjusting the H_o of each sight for the error. LSQ is run with the same GHA and Dec, run on with GD-UT, but with an adjusted H_o for each sight.

Table 4.1: Worked example of systematic error correction: e_s max removed from four consistent sights

		1 Rigel		2 Canopus		3 Peacock		4 Alpharatz	
	Sign of p ($IM_{CH/E}$)	pos.		neg.		neg.		pos.	
	Vertex		1,2		2,3		3,4		4,1
1	Lat		-40.1365		-40.0444		-40.157		-40.2030
2	Zn	79.67		132.54		224.88		346.16	
3	μ		$\mu_{1,2}$=52.87		$\mu_{2,3}$=92.34		$\mu_{3,4}$= 121.48		$\mu_{4,1}$=93.51
4	Tan½μ_x + Tan½μ_y	Tan½$\mu_{4,1}$+Tan½$\mu_{1,2}$ =1.5604		Tan½$\mu_{1,2}$+Tan½$\mu_{2,3}$ =1.5389		Tan½$\mu_{2,3}$+Tan½$\mu_{3,4}$ =2.8266		Tan½$\mu_{3,4}$+Tan½$\mu_{4,1}$ =2.8481	
5	d'Lat	$Lat_{1,2}$-$Lat_{4,1}$ = 0.0665		$Lat_{2,3}$-$Lat_{1,2}$ = 0.0921		$Lat_{3,4}$-$Lat_{2,3}$ = -0.1126		$Lat_{4,1}$-$Lat_{3,4}$ =-0.0460	
6	Cos(Zn-90)	0.9838		0.7368		-0.7056		-0.2392	
7	d = (5): 6)	d_1=0.0676		d_2=0.1250		d_3=0.1596		d_4=0.1923	
8	h =(7):(4)	h_1=2'.60		h_2=4'.87		h_3= 3'.39		h_4=4'.05	
9	H'_o (=H_o +h_i/60)	24.4266		35.3733		43.4183		19.5100	
10	Dec*	-8.1490		-52.6148		-56.7745		28.9617	
11	GHA*	142.7902		125.8399		276.7998		222.5233	
12	p (fix)	-1'.45		-0'.02		-1'.70		-0'.99	
13	Zn	79.65		132.53		224.88		346.14	
		Vertex coordinates (found with LSQ+GD-UT and H'_o applied to following pairs							
14			Rigel-Canopus -40.1499 152.4071		Canopus-Peacock -40.1069 152.4587		Peacock-Alpharatz -40.1336 152.4938		Alpharatz-Rigel -40.1499 152.4071
15	Fix (LSQ+GD-UT)		-40.1280 152.4339						
	Confidence ellipse								
16	σ		1'.7249						
17	θ		19°.6						
				P= 95% (k=2.4).	P=50% (k=1.2)	P=45% (k =1.09)	P=25% (k=0.76)		
18			a	2'.9919	1'.4959	1'.3588	0'.9474		
19			b	2'.8667	1'.4334	1'.3020	0'.9078		

To indicate the manner in which e_s max can be allowed for, we take the case of 'consistent' sights, assuming that these can be obtained through sight planning. But the method is not restricted to the consistent sights case only. Maximum e_s is equal to the smallest perpendicular (h) dropped onto the relevant PL from an intersection of two adjacent bisectors. Allowing for e_s max with three sights resolves in a true fix at the intersection of the bisectors. All random error is eliminated.

Fig 7: Removing e_s max from 4-polygon - The case of Rigel-Canopus-Peacock-Alpharatz
(see Attachm-Fig 3 in "Rejoinder", Addendum Issue 83)



To demonstrate the procedure with more than three sights, the sides of the polygon are numbered clockwise, where PL_1 and Zn_1 are the position line and Zn of sight 1 respectively, and so on.

