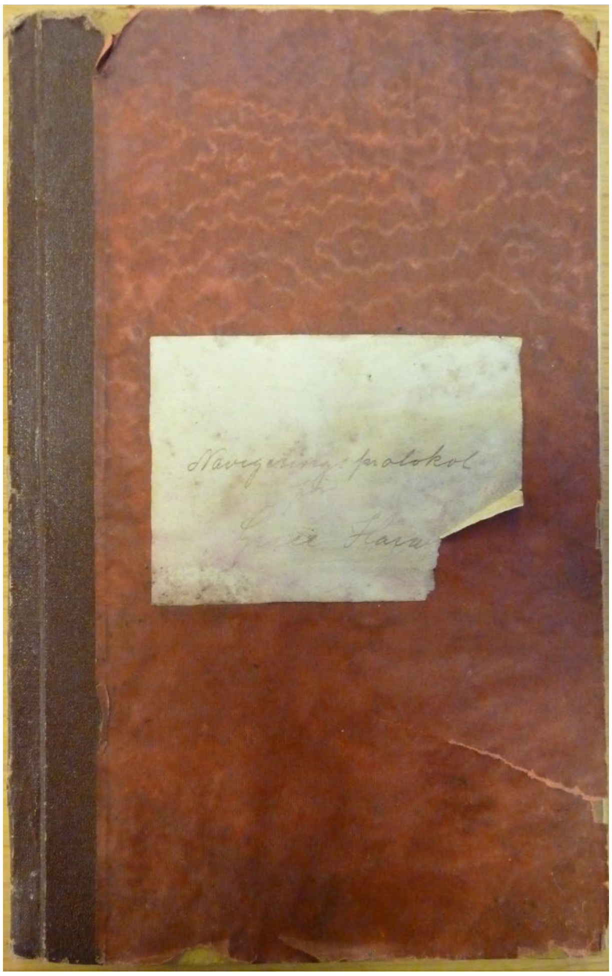
Navigation aboard the ship Grace Harwar 1925–1929

Lars Bergman



For anyone wishing to know how navigation was performed in practice on ocean voyages during the era of the last sailing ships, there is no better source than the notes that were kept on board. In the archive of Åland Maritime Museum, in Mariehamn, there are a few notebooks of this kind. One of these, *Navigation Protocol for Grace Harwar* is a 20 cm × 32 cm well-worn book with mostly faint pencil writing, covering the period September 1925 to July 1929. It was kept by the ship's master, Captain K.G.Svensson (1895–1974), who went to sea in 1911 and received a sea captain's certificate in Mariehamn in 1925.

During some trips, the notes are daily, but during others they are more sporadic or even sparse, which is why we can assume that observations have also been noted elsewhere. A study of these notes gives a good picture of how the ship was navigated. Out of a total of approximately 670 astronomical observations, the absolute majority, 91%, are observations of the Sun. Of the remaining observations, star sights make up 6% and planets 3%. The Moon is observed only once.

Official log books from these years have unfortunately not been found, which is why some assumptions have had to be made.

It is assumed that the reader is reasonably familiar with the most basic concepts used in navigation. This article consists of two parts, first a part that briefly deals with the navigation work on board, then a more technical part about calculation methods.

Swansea – Lüderitz Bay

The notes begin on 1 October, 1925 after sailing from Swansea, Wales, with a cargo of coal for Lüderitz Bay in present-day Namibia. They are initially carefully kept, with information on courses and logged distances, weather, winds and barometer readings. The astronomical calculations are well-marked on each line. Already on the third day out Jupiter was observed at dusk in the south, Polaris in the north and Arcturus in the west. Observations of celestial bodies to the north or south give the ship's latitude and observations to the east or west give longitude.

This first trip's notes give the impression that Captain Svensson was an ambitious and engaged navigator, the first-time commander in *Grace Harwar*.

On 22 October, is recorded *In sight of St. Antonio at about 8′ distance. Chronometer found to be highly inaccurate*. This Sun observation at the Cape Verde Islands showed that the error of the chronometer was just over a minute less than expected on that particular day and that the rate was 3 seconds faster per day than expected. This time error corresponds to a longitude error of 18′. On the next few days, the error appears to have been applied with the wrong sign but after five days a regularly changing error returns with the observed rate, although about 5 seconds offset. Whether this is due to carelessness or that more observations that are not noted here cannot be determined.

