Phoenicians: safer, quicker passages and, since the advent of power-driven craft, greater fuel economy. He now has at his command the means to explore complexities and subtleties which have escaped him for years. The ancient art is ever more fascinating.

REFERENCE

[1] Bowditch, N. *The American Practical Navigator*, Volume I. Defense Mapping Agency Hydrographic Center, 1977.

'Whither Astro?'

Mike Pepperday *writes*

In the May issue of the *Journal*, Mr Parker suggests[1] that my criticism of the Nautical Almanac Office's calculator instructions[2] was an unnecessary exercise if it is true that astronomical navigation has been superseded. However, it should surely be the publishing of those calculator instructions which is unnecessary if the sextant is obsolete – rather than my criticism of the said instructions. Well, perhaps Mr Parker is right. It is precisely this obsolescence which inhibits me from submitting a critique of those 'NAO sight reduction tables' which also appear in the *Nautical Almanac* year in, year out, and which are also irrelevant.

Do we agree – better **S** than nothing? As I understand it, the least squares solution is also valid where errors are not Gaussian.

The reason I don't discuss confidence zones is partly because there isn't a practising navigator on the planet who knows what they are and partly because they have no point: what is the use of a 95 percent ellipse? No navigator will tolerate being wrong 5 percent of the time. You're wrong or you're right and to the devil with the asymptote. Has any captain yet stood up before a court of enquiry and expatiated on the Gaussian curve? Was he acquitted?

Put it this way. Let there be taken, on a pleasant evening, four or five shots to each of four stars, evenly distributed around the horizon. This was my pre-GPS practice. Suppose the intercepts of the multiple shots agree (though if three agree for a star I wouldn't bother computing another – I only took the fourth and fifth in case one or two intercepts look dodgy), and suppose the **S** is small (though, because the sights are evenly distributed, the **S** is not so important).

Now in this situation I am 'confident' that the fix is within a mile. There are too many double checks for it to be wrong. The only remotely plausible situation where this fix can be wrong in latitude, or wrong in longitude outside of an incorrect clock, would be some remarkably biased refraction condition. In short, to an accuracy of a mile it just *can't* be wrong. But – BUT – if there is a reef within five miles of the fix my stomach will lurch and I will act on the assumption I am just about to hit that reef.

The above has nothing to do with ellipses. Nothing. Moreover, neither an erroneous clock nor this (quite unbelievable) refraction would be picked up by any **t**, **F** or **chi**-squared examinations. So forget 'em. I would like to stamp the lesson from this in bold type: **The quality of an astrofix is determined by observing procedure, not statistical analysis.**

I am sorry if I underplayed the importance of plotting lines in my original article.[2] I teach it enough. I recommend it for learners. In practice if you take plenty of sights,

https://doi.org/10.1017/S0373463300013655 Published online by Cambridge University Press

you don't have to plot. If you wish to plot, a sketch is good enough when the intercepts are short but in practice, that is when crossing an ocean taking sights as above, dusk and dawn, the navigator will lose interest in even sketching lines. This is a direct consequence of using the above observing procedure; methods using limited sights, especially if they are from assumed positions, do need plotting.

Global war is a new reason to preserve astro. Usually the justification is that the GPS receiver might fail or the Americans might switch the satellites off. Aircraft would go back to inertial navigation and I wonder whether a war which knocked out the GPS satellites would be a war which used ships.

Here is what to do if we do have a global war and you need celestial:

(a) Have your navigation computer to hand.
(b) Record four to six sights on each of four stars.
(c) Convert each sight into position line.
(d) Average intercepts and roughly sketch the four lines.
(e) Record the fix and examine S if available.

(a) Buy one of the navigation computers: A Merlin II or a Celesticomp V or a CN2000. They are (still) available off the shelf in the US and Australia. If you want to do it yourself, the software is fairly daunting and, notwithstanding my efforts,[2] the published literature will lead you up the garden path and the war may be over before you get it working.

If you insist on your own, then I would suggest a spreadsheet in a desktop computer. As a header at the top of the spreadsheet, provide for entry of the 'basic data'; namely, DR lat, DR long, date, height of eye, sextant correction, clock correction, course, speed, required fix time, time of the previous fix. At the bottom of the spreadsheet show the fix (so far), the accuracy S (so far), the bearing, distance and ETA to the next waypoint and the set and drift. Set and drift are given by the difference between the DR and the fix using the time-period over which the DR was carried.

Set out spreadsheet columns titled body number, body name, clock reading, sextant reading, azimuth, intercept, discrepancy: one row of the spreadsheet per sight. The last column, discrepancy, is optional and is the signed difference between each sight and the least squares fix. It is the square root of the sum of the squares of these discrepancies that is S.

(b) Record four to six sights on each of four stars. The four stars should be spread evenly in azimuth – that is, approximately every 90 degrees around the horizon.

Four stars. Not three – this just gives rise to doubt. Not seven – God did not make any duds. They listed seven in those HO 249 'air tables' to allow for clouds; little did they know that superstition would take over and the number seven would become sacred. Surveyors, who are better educated than mariners, who are not restricted to twilight time, who have hundreds of stars to choose from and who look for an accuracy of metres, rather than miles, used to take four stars (nowadays they use GPS). Four stars, distributed evenly in azimuth.

For accuracy it is appropriate to take four shots per star. The average of four sights has half the error of a single sight. To halve the error again you would need 16 sights which is not feasible in navigation. Surveyors used to take such large numbers of observations.

Taking four sights is also appropriate for, and more important for, the purpose of exposing blunders – see below.