Sight 1	Sight 2	Sight 3	Sight 4
Zn_1	Zn_2	Zn_3	Zn_4
$PL_1 = d_1$	$PL_2 = d_2$	$PL_3 = d_3$	$PL_4 = d_4$
h_1	h_2	h_3	h_4

Vertex$_{1,2}$	Vertex$_{2,3}$	Vertex$_{3,4}$	Vertex$_{4,1}$
$Lat_{1,2}$	$Lat_{2,3}$	$Lat_{3,4}$	$Lat_{4,2}$
$\mu_{1,2} = \lvert Zn_1 - Zn_2\rvert$	$\mu_{2,3} = \lvert Zn_2 - Zn_3\rvert$	$\mu_{3,4} = \lvert Zn_3 - Zn_4\rvert$	$\mu_{4,1} = \lvert Zn_4 - Zn_1\rvert$

The distances (d) are given by the vertex latitudes and the Zn concerned, e.g $d_3 = (Lat_{3,4} - Lat_{2,3})/\mathrm{Cos}(Zn_3 \pm 90^o)$. Using plane trigonometry, the perpendiculars for a 4-polygon are then given by[xxiii]:

$$h_1 = d_1/(\mathrm{Tan}\tfrac{1}{2}\,\mu_{4,1} + \mathrm{Tan}\tfrac{1}{2}\mu_{1,2})$$
$$h_2 = d_2/(\mathrm{Tan}\tfrac{1}{2}\,\mu_{1,2} + \mathrm{Tan}\tfrac{1}{2}\mu_{2,3})$$
$$h_3 = d_3/(\mathrm{Tan}\tfrac{1}{2}\,\mu_{2,3} + \mathrm{Tan}\tfrac{1}{2}\mu_{3,4})$$
$$h_4 = d_4/(\mathrm{Tan}\tfrac{1}{2}\,\mu_{3,4} + \mathrm{Tan}\tfrac{1}{2}\mu_{4,1})$$

The smallest **h** found defines e_s max. In Fig 6b (bottom), h_2 happens to be the smallest and the residual random error is reduced to the gray triangle. To find the fix, LSQ is applied by using the updated sights with their corrected H_o. A practical application of this approach is shown with the Rigel-Canopus-Peacock-Alpaharatz case (see "Rejoinder", Attachm.-Fig 3), using the GD-UT+K-Z results. The data and results are in Table 4.1.

As is seen from the results plotted in Fig 7, without allowing for possible systematic error the confidence ellipse at 95% probability covers an area of 8'.9 by 8'.5 around fix F_1. If e_s max (= 2'.6; h_1 in Table 4.1) is removed, the inner cocked hat triangle is obtained, reflecting residual random error. The confidence ellipse around its fix F'_1 is 3'.0 by 2'.9. At P = 50%, the size of its confidence ellipse at 1'.5 by 1'.4 converges on the cocked hat area. At P = 25%, the confidence interval's dimension centred on F'_1 (not shown in Fig 7; see Table 4.1) is smaller than the triangle's.

Annex-Table 1: Detail of the Due-North Model (see Fig 2 and Table 1.1, in 1st part of Epilogue)