On 3 November, the equator is passed at 23°W and a month later the port of destination is reached.

Lüderitz Bay – Barbados

After leaving Lüderitz Bay in ballast for Barbados for orders at the end of February 1926, on the 26th a chronometer check was made while land was still in sight. On this trip mainly Sun observations are made, mostly a morning altitude when the Sun is in the east and a meridian altitude at noon.

This was a standard procedure used for a long time. The morning altitude gave the local hour angle of the Sun, which is equal to the apparent local time. By comparing this time with the time obtained from the chronometer, the longitude is obtained. If possible, depending on latitude and season, one wishes to observe the Sun when it is on or near the prime vertical, i.e. due east (or west). Then the altitude change per unit of time is greatest, which is why an error in altitude has the least influence on the hour angle obtained, while an error in latitude has minimal influence. Usually, the calculation was postponed until the latitude was determined at the meridian passage at noon, and the latitude thus obtained was moved back to the time of the morning observation. Then the calculations could be completed and the morning longitude obtained advanced to noon. This is the so-called day's work. Instead of an observation in the morning, an afternoon observation could be used. No construction in charts or plotting sheets is required by this method.

A couple of days before arrival, Polaris, Sirius and Arcturus were observed. These are the only star sights made during the voyage.

During the stop at Barbados, at anchor in Carlisle Bay off Bridgetown, two Sun observations for rating the chronometer were made during April 1926. The rate has been calculated against the regulation made on February 26 outside Lüderitz Bay. At the bottom of this page is noted *Chronometer correction according to time signal on April 26* = -1^m2^s. It is not clear what kind of time signal that was used.

Barbados – Campbellton NB

During this voyage, the Sun was most often observed, and in the last days the altitudes were calculated and compared with those observed on board, the azimuth is indicated in several places. The impression is given that Svensson used line of position (LOP) navigation here as he approached land. The difference between observed and calculated altitudes is set off on the chart in the direction of the azimuth, or counter-direction depending on the sign of the difference, and a line of position is drawn perpendicular to the azimuth.

Campbellton NB – Buenos Aires

On 15 July, eight days out of Campbellton with a cargo of logs for Buenos Aires, is recorded *According to wireless time signal from Pittsburg, starboard chronometer's correction to GMT =* $+51^m11^s$*, port chr's correction =* -0^m28^s. Here it is clear that a radio receiver was on board, and also that they had two chronometers. On another page in the book, under the heading 15 July, there is a calculation of a chronometer check that was made during the departure from Campbellton on 8 July. By accident, that observation was first calculated using ephemerides for 15 July but then recalculated using data for the eighth. The correction was then found to be -4^s followed by the text *whereby average from the previous day when the altitude was measured over the eastern horizon and the corr was =* -16^s *thus calculated equal to* -10^s*, daily rate =* $+1^s$. By measuring altitudes both east and west and taking the average value of the corrections determined eliminates certain errors and is therefore, a wise strategy. How the rate $+1^s$ was calculated is not clear. Compared with the time signal, it should rather be around -2.5^s.

On 20 July, is recorded *according to the time signal obtained by radio, port chr corr to GMT =* -36^s *daily rate =* -1.6^s*, starboard =* $+51^m18^s$ *daily rate =* $+1.5^s$. These numbers match well with the previous wireless time signal.

On 13 August, a time signal was again obtained. During the voyage, observations were almost exclusively made of the Sun and thanks to the time signals, they had good control over their longitude.

Buenos Aires – Port Lincoln, Australia

The notes begin on the afternoon of 8 November, 1926 with a chronometer regulation when the ship was between Montevideo and Punta del Este and the position could be determined by bearings to shore.

During the 45 days that this ballast trip's notes cover, observations for 21 days are missing. The reason for this is unknown, but it is reasonable to assume that this was due to overcast weather. During the remaining 24 days, a total of 44 observations were carried out. Nine of these constitute the only observation of the day and are in these cases a meridian passage of the Sun when the noon latitude was directly determined. The remainder of the observations are mainly comprised of a latitude determination through the Sun at noon and a longitude determination through the Sun in the afternoon. Unlike before, there are no morning observations. A possible explanation for this is that, as the ship's course was mainly easterly, the rig obscured the Sun as it stood in the east in the mornings while in the afternoons there was a clear view aft from the poop deck as the Sun stood in the west. Although the reason could just as well be the master's daily habits.

