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# Mathematicians on board: introducing lunar distances to life at sea

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**Abstract.** Nevil Maskelyne, the Cambridge-trained mathematician and later Astronomer Royal, was appointed by the Royal Society to observe the 1761 transit of Venus from the Atlantic island of St Helena, assisted by the mathematical practitioner Robert Waddington. Both had experience of measurement and computation within astronomy and they decided to put their outward and return voyages to a further use by trying out the method of finding longitude at sea by lunar distances. The manuscript and printed records they generated in this activity are complemented by the traditional logs and journals kept by the ships' officers. Together these records show how the mathematicians came to engage with the navigational practices that were already part of shipboard routine and how their experience affected the development of the methods that Maskelyne and Waddington would separately promote on their return. The expedition to St Helena, in particular the part played by Maskelyne, has long been regarded as pivotal to the introduction of the lunar method to British seamen and to the establishment of the *Nautical Almanac*. This study enriches our understanding of the episode by pointing to the significant role played by the established navigational competence among officers of the East India Company.

## Introduction

In January 1761 two mathematicians, Nevil Maskelyne and Robert Waddington, embarked on the East India Company ship the *Prince Henry*. It was bound for China but the mathematicians would be carried only as far as the Atlantic island of St Helena. They had been appointed astronomer and assistant on a Royal Society expedition to observe the transit of Venus on 6 June, after which the assistant, Waddington, would return home and Maskelyne would commence a programme of observations, which would include an attempt to measure the parallax of Sirius using a zenith sector.[1]

The expedition is remembered as a failed attempt to observe the transit, but also for an achievement in quite a different direction, which was not part of the instructions from the Royal Society. It was the occasion of some of the earliest British attempts to find longitude at sea by the method of lunar distances. The expedition's pivotal position in this

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1 On the plans for the expedition see Derek Howse, *Nevil Maskelyne: The Seaman's Astronomer*, Cambridge: Cambridge University Press, 1989, pp. 18–26; on Maskelyne's observing project on St Helena see Nicky Reeves, 'Constructing an instrument: Nevil Maskelyne and the zenith sector, 1760–1774', Cambridge University PhD thesis, 2009.

story has been accepted from its early days down to the most recent histories of navigation. This was encouraged by both Maskelyne and Waddington, as they often referred to the voyages in their subsequent efforts to promote the lunar method. These were 'voyages' in the plural, because each man had an outward and a return passage and, thanks to their different instructions, they returned separately, so we have three voyages to consider, all in East Indiamen.[2]

Longitude at sea was traditionally determined 'by account'; that is, inferred from dead reckoning, which entailed keeping a record of direction and distance, based on courses steered and speeds estimated or measured. The two successful new methods of the eighteenth century both depended on finding the time at a standard meridian, from which the longitude distance could be determined by comparing this standard time with the local time at the meridian of the ship, which was measured astronomically by the sun or stars. Every four minutes of difference in time indicated one degree of displacement in longitude. In the so-called 'chronometer method', the standard time was kept by an accurate seagoing timepiece.[3] In the 'lunar' (or 'lunar distance') method, the place of the moon in the visible sky was measured and the time at the standard meridian calculated for this lunar position. Both methods had their advantages and disadvantages, the principal drawback of the lunar method being commonly given as the length and complexity of the calculations. Historians of science have been inclined to leave the matter there and to venture little further into the complexity of the lunar method, not addressing, for example, just how a lunar position could be used to find the time difference to the standard meridian. This paper shows that by looking at the procedures more closely, we can draw interesting conclusions about what was happening on board ship.

Because both Maskelyne and Waddington were keen to publicize their achievements in longitude finding on their return, we have a great deal of information. There is much to learn about what the mathematicians did on board and how they related to the crew. This was a novel experience for everyone concerned and, while the officers could learn a new navigational technique, the mathematicians had lessons to learn about the skilled practices already embedded in the shipboard routine.

At the same time another set of differences was in play: Maskelyne and Waddington were mathematicians with very different backgrounds.[4] The former was educated at Westminster School and the University of Cambridge in the Mathematical Tripos,

2 It is not clear whether, in nautical terminology, we should refer to Maskelyne and Waddington being 'in' or 'on' these ships; the former would be used for the crew, the latter for passengers. They were not crew, of course, but we shall see that they sometimes became involved with the life of the ship in ways not expected of a passenger.

3 The chronometer method is 'so-called' because historians of horology will not allow any timepiece extant at this time to qualify for the title of 'chronometer'.

