Reworking Slocum's navigation

SIEBREN VAN DER WERF delves into Joshua Slocum's methods of astronavigation using the moon as a clock

One hundred years on, sailors are still fascinated by Slocum's navigation methods, in particular his determination of longitude by observing the distance between the moon and the sun. Was this method widespread? How was it performed, and what was its accuracy?

Slocum's chronometer was a \$1 tin clock. He gives little detail about his navigation on the Atlantic crossings and it appears that he limited himself to meridian altitudes.

On 10 September, *Spray* passed the island of St Antonio, the northwesternmost of the Cape Verdes. The landfall was accurate, considering that no observations for longitude had been made. Longitude was obtained by noting the time of the sun's meridian transit. The steamship *South Wales* spoke to *Spray* and, unsolicited, gave her the longitude by chronometer as 48°W, 'as nearly as I can make it,' said the Captain. Slocum, with his tin clock, had exactly the same reckoning.

Evidently, his clock worked well and in principle he could therefore have obtained the longitude via the intercept method at times outside noon, in combination with the meridian altitude. This method was first described by the French naval officer Marcq St Hilaire, in 1875. It required, however, an accurate knowledge of the time. Slocum, undoubtedly, must have known this method. Yet, he seems never to have used it, perhaps because his tin clock was not so accurate after all. And the longer the time gap between checking his clock against that of another ship, the more uncertain his time became.

In the Pacific in 1896, Slocum described in some detail how he regained the time by combining three observations: of the arc between the sun and the moon, the lunar distance, of the sun's altitude and that of the moon. The moon loses a full circle to the sun in 29½ days, or nearly half an arc-minute in one time-minute.

Indeed, if you hold the sextant flat and bring the image of the sun towards the moon, so that their bright limbs just touch, you will see them come apart within minutes.

We must assume that Slocum used the *Nautical Almanac*. In Montevideo or Buenos Aires, and maybe in Gibraltar, he had the opportunity to purchase the volume for 1896, priced at 2s 6d.

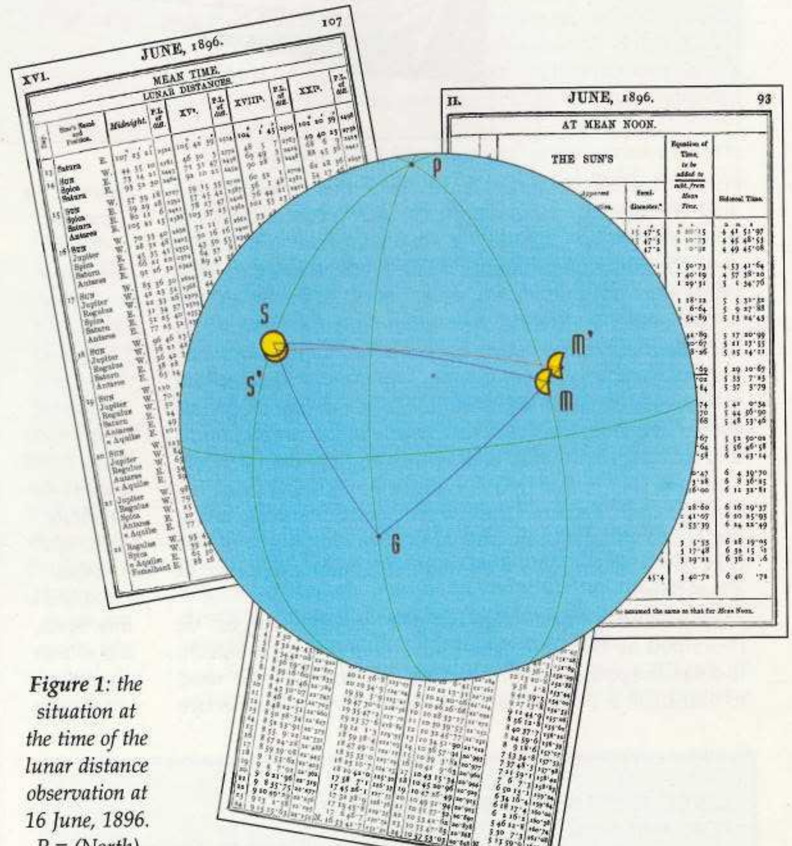


Figure 1: the situation at the time of the lunar distance observation at 16 June, 1896. P = (North) Pole. S' = apparent sun. M' = apparent moon. S = true sun. M = true moon. G = guessed position. The tables in the background are from the Nautical Almanac *for June 1896*

The distances from the moon to the sun and to a number of prominent planets and stars that are close to the ecliptic (the path of the sun), were tabulated in the *Nautical Almanac* for every third hour.