With four bodies you don't have a 'clutch of lines'; you get four lines. There is no difficulty determining position from them – they are ***easy*** to interpret. Four lines are much easier to interpret than three lines about which you can have endless argument (as readers of this *Journal* over recent years will be aware). A VDU is by no means essential; a rough pencil sketch is perfectly adequate.

Four stars evenly distributed in azimuth will tend to cancel systematic errors. Systematic error (index, refraction, height of eye, a personal tendency to set the body too high or too low) is likely to be more important than other errors.

Yes, you'll manage the 16 to 24 sights within the period of twilight, even in the tropics. After some experience you know to begin with a star to the east and conclude with a star to the west. The first shot of each star may take a little more time (to get an approximate sextant setting ignore most text books: either set the sextant to yesterday's reading or else turn it upside down in your left hand and bring the horizon *up*); the second and subsequent sights take only a minute each in good conditions, even if you are doing your own recording. In lumpy conditions, shooting stars can be very trying from a small boat. In any conditions you need to be well organized to take stars. It is straightforward if you are organized, but many small boat sailors who took Sun sights never took stars because they could never get their act together.

No, you never need to take forty sights. However, half a dozen is not enough. If you take only half a dozen sights to two stars, the error in the resulting fix may be dominated by systematic error. It makes a mockery of statistical analysis if the ellipse is swamped by, and displaced sideways by, say, error in the index correction.

Speculations about 'melange of lines', 'pin in the middle of the soup', 'the configuration looks a bit too diffuse' are imaginary fears. They do not occur.

(c) Set the computer with the basic data then convert each sight into position line, recording the azimuth and intercept.

On a spreadsheet, enter the body number: its name will show; enter the clock reading: the azimuth will show; enter the sextant reading: the intercept will show, the fix etc will adjust and all the discrepancies of previous sights will readjust. Do this for each sight. If the intercepts are extremely large it means the DR position was poor – change it if you wish. The column of intercepts will then change and make the position lines easier to plot. That won't affect the fix or the discrepancies, of course.

On the hand-held computers it is much the same although it takes four or five seconds per sight and they are not designed to re-compute lines if you alter basic data. If the name of the star is unknown, some computers figure it out for themselves. This is done by computing intercepts to all the stars (and planets) and taking the shortest. This could be adopted as the standard method on a fast spreadsheet which would save bothering about the names of bodies at all.

(d) Average and roughly sketch the four lines. Don't compute an average: eyeball it. That way you assess your shooting. Remember that celestial navigation is only good for a mile or so. For example if four intercepts are −3·4, 10·8, −2·4, −2·9, then the average is −3, and the second one was a blunder. This example illustrates why you take multiple sights: the first two disagreed so you needed the third; the agreement of the first and third might have been accidental so you had a fourth for confirmation.

It wouldn't be difficult to have a screen draw the lines but they are readily sketched by hand.

(e) Record the fix and consider **S**. Any blunders must have been deleted. The computers provide for this.

If sights were evenly distributed around the horizon and **S** is small, then the fix is good and a sketch will teach you nothing. If **S** is large and the discrepancies are all of the same sign then the lines are to the same side of (that is, all towards or all way from) the fix.

https://doi.org/10.1017/S0373463300013655 Published online by Cambridge University Press

If you don't display discrepancies (and this is about the only use for them), roughly sketch to see that the lines are all towards or all away. In this case the fix is good, though there is some sort of systematic error (sextant index correction probably). If the sights were not evenly distributed and **S** is small, the fix will probably be okay (it depends on the spread in azimuth) but it is advisable to sketch and interpret the lines. If **S** is large where the sights were not evenly distributed, the least squares fix is poor; sketch the lines and do your best.

It should be clear how valuable it is to have stars evenly distributed around the horizon. The discrepancies are not all that useful; they hardly show anything that the intercepts don't.

The above is the procedure for computer celestial navigation. It has been standard on the top-selling navigation computers since the mid-to late-eighties. (These computers are not on sale in Britain.) To my knowledge, no one sells the above described spreadsheet program. If the war which knocks out all the GPS systems occurs in 20 or more years' time, ship officers would need to be taught sextant navigation. They might have to be taught how to draw lines.

All the above was predicated on the assumption that a world war will knock down the GPS satellites. It is not necessarily 'idle to speculate'. On the contrary, prevention would be better than cure and discussion makes democracy. It appears that democracies don't make war on one another, which means we are okay if powerful countries are democracies. If it is also true that to get rich nowadays (and hence powerful) it is necessary to be a democracy, then we've got the game sewn up. No more war. The various squabbles which do go on are not going to bring down the GPS satellites.

GPS is part of the human race forever. The USA will soon release the full accuracy. Europe will sometime launch a parallel system and there will be a dense network of differential stations. Isn't it marvellous? The million-year problem of navigation and the ten-thousand-year problem of war both solved while we weren't looking. In a few years, children will carry or wear a 'phone/GPS. In a few more years you won't step outside without one.

Where does the sextant fit in? In the same place as the horse and buggy – as a hobby.

REFERENCES

[1] Parker, J. B. (1996). Whither astro? This *Journal*, **49**, 270.

[2] Pepperday, M. (1994). The *Nautical Almanac's* faulty calculator instructions. This *Journal*, **47**, 89.

KEY WORDS

1. Astro navigation. 2. Errors and accuracy. 3. Computers.

Observed Effect of Air-Sea Temperature Differences on Marine Sextant Altitudes

Mark Dixon

1. INTRODUCTION. While at anchor off the island of Waiheke in the Hauraki Gulf, North Island, New Zealand, the author was, by chance, able to observe the effect