4 For Maskelyne see Howse, op. cit. (1); Derek Howse, 'Maskelyne, Nevil (1732–1811), astronomer and mathematician', in *Oxford Dictionary of National Biography*, at http://ezproxy-prd.bodleian.ox.ac.uk:2167/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-18266, accessed 16 August 2018; Rebekah Higgitt, ed., *Maskelyne: Astronomer Royal*, London: Robert Hale, 2014. For Waddington see Jim Bennett, '"The Rev. Mr. Nevil Maskelyne, F.R.S. and myself"; the story of Robert Waddington', in Higgitt, op. cit., pp. 59–88; Bennett, 'Waddington, Robert (d. 1779)', forthcoming in *Oxford Dictionary of National Biography*.

becoming a minister in the Church of England, a fellow of Trinity College, Cambridge, and a fellow of the Royal Society, all before the St Helena expedition. Of the latter's formal education we know nothing and prior to the expedition we hear of him only as a merchant's clerk and mathematical instrument-maker in Hull, an occasional contributor to popular mathematical serials and an associate of the astronomer Nathaniel Pigott. Following the expedition, Maskelyne would promote the lunar distance method through the official, government-sponsored channels of the Royal Observatory and the Board of Longitude, Waddington through the independent, commercial possibilities available to him as a jobbing mathematical practitioner, such as publication and private instruction. Only Maskelyne was successful.

The eighteenth-century narrative of finding longitude at sea was contested in the period and remains so today.[5] A facile division between the principal two methods for candidate solutions has been elaborated in terms of social and educational background and biography: the chronometer method is the artisanal pitch for the great prize (literal as well as metaphorical), while the lunar method is the province of the educated elite of astronomers and mathematicians. This is not without substance – John Harrison himself attributed his perceived woes to 'my being neither University-man, Knight nor Earl, &c' – but is only part of the story.[6] Care is needed not to import our modern and more emphatic prejudices about the relationship between work of the hand and of the mind into a pre-industrial age. This is particularly so for science-related disciplines, where an instrument-maker such as John Bird or a watchmaker such as George Graham might be granted profound respect and telling authority. We forget too easily that Royal Society fellows were strongly supportive of Harrison and that he was, by some distance, the principal beneficiary of the grants made by the Board of Longitude, even before his major award. In addition, the present study illustrates social differentiation *within* the ranks of the 'Lunar-Men', to adopt another epithet from Harrison: not all belonged to his class of 'Philosophers or Priests'.[7]

The history of the longitude in the eighteenth century cannot help but be a study of the nature and management of practical, tacit or operative knowledge, because it was already exactly that in the period.[8] The board was obliged to consider how to assess, codify and communicate embodied skill, in deciding whether it was being presented with a solution that was, in the words of the Act it had to administer, 'Practicable and

5 Selected from a large literature: (for its substantial bibliography) William J.H. Andrewes, ed., *The Quest for Longitude*, Cambridge, MA: Collection of Historical Scientific Instruments, Harvard University, 1996; (for its balanced approach) Richard Dunn and Rebekah Higgitt, eds., *Finding Longitude*, Glasgow: Collins and Royal Museums Greenwich, 2014.

6 John Harrison, *A Description Concerning Such Mechanism as Will Afford a Nice, or True Mensuration of Time*, London, 1775, p. 58.

7 Harrison op. cit. (6), pp. 63, 61, 66.

8 Routes into discussion of these issues can be found in Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution*, Chicago and London: The University of Chicago Press, 2004; Lissa Roberts, Simon Schaffer and Peter Dear, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation*, Amsterdam: Koninkliijke Nederlandse Akademie van Wetenschappen, 2007; Pamela O. Long, *Artisan/Practitioners and the Rise of the New Sciences, 1400–1600*, Corvallis: Oregon State University Press, 2011.

Useful at Sea'. This proved all but impossible.[9] The issue was not confined to the chronometer method, which relied on the embodied skills of watchmakers: lunars relied on the practical, instrumental skills of seamen. The present study offers an insight into the first attempts to test this human resource. Although only an episode in a much longer narrative, coming as it does at a formative time for the lunar method, the St Helena expedition would have a significant influence on its content as well as its progress into use.

## Nevil Maskelyne

In the range of surviving records of the voyages, including printed accounts by the mathematicians, their correspondence, and journals kept by the ships' officers, an exceptional resource has been made available online through the 'Cambridge Digital Library' website of Cambridge University Library. The online catalogue refers to this folio notebook as Maskelyne's 'Journal of voyage to St Helena'.[10] It is a very immediate and direct record, written, certainly for the most part, by Maskelyne at sea.

Central to the manuscript is a table, set out in the manner of a sea captain's log or journal, covering the whole voyage to St Helena, with entries every day from 21 January to 6 April. It extends over four openings, i.e. eight pages, of the notebook. Maskelyne gives this table the title 'Journal of a Voyage from England to S$^{t}$: Helena Ship Prince Henry East India Man Charles Haggis Commander'.[11] To avoid confusion, since this is Maskelyne's title and is more correct in nautical terminology than is the library catalogue, we shall refer to the table as the *Journal* and the whole manuscript as the notebook.