On 14 November, the chronometer error suddenly changes by 5^s without any comment. The reason could be that they received a time signal by radio. What speaks against this hypothesis is that the daily rate should then have been adjusted to approximately double the amount, but the previously used rate continued to be used. This fact rather points to the change having been made by mistake. Another explanation could be that they signaled with a ship and found by comparison that their longitude differed by just over a minute of arc, but it is less likely that this small difference would have led to a change in the chronometer correction used.

During the latter part of the voyage, from 6 December at longitude 65.5° east, evening observations of planets and fixed stars are added.

The majority of longitude observations consist of determination of the hour angle. A few exceptions occur when the altitude is instead calculated and compared with the altitude observed on board. As the azimuth in these cases is close to 270°, in practice it can be considered that the altitude difference obtained constitutes the departure from the assumed longitude.

It is clear that Captain Svensson had a habit of observing celestial bodies when they were on or near the meridian (north or south) or the prime vertical (east or west), whereby in the former case the latitude and in the latter longitude could be determined. The use of position lines in other directions does not occur during this trip, despite the fact that this methodology had been included in Swedish-language textbooks for at least 50 years by this time and was most likely taught at the navigation schools.

Furthermore, we can see that in the vast majority of cases the calculations were performed at the arc minute level, tenths of a minute only occur exceptionally, and time indications are noted with integer seconds. This is quite sufficient for ocean navigation and corresponds well with the measurement uncertainties that always exist. The greatest uncertainty in an altitude is usually the value of the dip of the horizon, which can vary several arc minutes without being detectable. For determining longitude, it is the chronometer error that is absolutely decisive, where an error of 4^s causes a longitude error of 1′.

Port Augusta – Queenstown, Ireland for orders

1 February, 1927 *Grace Harwar* left Port Augusta with a cargo of wheat, but the first note is dated only on 23 February, south of New Zealand. It was known that they were then approaching land on the port bow and were obviously keeping look-out from the rigging. The true course was approximately ESE and close to abeam was identified Snares Island at a

distance of 33 nautical miles. As the island is only 130 m high it will disappear below the horizon at an eye level of 20 m above the water, whereby the distance could be determined. The position is of course highly approximate but better than nothing. After sailing for an hour or so, an altitude when the Sun was NWbW was measured, whereby the chronometer correction was calculated. After three quarters of an hour of further sailing, an altitude was taken again with the Sun then in WNW and the correction was calculated again. The average value of these two observations is used as a starting point for continued sailing, and a new rate has probably been calculated.

A week of regular Sun observations at noon and afternoon followed. The date line was crossed. After that, observations are missing on certain days such as 8 March, when only is recorded *Severe storm*. The daily rate used up to Cape Horn is $+2^s$, that was, the chronometer was losing. On 22 March in the morning, Diego Ramirez was sighted in NNE at a distance of 25 miles and an altitude of the Sun standing ENE gave the chronometer error. This time the position must also have been quite approximate. The rate is given as -1.5^s but how Svensson arrived at this figure is not clear. Comparing with the chronometer rating south of New Zealand just over 27 days earlier, the rate was probably -3.0^s. In any case with this, it turns out that the ship was 34′ further eastwards than previously thought, or close to 20 nautical miles at this latitude.

After Cape Horn, fairly regular Sun observations are continued. For 28–29 April when they are 2° south of the equator, is recorded *Damned calm & rain showers with varying wind puffs. To hell with everything*. Just north of the equator, sights of Venus and Arcturus are taken on a couple of occasions, but Sun observations dominate. On 13 May at latitude 12°N, the last note is made. *Grace Harwar* arrived in Queenstown on 17 June 1927 after a 137-day voyage. During the autumn, a trip was made with coal from Swansea to Lüderitz Bay.