		$90<Z<180$ NW quadrant	$90>Z>0$ SW quadrant			$90<Z<180$ NW quadrant	$90>Z>0$ SW quadrant
		GHA = 0° Dec = 0° H_o=60° Z= 100° d=30' α=360°	GHA = 0° Dec = 0° H_o=60° Z= 40° d=30' α=360°			GHA = 0° Dec = 0° H_o=60° Z= 100° d=30' α=360°	GHA = 0° Dec = 0° H_o=60° Z= 40° d=30' α=360°
1	$\cos Z = (\cos 90 - \sin H_o \sin Lat_Z)/\cos H_o \cos Lat_Z$; $\cos Z = -(\sin H_o \sin Lat_Z)/\cos H_o \cos Lat_Z = -\tan H_o \tan Lat_Z$; $\tan Lat_Z = -\cos Z/\tan H_o$			2	$\cos MD = (\sin H_o - \sin Dec \sin Lat_Z)/\cos Dec \cos Lat_Z$		
	Lat_Z	**5.7251**	**-23.8587**		MD	**29.4987**	**18.7472**
3	**$Long_Z$**	**-29.4987**	**-18.7472**				
5	$\cos Lat_V/\sin\psi = \cos Dec/\sin 90$; $\cos Lat_V = \sin\psi \cos Dec$			4	$\cos\psi = (\sin Lat_Z - \sin H_o \cos(90-Dec))/\cos H_o \sin(90-Dec)$; $\cos\psi = \sin Lat_Z/\cos H_o$ & $-\sin Lat_Z \cos H_o$		
	Lat_V	**11.5084**	**53.9948**		ψ	**78.4916**	**143.9948**
7	$\cos\omega_V = (\cos XV - \sin Lat_V \sin Dec)/\cos Lat_V \cos Dec$; $\cos XV = \cos\omega_V \cos Lat_V \cos Dec + \sin Lat_V \sin Dec$			6	$\sin Lat_V \cos\omega_V = \cos Lat_V \tan Dec$ (4-part formula); $\cos\omega_V = \tan Dec/\tan Lat_V$		
	XV	**90.0000**	**90.0000**		ω_V	**90.0000**	**90.0000**
				8	**$Long_V$**	**-90.0000**	**-90.0000**
9	$\sin Dec^* = \sin(d/60)$ (Cosine Formula) $\sin Dec^* = Dec + (d/60)\cos\alpha$ (rhumbline)			10	$\cos MD = (\sin H_o - \sin Dec^* \sin Lat_{Z^*})/(\cos Dec^* \cos Lat_{Z^*})$; $\cos MD \cos Dec^* \cos Lat_{Z^*} + \sin Dec^* \sin Lat_{Z^*} - \sin H_o = 0$ (Lat-finding polynomial)		
	Dec*	**0.5000**	**0.5000**		**$\sin Lat_{Z^*}$**	**0.1098**	**-0.3960**
11	$\cos Z^* = (\sin Dec^* - \sin H_o \sin Lat_{Z^*}/\cos H_o \cos Lat_{Z^*}$				**Lat_{Z^*}**	**6.3065**	**-23.3312**
	Z^*	**100.0124**	**39.9982**	12	$\cos\theta = (\sin Lat_{Z^*} - \sin H_o \sin Dec^*)/\cos H_o \cos Dec^*$		
13	$\cos Lat_{V^*}/\sin\theta = \cos Dec^*/\sin 90$; $\cos Lat_{V^*} = \sin\theta \cos Dec^*$				θ	**78.1946**	**143.8269**
	Lat_{V^*}	**11.8158**	**53.8285**	14	$\cos\theta = (\sin Lat_{V^*} - \sin Dec^* \cos X^*V^*)/\cos Dec^* \sin X^*V^*$; $\pm \cos\theta \cos Dec^* \sin X^*V^* + \sin Dec^* \cos X^*V^* - \sin Lat_{V^*} = 0$		
14*	$\cos X^*V^* \cos 90 = 0 = \sin X^*V^*/\tan(90-Lat_{V^*}) - \sin 90/\tan\theta$; $\sin X^*V^* \tan Lat_{V^*} \pm 1/\tan\theta = 0$; $\sin X^*V^* = \pm 1/\tan\theta \tan Lat_{V^*}$ (4-part formula)				$\sin X^*V^*$	0.9991	0.9999
	X*V*	**87.5575**	**89.3806**		**X*V***	**87.5575**	**89.3806**