Maskelyne twice published a very selective 'extract' on finding longitude by lunar distance from the *Journal* in the *Philosophical Transactions* in 1762 and in his *British Mariner's Guide* in 1763.[12] That topic, however, is completely absent from the *Journal*'s first two pages (i.e. the first opening, as ruled into columns by Maskelyne), covering the first nineteen days, up until 8 February, wherein there is nothing at all about lunars. It is instructive to follow how the *Journal* develops.

In this first period the longitude is given simply by account and there is an emphasis on recording magnetic variation. Maskelyne had asked the Royal Society whether he could borrow a variation compass and a dip circle, had tested them both beforehand and had arranged for the instrument-maker John Bird to put the compass into good order.[13] We

9 Jim Bennett, 'The travels and trials of Mr Harrison's timekeeper', in Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum, eds., *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*, London: Routledge, 2002, pp. 75–95.

10 Nevil Maskelyne, 'Journal of voyage to St Helena', Cambridge University Library MS RGO 4/150, at https://cudl.lib.cam.ac.uk/view/MS-RGO-00004-00150, accessed 14 August 2018.

11 Maskelyne, op. cit. (10), ff. 5v–9r.

12 Nevil Maslekyne, 'A letter … containing the results of observations of the distance of the moon from the sun and fixed stars, made in a voyage from England to the Island of St. Helena, in order to determine the longitude of the ship', *Philosophical Transactions* (1761–1762) 52, pp. 558–577, 573; Maskelyne, *The British Mariner's Guide: Containing, Complete and Easy Instructions for the Discovery of the Longitude at Sea and Land*, London, 1763, pp. 106–107.

13 Maskelyne to Thomas Birch, 8 November 1760, British Library MS Add 4313, f. 236.

know, therefore, that Maskelyne intended to study variation and we see from the *Journal* that he planned to compare measurements with values taken from the 'new Tables' and from the 'new Chart', the columns relating to variation being headed

Variation Observed

Variation by new Tables

Variation by new Chart

X of Varn Observ$^{d}$. from Tables

X of Var. Obs$^{d}$. from Chart.[14]

The 'new Tables' will have been the extensive series published by William Mountaine and James Dodson in the *Philosophical Transactions* for 1757, and the 'new Chart' the corresponding chart first published in 1758 as an updating of the work of Edmond Halley.[15]

Regular measurement of magnetic variation was already standard practice on East Indiamen and Maskelyne was fortunate to find himself on a ship commanded by Captain Charles Haggis, who was clearly a particularly careful and ambitious navigator.[16] We see Maskelyne's relationship with the officers in technical matters developing during this early part of the voyage, recorded in the 'Variation Observed' column from the first opening of his *Journal*. We can compare his measurements with those of Captain Haggis, recorded in his journal for the voyage, preserved in the East India Company archive at the British Library.[17]

At first, Maskelyne's record does not consistently concur with that of Haggis. Then, from 10 February Maskelyne begins to enter measurements additional to his own, attributed to 'P' for the first mate John Papworth and 'B' for the second mate William Bezoil. When this happens, as it does with increasing frequency, the readings coincide in value with those similarly attributed to these officers in the captain's journal. Occasionally Maskelyne has measurements marked P or B that are not in the official journal and on one occasion he has a whole group of variation measurements not recorded elsewhere – a reminder that the journal submitted by the captain to the company is a fair copy of one of a number of navigational registers being kept on the ship.

As the voyage proceeds, the values of the unattributed measurements in Maskelyne's *Journal* come to fall into coincidence with those attributed to the captain in his own

14 Maskelyne, op. cit. (10), ff. 5v–6r; 'X' refers to a difference or divergence.

15 William Mountaine and James Dodson, 'A letter … concerning the variation of the magnetic needle; with a sett of tables annexed', *Philosophical Transactions* (1757–1758) 50, pp. 329–349; A.R.T. Jonkers, *Earth's Magnetism in the Age of Sail*, Baltimore: Johns Hopkins University Press, 2003, pp. 189–195.

16 The comment on the measurement of variation is based on the author's reading of a number of captain's journals in the British Library.