Lüderitz Bay – Ilo for order

On 19 January, 1928, the ship set sail, eastwards, in ballast for Ilo in southern Peru. On 12 March, about 360 nautical miles south of Cape Leeuwin, SW Australia, Sirius was observed WNW in rapid succession with α Centauri (Rigil Kentaurus) in SE½S. Altitudes and azimuths were calculated and it is likely that these sights were plotted as lines of position, as no observed position is indicated. The sights are made late in the evening when the Sun was 39° below the horizon but the Moon was up and apparently the horizon must have been judged to be distinct enough. Otherwise, it is common for observations of stars to be made at dawn or dusk, when the horizon as well as the stars are visible. The angle between the LOPs was only 31° and the observed position was 27 miles SWbW of that assumed in the calculations. It is consequently impossible to assess how reliable the position determination was, but it is interesting to note that the so-called intercept method according to St Hilaire seems to have been used. This was the only observation of the day and perhaps the cloudiness made observation of stars closer to the meridian and prime vertical impossible, which previously seems to have been the rule for Captain Svensson.

The voyage continued between 40° and 49° south latitude until approximately 105°W, when they slowly retreated northward. On 27 April, after a morning and noon altitude of the Sun, Pollux was observed at dusk for latitude as well as Aldebaran and Rigel for longitude. Three days later, altitudes of β Argus (Miaplacidus), ε Argus (Avior) and δ Argus were taken. From the first two, the latitude was calculated, but the results differed 3° from each other due to the fact that the hour angle for β Argus was noted incorrectly in the calculations and that its logarithm of cosine was taken for a table value one hour too large. No calculation was made for the third star. For the rest of the voyage only the Sun was observed in the traditional way. On 4 May, three days before arrival Ilo an altitude of the Sun lying NEbE was taken in the morning, when calculated intercept and azimuth suggest that it was laid out as a line of position on the chart.

Ilo – Wilmington – Port Lincoln

From Ilo, the voyage continued to Guanape Island where guano was loaded. The destination was Wilmington, North Carolina, and that trip went through the Panama Canal. In November 1928 Wilmington was departed in ballast and in March 1929 the ship arrived at Port Lincoln, Australia. During these trips, only Sun observations were noted.

Wallaroo – Queenstown for orders

On 18 April 1929, *Grace Harwar* left Wallaroo with a load of wheat. On the 57th day she passed Cape Horn and the following day, 14 June, a chronometer rating was made in sight of Staten Island. At dusk, Sirius was observed in WNW and Antares in ESE. An error in each star calculation fortunately canceled each other out, which is why the average value was still reasonably correct. The chronometer error found does not appear to have prompted any correction of the rate.

Alan Villiers, in his “By Way of Cape Horn” writes about this passage of the Horn: *On the night of the day that we passed Cape Horn – June 13th – the stars came out and Captain Svensson was able, for the first time in weeks, to establish the ship's position accurately. He discovered that the longitude was four degrees out – not four minutes or four miles, but four degrees. We were four degrees farther on than we had thought we were; we had been able only to plot the ship's course by dead reckoning, which is insufficient at the best of times, ... The only means of checking come from the light of the sun, or of the stars; we never saw either for over three weeks. ... The next day we saw Staten Island, away on the port beam, ...*

According to Svensson's notes, the latitude from the Sun and longitude from Sirius were determined on 6 June, so the veracity of Villiers' story is questionable. No star observation is noted on 13 June.

On 25 July, the last notes seem to have been made, south of the Cape Verde Islands. A morning sight of the sun which is partly calculated as an LOP, partly as a normal hour angle observation. The azimuth was also used to determine the deviation of the compass.

It was a long voyage; the vessel arrived Queenstown on 3 September 1929.

Summary

The review of *Navigation Protocol for Grace Harwar* has shown that the Sun was the celestial body that was observed by far the most often. Following age-old practice, latitude and longitude were determined separately. This procedure means that the times for observation are more or less locked down, but that in itself does not have to constitute a major disadvantage out on the oceans, where fixed routines may have more importance than flexibility in terms of observation times. At the same time, it is seen that Captain Svensson was no stranger to observing stars and planets, and when the need was called for, could also make observations at arbitrary azimuths. These observations seem to have been used mostly when making landfall. Every opportunity to check the chronometers was taken advantage of, which was of the utmost importance. During the latter part of the 1920s, the transmission of time signals by radio was quite well developed. From among others Paris, Nauen, Washington-Arlington, San Francisco, Calcutta, Hong Kong, Melbourne, Cape Town, Buenos Aires and Valparaiso, time signals were sent, but for reception, of course, a suitable radio receiver with the required power supply and a suitable antenna were required. A working radio receiver was located in *Grace Harwar* at least one trip.