No.	Quantity		
15	**Q*X*** = XV-X*V* = 90-X*V*	**2.4425**	**0.6194**
17	**Long$_{V*}$**	**-87.6092**	**-89.6344**
	Diff Long$_V$ and Long$_{V*}$ = XQ*	2.3908	0.3656
19	Cos(θ & 180-θ) = (CosXQ*-CosDec*CosQ*X*)/SinDec*SinQ*X*; CosXQ* = Cos(θ & 180-θ)SinDec*SinQ*X*+CosDec*CosQ*X*		
	XQ*	**2.3908**	**0.3656**
21	Cos(180-*Z* & *Z*) = (CosSX-SinH$_o$CosLat$_Z$)/CosH$_o$SinLat$_Z$; CosSX = Cos(180-*Z* &*Z*)CosH$_o$SinLat$_Z$+SinH$_o$CosLat$_Z$		
	SX (=MD)	**29.4987**	**18.7472**
22	Cos(d/60)Cos(180-ψ) = Sin(d/60)/TanXT - Sin(180-ψ)/Tan(θ & 180-θ); TanXT = Sin(d/60)/[SinψTanθ - Cos(d/60)Cosψ]		
	XT	**58.7124**	**60.5114**
24	TanLat$_T$=TanεSinR'X = Tanε*Sin(R'X±XQ*); TanεSinR'X =Tanε*(SinR'XCosXQ*±CosR'XSinXQ*)		
	R'X	**58.1935**	**46.1101**
25	Cos(d/60)Cosθ = Sin(d/60)/TanX*T-Sinθ)/Tan(180-ψ; Cos(d/60)Cosθ = Sin(d/60)/TanX*T+ Sinθ/Tanψ; TanX*T = Sin(d/60)/[Cos(d/60)Cosθ-Sinθ /Tanψ]		
	X*T	**58.8134**	**60.1073**
	Q*T = X*T± Q*X*	56.3709	60.7267
	R'Q* = R'X±XQ*	55.8027	46.4756

No.	Quantity		
16	Cosω$_{V*}$ = (CosX*V*-SinLat$_{V*}$SinDec*)/CosLat$_{V*}$CosDec*		
	ω$_{V*}$	**87.6092**	**89.6344**
18	CosDec*Cos(θ & 180-θ) = SinDec*/TanQ*X*-Sinθ/Tan90; TanQ*X* = ±TanDec*/Cosθ		
	Q*X* (Q*X*+X*V* = 90)	**2.4425**	**0.6194**
20	Cosε* = (CosDec* - Cos(XQ* or RQ*)CosQ*X*)/Sin(XQ* or RQ*)SinQ*X*		
	ε* (=LatV*)	**11.8158**	**53.8285**
22	CosMDCos90=0=SinMD/TanLat$_Z$-Sin90/Tanε; Tanε = TanLat$_Z$/SinMD		
	ε (= LatV)	**11.5084**	**53.9948**
23	SinLatT = SinXTSinε		
	Lat$_T$	**9.8167**	**44.7621**
23*	Cosε = (CosLat$_T$ - CosR'XCosXT)/SinR'XSinXT; CosLat$_T$ = CosεSinR'XSinXT+CosR'QcosXT		
	Lat$_T$	**9.8167**	**44.7621**
	Long$_T$ = R'X	**58.1935**	**46.1101**
23**	Cosε* = (CosLat$_T$ - CosR'Q*CosQ*T)/SinR'Q*SinQ*T; CosLat$_T$ = Cosε*SinR'Q*SinQ*T+CosR'Q*CosQ*T		
	Lat$_T$	**9.8167**	**44.7621**

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i It is immaterial whether the calculations use Lat$_{DR}$ ~ Long$_{DR}$ or Lat$_{EP}$ ~ Long$_{EP}$, where Lat$_{EP}$ = Lat$_{DR}$ + p$_1$CosZn$_1$ and Long$_{EP}$ = Long$_{DR}$ +p$_1$SinZn$_1$/Cos[½(Lat$_{DR}$+Lat$_{EP}$)].

ii "General conventions and solutions – their use in celestial navigation", Jnl of the Inst. of Navigation, Vol 26-4, 1979.