17 Captain Charles Haggis, journal of the *Prince Henry*, British Library IOR/L/MAR/B/325G. The journal also provides evidence of Haggis's care and competence as a navigator, both when Maskelyne is on board and afterwards. Haggis, for example, makes frequent and regular determinations of magnetic variation from measurements of solar azimuth or amplitude (or both), and later in the voyage he uses the new method of double altitudes for finding latitude from the sun, as a check on latitude determined by meridian altitude; this is discussed later in this article.

journal, where they are marked 'mine', and eventually Maskelyne does indeed mark these measurements in his *Journal* with 'H' for Haggis. Increasingly Maskelyne averages measurements, while keeping the readings from individual officers separate. Towards the end of the voyage there are small differences between readings in Maskelyne's and the captain's journal – perhaps reflecting some new negotiation or discussion regarding the official readings.

It might be hazardous to attempt a complete explanation of these changing patterns in the records but they certainly allow us to say that Maskelyne is engaging with an established navigational culture and its instrumental practices in a dynamic way as the voyage proceeds, that he came on board with a set of interests and ambitions and has accommodated a parallel set on the ship.

If we turn now to the record of longitude, on the first opening of the *Journal* there is no sign of attempted determination by lunars. This changes on the second opening, from 9 February, with the introduction of four new columns:

> Long. corrected by Obs$^{ns}$. of ☽
>
> Long by new Tables of Var$^{n}$.
>
> Long by Chart
>
> Long By Observ$^{n}$. of ☽.[18]

From these new headings, Maskelyne's ambition seems now to have changed. Previously, he had intended to compare the measured variation with the figures from the tables and the chart, for the positions of the ship in latitude (usually astronomically measured) and longitude (by account). His new columns suggest that he hopes to find the longitude using the measurements of latitude and variation. How could he test his results for longitude? The general motivation for seeking a new method stemmed from the acknowledged inadequacies of finding longitude by account. Maskelyne's project needed an independent measure of longitude and he introduced his lunar columns at the same time as those for longitude by variation. An alternative explanation is that Maskelyne was simply introducing two new methods for longitude alongside dead reckoning and that the outcome of this three-way trial would be evident on reaching St Helena.

Mountaine and Dodson had announced to the Royal Society in 1755 their ambition to update Halley's work with a new collection of variation measurements 'throughout the known world'.[19] They reminded the society that they had already published such a revised chart in 1745 but pointed out that, with the pattern in constant change, it was now time for another, more ambitious, effort. The use at sea of such data would be for steering correction and for position finding. In line with current maritime practice, they did not see this as the basis of a global solution to the longitude problem but as

18 Maskelyne, op. cit. (10), ff. 6v–7r.

19 William Mountaine and James Dodson, 'An attempt to point out, in a concise manner, the advantages which will accrue from a periodic review of the variation of the magnetic needle, throughout the known world', *Philosophical Transactions* (1753–1754) 48, pp. 875–880.

useful in gauging position with respect to known patterns of distribution. Indeed, such was the diversity in the pattern of variation that in places its measurement was more useful for finding latitude than longitude.

For their tables of 1757, Mountaine and Dodson reported that the commissioners of the navy and the directors of the East India Company had given them free access to all their masters' logbooks and journals, and that the Hudson's Bay Company had given them tables of observations made by their captains.[20] Maskelyne's *Journal* reveals a number of occasions where a longitude deduced from the tables was significantly closer to the longitude by lunars than was the longitude by account. On the first occasion, for example, on 9 February, the longitude by account was 27° 33′ (W), by the variation tables 29° 9′ and by lunars 30° 35′. On 11 February the equivalent figures were 26° 47′, 28° 18′ and 29° 22′.[21] Taking the lunar result as the standard, the longitude by variation was consistently better throughout the voyage. At this stage Maskelyne cannot have been certain that lunars were giving the most accurate results but this was amply demonstrated on reaching St Helena, where he could take the longitude by eclipses of Jupiter's satellites. The 'ship's common reckoning' was 7° 12′ in error; the position he deduced from his latest lunar measurement taken seven days before landfall was out by 1° 28′.[22] On both counts Waddington would report very similar results to the secretary of the Royal Society, Thomas Birch.[23]

Even the relatively good performance of magnetic variation for position cannot have encouraged Maskelyne in the thought that this could be the basis of a general method, however useful seamen found it in local and limited contexts. There would have been much interpolation in using these tables and, since Mountaine and Dodson set out their data in columns at intervals of roughly a decade between 1700 and 1756, it was clear that the changes over time could be dramatic.

Was the need for independent determinations of longitude, in testing the magnetic method, the stimulus for Maskelyne's engagement with lunars (as mooted above)? The evolution of the *Journal* might suggest so but this is probably not the whole story. That he equipped himself with a Hadley quadrant is hardly surprising for a mathematical astronomer preparing for a sea voyage. However, Maskelyne – admittedly with hindsight – gave this a more particular significance, writing to Birch from St Helena on 13 May,

> my principal attention on board of ship was taken up in observing the distances of the Moon from the Sun and stars, with a Quadrant which I had of M$^{r}$. Bird in order to be satisfied from my own experience of the practicability of that method of finding the Longitude.[24]

20 Mountaine and Dodson, op. cit. (15), p. 330.

21 Maskelyne, op. cit. (10), f. 6v. Maskelyne refers to his observations of 11 February in his paper in *Philosophical Transactions*: Maskelyne, 'A letter', op. cit. (12), p. 577.