Compass deviation determinations by bearings of the Sun and calculating its azimuth occur quite often.

An observation made is that the total correction for altitudes often has a value that indicates an unreasonably large height of eye. A review of all the altitude corrections during the trip Buenos Aires – Port Lincoln shows that the average height of eye used is 11.0 m with a standard deviation of 0.7 m. For a ship of *Grace Harwar's* size, 8 m is probably a more reasonable value in ballast. A likely explanation for this relationship is that the index correction of the sextant was added by mental arithmetic to the table value before this was noted.

Only one lunar observation is recorded, at dusk on 1 March, 1928. The Moon was waxing, 76% illuminated, and the latitude was calculated as an ex-meridian sight. The hour angle and altitude corrections contain minor miscalculations, but the latitude was still correct within a few arc minutes. It is a little surprising that the Moon was not been used more often, as the combination of Sun and Moon sometimes gives the opportunity for good position determination during daytime.

Calculation methods

Svensson often refers to table numbers and uses designations that correspond to Korsström's *Lärobok i navigation*, Helsinki 1911, which is why we can assume that this textbook with associated nautical tables was on board. In addition, we can assume that the standard nautical almanac (NA) was available.

The hour angle was calculated using the formula suitable for logarithmic calculation

$\sin^2(t/2) = \sec \varphi \cdot \csc p \cdot \cos(s/2) \cdot \sin(s/2-h)$,

where t is the hour angle, φ latitude, p polar distance, h the true altitude and $s = \varphi + p + h$. The observed altitude was corrected to true altitude by corrections for dip of the horizon, refraction, parallax and semi diameter. Korsström's contains tables for different celestial bodies where these corrections have been combined into a total correction. For the Sun, it is table 19 that Svensson often refers to. A typical example is shown in Figure 1 from March 12, 1926.