iii Bennett uses H*$_{o,1}$ = H$_{o,1}$ + dCosΔA, where ΔA = Zn-α, called "a standard method employed in sight reduction" (ibid. p 279). The result is in fact the same as H*$_{o,1}$ computed from triangle XZZ*: CosΔA = (Cos XZ*-Cos(d/60)CosZX)/Sin(d/60)SinZX = (Sin H*$_{o,1}$ - Cos(d/60)Sin H$_{o,1}$)/Sin(d/60)Cos H$_{o,1}$, so that Sin H*$_{o,1}$ = CosΔASin(d/60)CosH$_{o,1}$ + Cos(d/60)Sin H$_{o,1}$. Needless to say that in both computations the displacement at Z is assumed to be the same in magnitude and direction as the displacement at X, or if not the same than at least sufficiently close in magnitude and direction.

iv Apply the Sine rule in triangle PXZ (see Fig 3): $SinMD = CosH_oSinZn/CosDec$; Lat_Z (or Lat_{DR}) follows from the Lat-finding polynomial (see "Rejoinder", Techn. App. 1) applied to triangle PXZ: $CosMD = (SinH_o - SinDecSinLat_Z)/CosDecCosLat_Z$ from which follows $CosMDCosDecCosLat_Z + SinDecSinLat_ZSinH_o = 0$ or $aCosLat_Z + bSinLat_Z - d = 0$, which is a 2nd degree polynomial in $CosLat_Z$

v Sight planning is of course an integral part of both coastal and celestial navigation. For example, compare the desirable conditions for minimizing error with station-pointer fixes obtained through horizontal sextant angles (see ANM, Vol III, p173-176).

vi In Huxtable's thought experiment of the three sights, H_c would be accurately known at any point in time, so that for a given sight at time t we have $p'_t = H_{o,t} - H_{c,t} = \pm e$; p'_t is a pseudo-intercept. When the vessel is on the top of average 2 M waves, H_o for all sights reads 0°.04 too high, $p'_t = e = +$ 2'.4 and when in the through 0°.04 too low, $p'_t = e = -$ 2'.4 (Dip must be subtracted from sextant altitude and is equal to $0°.0293h^{½}$; h in meters). There is an equal chance that e is + or -. The actual peaks and troughs form a random error distribution around the 2M mark, so that less frequently values for e exceeding ± 2'.4 will be recorded due to irregular waves. If all these values are plotted for each sight and the pseudo-intercepts drawn most of them will form a polygon with a radius e around the known position but more extreme values will tend to lie between $\pm e$ and $\pm 2e$. This experiment would not support the 1 in 4 probability argument. The whole matter of intercepts becomes irrelevant. Also noted is that in actual sextant work the method of averaging sextant altitude H would tend to cancel the effect of the kind of wave action imagined in this example.

vii P = 25%, the scale factor is k = 0.76. The radius **a** of the ellipse = 0'.35 and **b** = 0'.25. The absolute intercept distances from the fix for the Sun, Moon and Vega are respectively 0'.33, 0'.23 and 0'.25.

viii The celestial bearings are calculated, not observed. The observer and each pair of terrestrial objects lie on the same circle, whereas the celestial observer is on a position circle drawn from the GP of the object. More importantly, the displacement caused by the error is not a displacement in bearing arc but in position circles.

ix Fig 4 draws the random error proposition in the manner suggested in the ANM, by taking particular values and signs for the error in three bearings (Vol III, p 165-166). The confidence interval (gray area in Fig 4) could be found by giving the likely random error a value (± x° or ± 2x°). The fix has a 1 in 8 chance of lying inside the cocked hat with vertices 1-2-5 and an equal chance of lying within the one with vertices 2-4-6; total chance: 25%. If the clockwise error is + and the anti-clockwise error - (see Fig 4), the two error combinations that produce these two particular cocked hats are respectively + + - and - + -. With all other combinations the fix would lie outside the cocked hat. Notable about the terrestrial cocked hat error theory in the ANM is that the determination of the fix if random error prevails is simply not pursued.

x See ANM, "The Cocked Hat Arising from the Same Error in Three Lines" and Fig 76 (Vol III, p 162-164). If only systematic error is present (compass error), the circles drawn through each pair of objects intersect where the actual fix is. If these circles do not intersect in one point the bearings will form a cocked hat, which is attributed to random error, assuming no plotting mistakes were made. The confidence interval of this random error can only be found in the manner shown in Fig 4, but this approach is not demonstrated in the ANM.