22 Maskelyne, *The British Mariner's Guide*, op. cit. (12), p. 107.

23 Waddington to Thomas Birch, 13 May 1761, British Library MS Add. 4320, f. 83.

24 Maskelyne to Thomas Birch, 13 May 1761, British Library MS Add 4313, f. 242. The quadrant was of twenty inches radius and Bird was the leading maker of astronomical measuring instruments; Maskelyne affirmed, 'I was secured from any errors in the construction of the quadrant, by the known skill of the artist'. Maskelyne, 'A letter', op. cit. (12), p. 559.

Derek Howse has suggested, admitting to no more evidence than plausibility, that Maskelyne had been asked by the Astronomer Royal, James Bradley, or other members of the Board of Longitude to undertake lunar distance determinations as a continuation of the trials they had previously arranged of Tobias Mayer's lunar tables and reflecting circle, conducted by Captain John Campbell.[25] Maskelyne took with him the data – tables, ephemerides and a celestial chart – that would be used in such a project. Even if this was his intention, it seems that testing the magnetic method, not least with the benefit of all the measurements being taken on board, gave Maskelyne a reason to bring lunars into his regular programme of work and to accommodate them in the record of his *Journal*.

The first example of a lunar distance taken from the sun, of which we can be certain, is recorded for 10 February; there is then a determination using the star Cor Leonis (Regulus) on 15 February.[26] In the pages of Maskelyne's notebook surrounding the formally organized *Journal*, there is an apparent confusion of rough working and calculation, but it is possible to pick out some coherent sections. There is, for example, a record of Maskelyne keeping the longitude by account and comparing his positions with those of the captain.[27] As he became more familiar with shipboard life, he acquired the record of courses steered and distances from the first mate, along with his longitudes by account and again compared them with those of the captain. This activity by Maskelyne parallels his engagement with the ship's officers over magnetic variation. It may seem surprising that Maskelyne, who is so associated with astronomical methods, was becoming so concerned with dead reckoning, but the relevance of this will become clear.

Several of the lunar distance determinations are recorded in a fairly coherent way in the confusion of notes surrounding the *Journal*, for example the measurement by the moon and Cor Leonis on 15 February.[28] Maskelyne began by regulating his watch from an altitude of the sun. Talking himself, or rather writing himself, through his procedure, he then says that he measured the distance from the star to the western limb of the moon.[29] He had to adjust the watch reading by the correction found by his solar altitude observation, to find the current time at the meridian of that observation (the watch itself is not adjusted); he also made a further small correction for the rate of the watch, since the lunar distance was being taken some eight hours after the altitude. This can serve as a nice example of the kind of detail to which Maskelyne had to attend as he went through his long calculation.

What method was Maskelyne using in this early attempt at finding longitude by lunar distance? It may be the earliest for which we have a fairly full record. In this period we should not be thinking in terms of a single lunar distance method but of several alternative procedures and, within these, a number of variants for how the different steps are made. As the general method became established, this number of procedures and subprocedures increased rapidly, but we can begin with the choice Maskelyne sets out in

25 Howse, op. cit. (1), p. 29.
26 Maskelyne, op. cit. (10), ff. 6v–7.
27 Maskelyne, op. cit. (10), ff. 1r, 1v, 2v. See also Maskelyne, op. cit. (24), f. 242v.
28 Maskelyne, op. cit. (10), ff. 3v–5r.
29 The 'limb' is the edge of the apparent disc of the moon.

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his first published account, which appeared in the *Philosophical Transactions*. This was dated 9 September 1761 and sent from St Helena to Birch.[30] So although it was not read formally to the society until after Maskelyne's return, it concerned the outward voyage. At this stage Maskelyne had in mind two methods that had appeared in the astronomical literature.