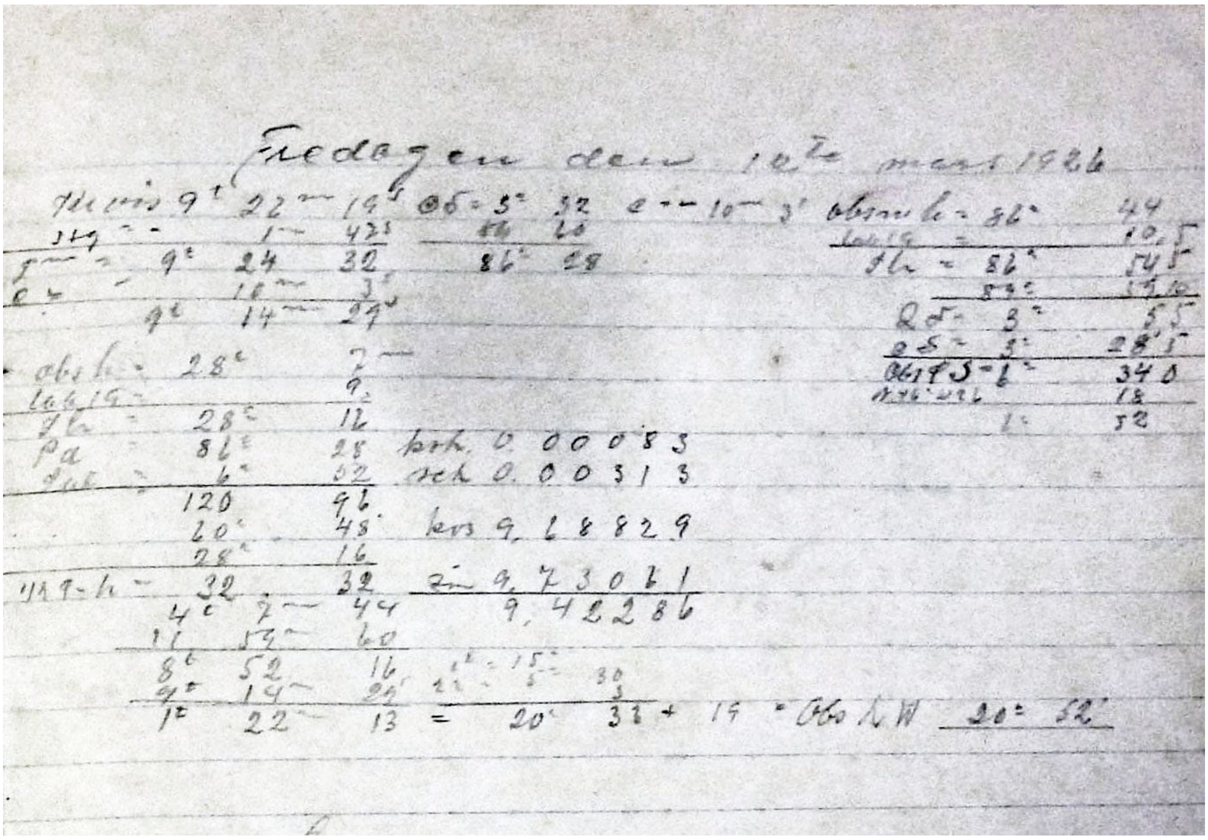


Fig 1. Day's work on 12 March 1926

On the right is shown the noon altitude 86°44′ which with a total correction of 10.5′ gives a true altitude of 86°54.5′. By subtracting this from 90°, or as here 89°60′ for ease of computation, the zenith distance 3°5.5′ is obtained. The declination of the sun at noon, 3°28.5′S is added to the zenith distance and the noon latitude 6°34′S is obtained. The course from the morning observation was N46°W and the distance sailed 26′. In the traverse table, the latitude difference 18′ is found, giving the morning latitude 6°52′, which is found in the hour angle calculation on the left. This starts with the chronometer reading $9^h26^m19^s$ corrected with -1^m47^s which gives GMT $9^h24^m32^s$. To this is added the equation of time 10^m3^s which gives the apparent time in Greenwich, GAT $9^h14^m29^s$. To the right of the chronometer time is the

Sun's declination, as subtracted from 90° gives the polar distance 86°28′. Then the actual hour angle calculation begins. The observed altitude is corrected according to table 19 to true altitude and the sum s calculated, 120°96′. This is halved and the altitude is subtracted. The logarithms of csc p, sec φ, cos $s/2$ and $\sin(s/2-h)$ are obtained from the table and summed to 9.42286. As is customary, all negative logarithms are tabulated with 10 added, and in the sum the tens number has been dropped. The resulting sum of the logarithms must therefore be interpreted implicitly purely mathematically as $\log \sin^2(t/2) = 9.42286-10 = -0.57714$ but as all tables follow the same convention, one can directly search the hour angle from the value 9.42286. The hour angle was widely expressed in time measures during this period. As this is a morning observation of the Sun, the hour angle was easterly, which is why it is subtracted from 12 hours to give the local apparent time LAT $7^h52^m16^s$ (note that the time was mistakenly set to $8^h52^m16^s$, but the calculation has nevertheless been carried out correctly). The time difference to GAT, $1^h22^m13^s$, is converted to arc measure where 1^h equals 15° and gives longitude 20°33′. Since GAT is the larger quantity, the longitude is westerly. The course and distance until noon gives a departure of 19′ which this close to the equator can be considered equal to the longitude difference. Thus 19′ is added to 20°33′ and the noon longitude is obtained as 20°52′W.

In cases where the altitude has been calculated, the so-called German Navy formula has been used. It is well suited for calculation with logarithms. One has $h = \cos(\varphi-\delta) \cdot \cos \psi$ where the auxiliary variable ψ is got from $\sin^2(\psi/2) = \sec(\varphi-\delta) \cdot \cos \varphi \cdot \cos \delta \cdot \sin^2(t/2)$. The value of ψ does not need to be noted as $\log \cos \psi$ is immediately present on the same line as $\log \sin^2(\psi/2)$, possibly after interpolation. An example of an altitude calculation of Jupiter from 13 December, 1926 is shown in Figure 2.