Nowadays lunar distances are no longer tabulated. One can, however, always construct them from the declination and hour-angle tables via the spherical triangle PSM: $\cos(LD) = \sin(DEC_S)\sin(DEC_M) + \cos(DEC_S)\cos(DEC_M)\cos(GHA_S - GHA_M)$.

Slocum centenary celebrations

The Spray Slocum Society is organising several commemorative events to mark the centenary of the voyage for those unable to get to Boston.

- A parade of sail down the Thames by *Spray* replicas on 24 April.
- A *Spray* rally in June from Portsmouth to Portugal, from where yachts will sail to Horta, in the Azores, to join yachts sailing from America on Slocum's route.

The almanac says in its *Explanations: Lunar Distances*, 'These pages contain, for every third hour of Greenwich Mean Time, the angular distances, available for the determination of the longitude, of the apparent centre of the moon from the sun, the larger planets and certain stars as they would appear from the centre of the earth. When a lunar distance has been observed, and reduced to the centre of the earth, by clearing it from the effects of parallax and refraction, the numbers in these pages enable us to ascertain the exact Greenwich Mean Time at which the objects would have the same distance.'

One of Slocum's observations can be dated accurately: he left the island Juan Fernandez on 5 May, and on the 43rd day from land 'the sky being beautifully clear and the moon being "in distance" with the sun, I threw up my sextant for sights. I found from the result of three observations, after long wrestling with lunar tables, that her longitude agreed within five miles of that by dead-reckoning.'

The day was 16 June. The moon was close to first quarter and the observations must have been made in the (local) afternoon. Also his position we know, because he sights the southernmost island of the Marquesas on the same day.

It is then interesting to construct a simulation of his observations and work them out by using the *Nautical Almanac* tables. In this way we can see what is involved and get an impression of his 'wrestling'. We can also get an idea of the accuracy that can be achieved. Modern computer programs on celestial mechanics exist nowadays in PC versions (I used the program *SkyMap* by Chris Marriott), and they allow one to look back in time and verify the tables of the almanac. This is important, because Slocum writes that he discovered an error in them: 'The first set of sights . . . put her many hundred miles west of my reckoning by account . . . Then I went in search of a discrepancy in the tables, and I found it.'

When checking the tables against the computer, all values reproduce very accurately, except for the times for the moon's right ascension and declination, which appear to be shifted by 12 hours. This must be the 'error' that Slocum mentioned. However, the tables of the lunar distances count the hours starting at noon, rather than at midnight. The discrepancy in the moon's tables also disappears when the times are understood as hours after noon. In the almanac's chapter *Explanations* it is found that this is, indeed, the

Simulation of the observation on 16 June, 1896

The altitudes are assumed to be lower-limb observations for an eye-height of 2.5m. The lunar distance will be measured between the bright limbs.

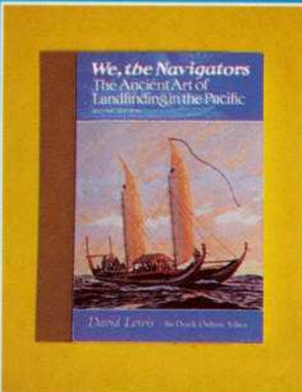
1. Obs. alt. sun = 40° 39'.4, obs. alt. moon = 48° 46'.3, obs. LD = 70° 14'.6
semidiameters: $s.d_S = +\ 15'.8$, $s.d_M = +\ 16'.1$
corrections for dip: 2'.8 for sun and moon
wherefrom the apparent altitudes:
$ALT_{S'} = 40°\ 52'.4$, $ALT_{M'} = 48°\ 59'.6$, $LD' = 70°\ 46'.5$
via formula (1): $AZ_{SM} = 109°\ 22'.1$

2. Further correction for refraction and parallax:
refraction: $a.r._S = 1'2$, $a.r._M = 0'8$
parallax: $Par._S = +\ 0'.1$ $Par._M = +\ 38'.6$
wherefrom the true altitudes: $ALT_S = 40°\ 51'.3$, $ALT_M = 49°\ 37'.4$
Formula (1) with ALT_S, ALT_M en AZ_{SM} gives: LD = 70° 22'.6