A lunar distance method had been proposed by Edmond Halley and published in his posthumous *Astronomical Tables*, of 1752.[31] Here, only one observation is needed (apart from the altitude measurement to correct the time shown by the watch and check its rate). The lunar distance is the angle between the moon and a star at a similar altitude, or between the moon and the sun, if the moon is in her first or last quarter. We can take the case of measurement to a star. The ship's longitude by account is converted to an estimated time at the standard meridian, which Halley takes to be Greenwich, and using this assumed time, the longitude and latitude of the moon are calculated using the relevant tables and equations, transposed into the moon's right ascension and polar distance, and then the moon's zenith distance and azimuth for the ship's position by account. The zenith distance and azimuth of the star can be found from its tabulated right ascension and declination. Applying the calculated parallax and refraction as appropriate to these two positions (not the parallax to a star, which is much too small to be considered), the calculated apparent lunar distance is found and then compared with the measured apparent lunar distance. If the ship's longitude by account is correct, these will be the same and the longitude by account is confirmed. It is much more likely that a discrepancy will be found and used to make a second estimate of the time difference from Greenwich. The calculation is repeated for this revised value, followed by a proportional calculation using the two discrepancies to find the time difference from the standard meridian, and so the position where the discrepancy would be zero, which is the longitude of the ship.

Halley's method relies on solving the spherical triangle whose apexes are the zenith and the apparent positions of the moon and star. Two sides (the zenith distances of the moon and star for the assumed time, adjusted for parallax and refraction) are calculated, as is the angle at the zenith, being the difference in azimuth between the moon and the star. The third side is the apparent lunar distance.

In Maskelyne's paper in *Philosophical Transactions* he acknowledges that the single measurement is a convenience, but says he prefers the alternative method proposed by the French astronomer Nicolas Louis de Lacaille, which requires three simultaneous measurements – of the altitudes of the moon and the star in addition to the angle between them. Maskelyne gives a routine for using these measurements to adjust the measured lunar distance for refraction and for parallax. In the former spherical triangle the two measured altitudes, converted to zenith distance, and the measured apparent lunar distance, yield the azimuthal angle at the zenith. This in turn, once the two

30 Maskelyne, 'A letter', op. cit. (12).

31 Edmond Halley, *Astronomical Tables: with Precepts Both in English and Latin for Computing the Places of the Sun, Moon, Planets, and Comets*, London, 1752, sig (d) ff. Note also Halley, 'A proposal of a method for finding the longitude at sea within a degree', *Philosophical Transactions* (1731–1732) 37, pp. 185–195.

zenith distances are adjusted for refraction and parallax, can be used to solve the triangle containing the corrected lunar distance, which is then used for the longitude determination.[32] Finding this corrected value would thereafter be referred to as 'clearing the distance'.

The longitude by account gives a time difference from the standard meridian as before and the true lunar distance calculated on this assumption and compared with the corrected measurement. For this calculation Maskelyne says he has the advantage of lunar tables based on observations made at Greenwich and the lunar equations and tables of Tobias Mayer. It is necessary also to calculate what Maskelyne calls 'the horary motion of the moon', because the lunar motion varies over time.

Again there will probably be a discrepancy between the calculated true distance and the measured distance adjusted for refraction and parallax, but provided the discrepancy is not more than ten or twelve minutes and the lunar distance not less than twenty or thirty degrees, the horary motion of the moon in the ecliptic can be taken as her motion towards or away from the star, and its application will convert this discrepancy into a difference in time; that is, a correction to the longitude by account. Otherwise the calculation must be repeated for one hour later than the first and the two results will yield the horary motion of the moon to or from the star and in turn the correction for the longitude by account. Maskelyne points out that this is not, in fact, the longitude of the ship at the time of the lunar distance measurement but of the meridian where the observation was made to regulate the watch.

We have said nothing about a number of other considerations, such as the index error of the instrument, the semi-diameter of the moon and the dip (or depression) of the horizon, which depends on the height of the observer's platform. More importantly, we have taken for granted the involved procedures for actually making all these calculations, for which Maskelyne, and many others, would devise routines, desperately trying to reduce the time, labour and occasion for mistakes. Waddington said that, at this stage in the development of the lunar procedure, the calculation took six hours to complete.[33]

The first such reduction in time and labour, according to Maskelyne, would be to select Lacaille's method over Halley's: it requires more observations and more observers, but the two additional measurements greatly reduce the calculations that are needed, by providing more direct input from observation. To achieve this Lacaille adopts something closer to a team of observers, instead of Halley's lone mathematician. The longitude by account is essential to both methods and we now understand why Maskelyne headed the first column for lunars added to his *Journal* 'Long. *corrected* by Obs$^{ns}$. of ☽' (emphasis

32 For secondary accounts of the lunar method see Charles H. Cotter, *A History of Nautical Astronomy*, London: Hollis & Carter, 1968; W.E. May, *A History of Marine Navigation*, Henley on Thames: Foulis, 1973; Derek Howse, *Greenwich Time: And the Discovery of the Longitude*, Oxford: Oxford University Press, 1980; J.B. Hewson, *A History of the Practice of Navigation*, Glasgow: Brown, Son & Ferguson, 1983; Howse, 'The lunar-distance method of measuring longitude', in Andrewes, op. cit. (5), pp. 150–162. Note also Simon Schaffer, 'Swedenborg's lunars', *Annals of Science* (2014) 71, pp. 2–26. Still useful is Andrew Mackay, *The Theory and Practice of Finding the Longitude at Sea or Land*, London, 1793. For Lacaille see Ian Stewart Glass, *Nicolas-Louis De La Caille, Astronomer and Geodesist*, Oxford: Oxford University Press, 2012, esp. pp. 37, 114, 128–129, 140.