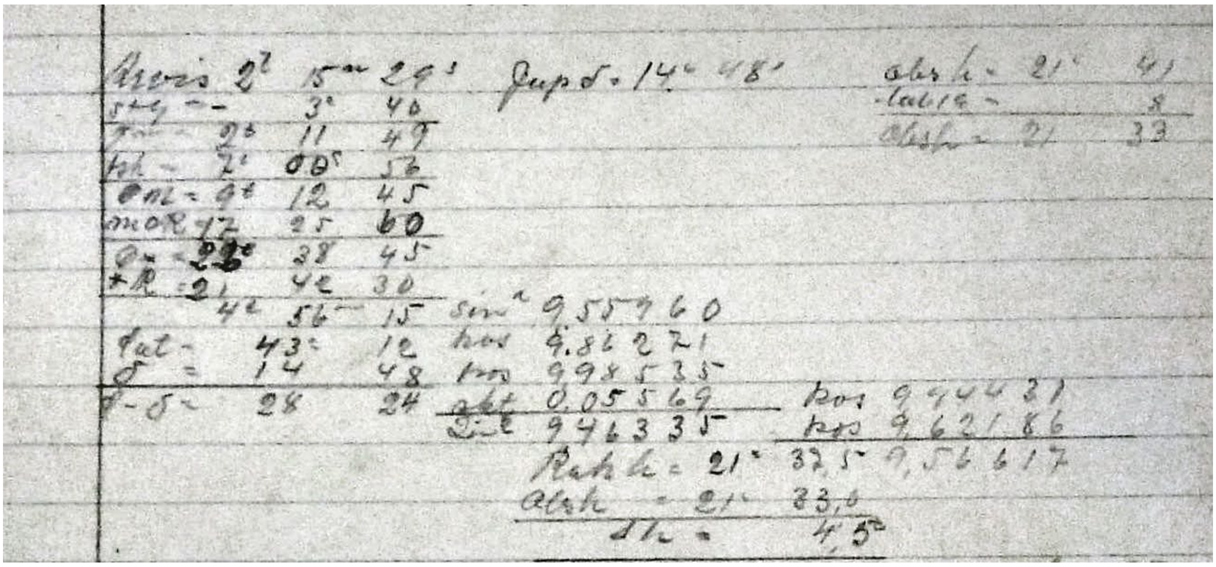


Fig 2. Altitude calculation of Jupiter on 13 December, 1926

The chronometer corrected for its error gives GMT $2^h11^m49^s$ reckoned astronomically, that is, from noon. The easterly longitude is added and gives the astronomical mean time of the place $9^h12^m45^s$. To this is added the right ascension of the Mean Sun, from the NA named RAMS, Right Ascension of the Mean Sun. This right ascension increases almost 10^s per hour which is why the required value is easily interpolated by mental arithmetic. Hereby the local sidereal time is obtained. Jupiter's right ascension is subtracted and what remains is the hour angle, $4^h56^m15^s$. With modern designations, this corresponds to LHA = GHA Aries + longitude + SHA, where GHA Aries is obtained from the NA against the argument (civil) GMT.