3. Interpolation in lunar distance table gives GMT = 23h 39m 31s, on 16 June, 1896

4. Sun's transit through Greenwich meridian: 12h 1m 8s, from which: $GHA_S = 174°\ 35'.7$
Latitude, estimated from earlier local meridian transit: LAT = – 10° 38'.0 (minus for south). At deduced GMT the declinations are: $DEC_S = +\ 23°\ 24'.0$ en $DEC_M = +\ 8°\ 14'.9$
Formula (2) gives: $LHA_S = 36°\ 14'.9$ and $LHA_M = -\ 35°\ 51'.7$.
Longitude from triangle PSG: $LONG = GHA_Z - LHA_Z = 138°\ 20'.8$.
Idem for moon: at GMT the moon and the sun differ in right ascension by: $r.a._M - r.a._S$ = 4h 48m 28.4s. An hour is 15° and the difference in hour angle is 72° 7'.1. From GHA_S follows $GHA_M = 102°\ 28'.6$, whereafter again the longitude: $LONG = GHA_M - LHA_M = 138°\ 20'.3$.

BOOK REVIEW



We, The Navigators – The Ancient Art of Landfinding in the Pacific
by David Lewis (University of Hawaii Press, £12.95. ISBN 0-8248-1582-3). About 5,000 years ago, some of the inhabitants of island groups in south-east Asia embarked on a waterborne migration that eventually took their descendants almost to the other side of the Pacific Ocean. Their canoes laden deeply with crop seeds, domestic animals and plants, they voyaged across thousands of miles of empty ocean without the benefit of compass or sextant. Over the centuries, they evolved unique methods of position-finding that have long baffled Western navigators.

Surely they must have found the first islands by luck – but how then did they retrace their routes, so that they could set sail in their cockleshell craft in confident expectation of making a landfall where they intended to?

Lewis, a New Zealander whose own small-boat exploits include a circumnavigation by catamaran and four sailing expeditions to Antarctica, has been heaped with honours by the Royal Institute of Navigation and the Institute of Navigation, Washington, as well as the Cruising Club of America and the Royal Cruising Club, and is well qualified to interpret the secrets of long-dead Polynesian and Micronesian navigators.

He researched this book not just in dusty libraries, but by crewing on board a replica double canoe on a voyage from Hawaii to Tahiti, and on traditional *prahus* in South-East Asian waters. Various theories about traditional navigation are carefully dissected and matched to his own experiences and those of the Polynesian navigators he has met. Seabirds, cloud patterns, ocean swell and the sun and stars all play their parts in this fascinating, well-written book, which will be of interest to anyone involved with small-craft navigation. **PN** way in which the tables are organised. 'Thus, suppose the right ascension of the moon were required at 0940 mean civil time on 22 April, 1896, or 21 April, 2140 mean astronomical time . . . All times are thus astronomical times and mean noon is counted as 0 hours, whereas it is 12 hours in civil time.' In the lunar distance tables, noon and midnight are indicated explicitly and no confusion is possible. But for the tables of the moon's right ascension and declination, the place where the change of the date is indicated, misleadingly suggests the use of civil time. Slocum 'corrected' this 12 hour shift and sailed on with his tin clock fast asleep.

The situation at the time of Slocum's observations is sketched in **Figure 1**. From his position **G**, he measures the apparent lunar distance LD' = S'M' and the altitudes of the sun and the moon. The procedure, by which from these the true lunar distance LD is found, can, for instance, be found in William Chauvenet's *A Manual of Spherical and Practical Astronomy* (Ed Lippincott, London 1891). It is a lengthy and tedious procedure, mainly because of the inevitable use of logarithm tables. Its principle is, however, simple and consists of the following steps:

1. The measured altitudes are first reduced for semidiameters and dip to the apparent altitudes $ALT_{S'}$ and $ALT_{M'}$. The apparent zenith distances GS' = 90° – $ALT_{S'}$ and GM' = 90° – $ALT_{M'}$, together with the apparent lunar distance LD', fix the triangle $GS'_{M'}$ and the azimuthal angle between sun and moon, $AZs'_{M'} = AZs' - AZ_{M'}$, follows from the well-known triangle relation:

$\cos(LD') = \sin(ALT_{S'}) \sin(ALT_{M'}) + \cos(ALT_{S'}) \cos(ALT_{M'}) \cos(AZ_{S'} - AZ_{M'})$ (1)

2. The apparent altitudes must be further corrected for refraction and for parallax to give the true altitudes ALT_S and ALT_M. These are both 'vertical' corrections, which do not influence the azimuthal angles, so that $AZ_{SM} = AZ_{S'M'}$. This is the crux that makes the lunar distance method work: the spherical triangle GSM is fixed and the true lunar distance, LD = SM follows from formula (1), in which now the primes are dropped.