xi This observation is also made by Bennett: "For two bodies the least-squares solution is still appropriate, although no errors of observation for the individual bodies are obtained.." (G.G. Bennett, op. cit, p 279). In the same publication of 1979 Bennett refers to his use of a "least-squares sub-routine", which includes a "sub-routine" for running on earlier sights (ibid. p 279). Bennett worked for some time at the Royal Greenwich Observatory in England and it is quite evident that Yallop-Hohenkerk plagiarized the LSQ method either from Bennett or from its original author.

xii See ANM Vol III p 180.

xiii This is also demonstrated in the ANM for deck watch error (Vol III, p 181-184), and of course for distance obtained with vertical sextant angle (Vol III, p 166-168).

xiv Called "fortuitous" (see ANM Vol III, p 162).

xv The same argumentation would follow if the DR position was chosen to lie outside the cocked hat rather than inside it.

xvi Typical examples of this approach are found in the widely read book "Celestial Navigation for Yachtsmen" by M. Blewitt. The sources quoted by M. Blewitt all uncritically support the bisector theory.

xvii A comparison of the Y-H Sun-Moon-Vega case (consistent; see "Dilemmas" Fig 5 and "Rejoinder" Attachm.-Fig 1) and the Y-H Moon-Vega-Dubhe (inconsistent; see "Rejoinder" Fig 1) analyzed with LSQ will illustrate these propositions.

xviii In the Y-H Sun-Moon-Vega case for instance these two arrangements are ATT and TAA, if each Zn can assume a value Zn ± 180°. The actual case is $A_{vega}T_{sun}T_{moon}$

xix The number of possible combinations of T(oward) and A(away) are given through the 'triangle of Pascal'. With two sights the number of combinations equals 1+2+1 = 4, with three sights 1+3+3+1 = 8, with four sights 1+4+6+4+1 = 16, etc. The number of possible combinations doubles with each extra sight.

xx It seems that with additional sights the chance of obtaining a consistent cocked hat polygon diminishes, so that taking more sights than say three or four quickly becomes inefficient in terms of determining the fix, i.e additional sights may become of little extra use.

xxi For example if we take the Yallop-Hohenkerk configuration of four sights in the order Vega, Moon, Dubhe and Sun, the PLs form an irregular polygon. Denoting the intercepts with T(oward) and A(way), fully consistent are $T_VT_MT_DA_S$ and $A_VA_MA_DT_S$. Semi- consistent are $A_VA_MT_DT_S$, $T_VT_MA_DA_S$, $T_VT_MT_DT_S$, $A_VA_MA_DA_S$, $A_VT_MT_DA_S$, $T_VA_MA_DT_S$, $T_VA_MT_DA_S$ and $A_VT_MA_DT_S$. The latter combination is the actual Y-H case. If any very acute angle between two intersecting PLs in this case is rejected, $A_VA_MT_DT_S$, $T_VT_MA_DA_S$, $T_VA_MT_DA_S$ and $A_VT_MA_DT_S$ provide suitable consistent cocked hat triangles, so that the total chance (assuming irregular polygons) of obtaining a consistent cocked hat is 2 + 4 out of 16 = 37½%. In these cases if any systematic error is present and is eliminated, the confidence interval would converge toward the cocked hat area.

xxii If a systematic deck watch error is suspected, all variables affected by the wrong GMT of the sight should be recalculated.

xxiii With reference to Fig 6b (bottom), the distance d is divided by the perpendicular h_2 in d' and d", so that $Tan½\mu_{1,2} = d'/h_2$ and $Tan½\mu_{2,3} = d''/h_2$. Substitution gives $d-d'' = d''(Tan½\mu_{1,2}/Tan½\mu_{2,3})$ and $d'' = d/(1+ Tan½\mu_{1,2}/Tan½\mu_{2,3})$. Substitution gives $h_2 = d/(Tan½\mu_{1,2}+Tan½\mu_{2,3})$.