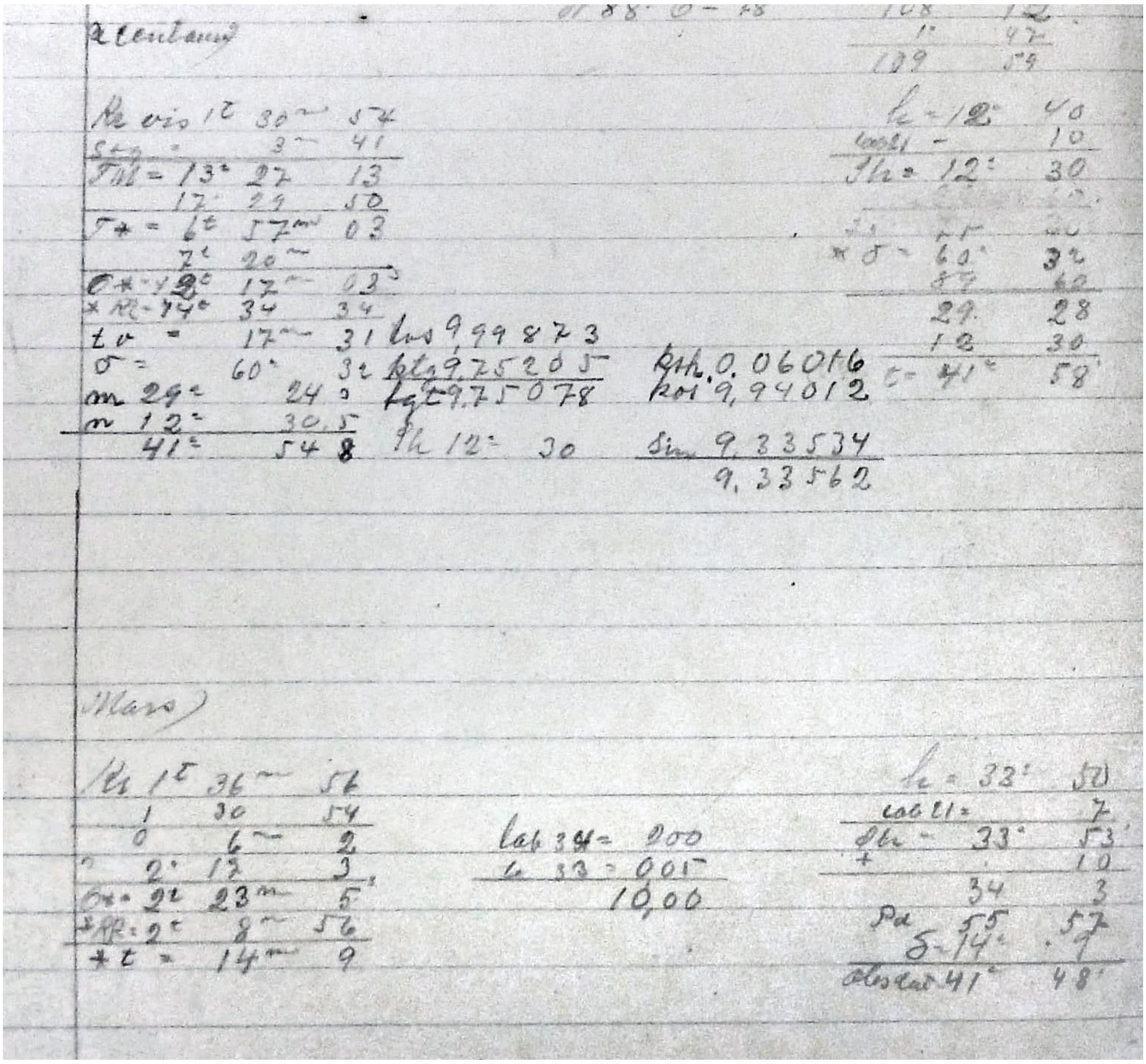


Fig 3. 14 December 1926. Note that the hour angle for α Centauri is counted from the lower meridian and thus is 12^h *minus* $17^m 31^s$*, why the latitude here is obtained as n+m. On the right, the latitude is calculated as a lower meridian passage.*

On 14 December 1926, Figure 3, observations in rapid succession of α Centauri (now known as Rigil Kentaurus) to the south, Jupiter to the west and Mars to the north. α Centauri was calculated partly as a meridian altitude (below the pole), partly the latitude was solved by the formula $\varphi = n - m$, where $\tan m = \cot \delta \cdot \cos t$ and $\sin n = \sin h \cdot \csc \delta \cdot \cos m$. (At other times the calculations have been carried out according to $\cot m = \cot \delta \cdot \cos t$ and $\cos n = \sin h \cdot \csc \delta \cdot \sin m$ with $\varphi = n + m$).

Mars was calculated as an ex-meridian altitude using tables 33 and 34 in Korsström. Table 33 gives the change in altitude per unit time near the meridian and table 34 gives the square of the hour angle. Multiplication of these two tabulated values gives the correction to be applied to the true altitude to find the corresponding meridian altitude.

The British NA 1926 listed for every two hours GMT for the Sun the quantities RAMS, Dec. and Equation of Time. From the year 1929 these were changed to R., Dec. and E, which was an adaptation to the change in the starting point of GMT introduced in 1925. Up to and including 1924, the GMT day began at mean noon in Greenwich. The quantity R was linked to the sidereal time and the quantity E to the equation of time. It was not until 1952 that the right ascension was exchanged for the ”modern” GHA, Greenwich Hour Angle, expressed in degrees.

Grace Harwar

The ship *Grace Harwar* was built in Port Glasgow in 1889, by W.Hamilton & Co for W.Montgomery in London. The vessel was owned by Gustaf Erikson in Mariehamn between 1916 and 1935. Her last voyage was in 1935 from Port Broughton to Falmouth with 2900 tons of wheat. Then she was scrapped, after more than 45 years' work on all oceans. *Grace Harwar* was probably the last full-rigged ship in commercial world-wide trade.