3. With LD known, the Greenwich Mean Time (GMT) is found by interpolating in the lunar distance table.

4. Knowing now the GMT, Slocum could have used the sun's and the moon's true altitudes to find, by the intercept method, two crossing position lines and so his position. But this he seems not to have done.

Instead, he determined the local time. A simple way to achieve this was to rely on his last observed meridian altitude, from which he took his latitude (LAT). The local hour angle (LHA) is then directly obtained from the spherical triangle PSG for the sun, or from PMG for the moon, via: $\sin(ALT) = \sin(DEC) \sin(LAT) + \cos(DEC) \cos(LAT) \cos(LHA)$ (2) whereafter the longitude follows as LONG = GHA – LHA.

In the Indian Ocean, the tin clock lost its minute hand and even had to be boiled to make it run again

Though simple in principle, the 'wrestling' is indeed considerable when it has to be done with the use of logarithm tables.

A simulated observation, on 16 June, 1896, and close before sighting the Marquesas, is given in the panel. How accurate a result may one expect? When in the example the measured lunar distance is 1' off, the resulting longitude will be off by 30'. A 1' error in either the sun's or the moon's altitude causes only a 1'.5 error in the longitude. The adopted latitude is even less critical: if LAT is in error by 1'.0, also the longitude will suffer a 1'.0 error.

Another source of error lies in the fact that the three observations cannot be not done simultaneously. Taking the instant of observation of the lunar distance as the time that is to be determined, this non-simultaneity translates into an error in the altitudes. Though these do not strongly influence the value found for the longitude, an improved simultaneity can be achieved by making the observations for altitude twice, first preceding the lunar distance observation and then, following it, once more but in inverse order, and thereafter averaging them.

An experienced navigator such as Slocum could certainly measure a lunar distance with an accuracy better than 0'.5 and thus find his longitude within 15 miles.

In the Indian Ocean, the tin clock lost its minute hand and even had to be boiled to make it run again. On this long passage, Slocum again found the longitude from the sun's meridian transit. But the lunar distance method must have served to retrieve the time after the clock had stopped.

In Cape Town, Slocum met astronomer Dr David Gill, and they discussed the determination of the standard time at sea by the lunar distance method. He even presented a talk about it. It thus seems that the lunar distance method was not so widely known, despite the fact that the principle was given in the *Nautical Almanac* and the calculation procedure could be found in nautical handbooks. Slocum himself had probably not used it before in his long years at sea, because he felt his vanity 'tickled' when his observations of 16 June, 1896, came out so nicely. ❒

***Footnote:** The SkyMap program can be obtained from Chris Marriott at 9 Severn Road, Culcheth, Cheshire WA3 5ED.*

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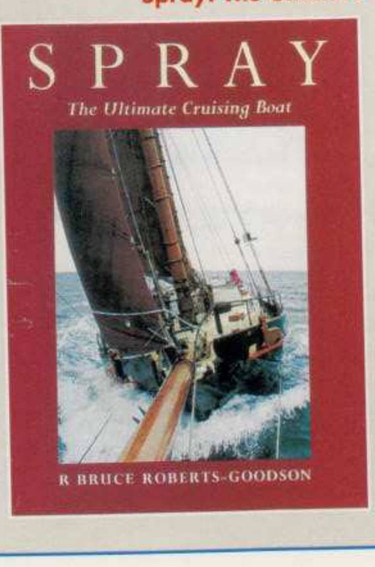
Spray: The Ultimate Cruising Boat



(Adlard Coles, £16.99) is a new book by Bruce Roberts-Goodson, the internationally renowned boat designer, who sails *K*I*S*S*, a steel Spray 28 in which he plans to cruise the European waterways and Med. He has been associated with*Spray*, designing and building replicas in wood, GRP and steel, for yachtsmen all over the world. There are currently 800 Sprays in existence built to his designs. 'We've sold thousands of plans and at least another 800 are being built. I'm finding more every day,' says Roberts. He is also Editor of the Slocum Spray Society newsletter