33 Waddington to Pigott, 26 May 1761, Royal Astronomical Society, RAS MSS Pigott, 84.

added). He used a similar expression in writing to Birch on 13 May, referring to 'my reckening [*sic*] corrected from my observations of the Moon'.[34]

In his paper in *Philosophical Transactions* Maskelyne is emphatic about what happened on the voyage to St Helena: Lacaille's was, he says,

> the method I constantly practised myself, during my voyage, having always two observers, who were ready, one to take the altitude of the star, and the other of the Moon's upper or lower limb, at the instant I spoke when I had made the observation of the distance of the star from the Moon.[35]

He also describes his calculations as based on a standard meridian at Greenwich and the only specific tables he mentions had been prepared by the assistant at Greenwich, Gael Morris, from observations by James Bradley, Morris having had the benefit of the lunar equations and tables of Tobias Mayer.

How does this compare with what the notebook tells us about Maskelyne's practice at sea? We can resume our examination of Maskelyne's procedure on 15 February, where we saw that he took a lunar distance to Cor Leonis and noted the corrected time for the meridian of the prior solar altitude measurement. Maskelyne then tells himself, 'The next thing to be done is to Compute Altitude of Moon & Star at the time of the Observation in order to allow for refraction & Parallax'.[36] This he proceeds to do: he finds the lunar altitude not from a measurement but by calculation. 'For this purpose', he continues, 'I take the ☽'$^{s}$. Long & Lat out of the Connoissance Des Temps for the given time which by Acc$^{t}$. is $11^{h}.29^{m}.3^{s} + 1^{h}.30^{m}.28^{s}. + 9^{m}.30^{s}. = 13^{h}.9^{m}$. At Paris'. The first figure there is the corrected local apparent time for the meridian of the solar altitude measurement, the second is the ship's longitude by account, converted to time, and the third is the time difference between London and Paris.

There are two things to note here. Maskelyne is using tables from the *Connaissance des temps* – something he does not acknowledge in his *Philosophical Transactions* report, with its emphasis on Greenwich. More importantly, his method sits somewhere between Halley's and Lacaille's. There is no reference to measurements of the altitudes of the moon and star. From the Paris time of his measurement, he uses the *Connaissance des temps* to find the longitude and latitude of the moon; that is, its position with respect to the ecliptic. For Cor Leonis, he takes the right ascension and declination from Senex's chart of the zodiac.[37] From these data he calculates the altitudes of the moon and star and uses these values to clear the distance.

Having corrected his measured lunar distance for refraction and parallax by computation, without additional observations, Maskelyne then calculates a lunar distance for the assumed time and finds a discrepancy of 2′ 37″ from the cleared observed distance,

34 Maskelyne, op. cit. (24), f. 242v.

35 Maskelyne, 'A letter', op. cit. (12), p. 564.

36 Maskelyne, op. cit. (10), f. 3v.

37 John Senex, *Zodiacus Stellatus fixas omnes hactenus cognitas, ad quas Lunae Appulsus ullibi; Terrarum Telescopio Observari poterunt, complexus*, London, 1718; Deborah J. Warner, *The Sky Explored: Celestial Cartography, 1500–1800*, New York: A.R. Liss, 1979, pp. 239–242.

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which, applying the horary motion of the moon, yields a difference of 4′ 17″ of time or 1° 4′ of arc between the actual longitude of the ship and the longitude by account.[38]

By contrast, we can look at Maskelyne's rough notes for his measurement to the star Spica (Alpha Virginis) on 25 March, some five and a half weeks later, where there are three distance observations, each accompanied by a time from the watch, the altitude of the lower limb of the moon and the altitude of the star.[39] They extend over seventeen minutes, and the three astronomical measurements within each group are simultaneous. There are at least three and quite possibly four observers (one reading the watch) working together. Maskelyne has recruited a team.

We can be certain that Maskelyne had been engaging the crew's interest in his lunar observations from the beginning, for Captain Haggis records his first observation, the one on 10 February: 'Longitude computed from an Observation of the distance of the Moon from the Sun taken by the Rev. M$^{r}$. Maskelyne, and reduced to Noon 30°:22′ West'.[40] This figure agrees with Maskelyne's in his *Journal*, in the *Philosophical Transactions* and in *The British Mariner's Guide*. Haggis records almost all Maskelyne's subsequent determinations fully in his journal and the attention he devotes to this is evidence of his engagement with what Maskelyne is doing.[41] However quickly Maskelyne came fully to adopt Lacaille's method, it must have been based on a growing assurance, as he became more accustomed to shipboard life, that an East Indiaman was a place where the necessary skilled assistance was available, where taking altitudes with a Hadley quadrant, for example, was a familiar procedure.

Historians are inclined to a generally positive assessment of seamanship in East India Company vessels and this includes, tentatively at present, their navigational practice, even if it did not necessarily entail the use of the latest work of the theoreticians.[42] While the present study is narrow in scope, it adds to an impression of competence in technical aspects of navigation. A good example of this is Captain Haggis's use of the method of finding latitude by two ex-meridian altitudes of the sun, published by Richard Harrison 'of Whitehaven' in 1759 with a set of 'New Logarithmic Solar-Tables'.[43] Maskelyne tried the method successfully, using Harrison's tables, on the voyage to St Helena and Haggis took this up on his onward voyage to China, using it

38 Maskelyne, op. cit. (10), f. 4v.

39 Maskelyne, op. cit. (10), f. 10v.

40 Haggis, op. cit. (17), 10 February 1761.

41 Haggis, op. cit. (17), 11, 19, 28 February, 9, 10, 13, 18, 25, 26, 29 March 1761.

42 For some of the literature on this see Andrew S. Cook, 'Establishing the sea routes to India and China: stages in the development of hydrographical knowledge', in H.V. Bowen, Margarette Lincoln and Nigel Rigby, eds., *The Worlds of the East India Company*, Woodbridge: Boydell Press, 2002, pp. 119–136; David Philip Miller, 'Longitude networks on land and sea: the East India Company and longitude measurement "in the wild", 1770–1840', in Richard Dunn and Rebekah Higgitt, eds., *Navigational Enterprises in Europe and Its Empires, 1730–1850*, Basingstoke: Palgrave Macmillan, 2015, pp. 223–247. For a recent analysis of the relationship of practice with theory, though mainly treating a slightly later period, see Jane Wess, 'Navigation and mathematics: a match made in heaven?', in Dunn and Higgitt, op. cit., pp. 201–222.

43 Richard Harrison, *A New Sett of Logarithmic Solar Tables, Calculated and Constructed for Determining the Latitude at Sea, by Taking Two Altitudes either in the Forenoon or Afternoon, with the Intermediate Time by a Common Watch*, London, 1759.

as a check on his determinations by the meridian altitude of the sun.[44] It seems very likely that Maskelyne had introduced him to the method (Maskelyne would publish an account in *The British Mariner's Guide* of 1763) and the set of tables he probably left with Haggis concluded with an advertisement from the printers Mount, Page & Son for Mountaine's 'New Variation Chart', and a pamphlet on its use 'in correcting the Longitude at Sea' – just what Maskelyne had been trying to do.[45]

We might note that Richard Harrison presents the double-altitude observation as yielding not only the latitude but also the local time, so it can be a vital component in the chronometer method for longitude, where standard time kept by the watch is compared with local time at the ship, found astronomically. Double altitudes would be especially valuable, when an effective meridian sight is not possible:

> if such a Thing as an Automaton could be constructed, that would keep true regular Time (for which Mr. Harrison bids the fairest) it would be of the greatest Utility in this respect [finding longitude]; yet then, this would not avail, unless the true Time of Day could be had.[46]

Double-altitude work required astronomical measurement followed by challenging calculation, and its integration into longitude finding by 'automaton' illustrates the dangers of a polarized treatment of the two principal candidate methods for longitude.

While supporting a positive assessment of navigational skill in East Indiamen at this time, this study also suggests that the question should not be reduced to whether officers adopted the published recommendations of shore-based mathematicians. They had a mathematical culture of their own, which was open to innovation, certainly, but when the opportunity arose, could be part of a more dynamic exchange of knowledge and skill. In turn, Maskelyne's facility with the quadrant was improving also. He explained, for example, how he developed a technique of rocking the quadrant – sweeping the direct image of the star in alternate directions past the target limb of the reflected image of the moon until he was sure of contact.[47]

Maskelyne's initial, 'hybrid' procedure, where the altitudes of moon and star were calculated, not measured, survived to appear in *The British Mariner's Guide*, even though Maskelyne had by then fully embraced Lacaille's method, with its additional observations. There it appears in an appendix intended to cover what 'may sometimes happen, though very rarely, that, at the observation of the distance of the moon from

44 Maskelyne, op. cit. (24), f. 242; Haggis, op. cit. (17), 25, 26, 27, 28, 29 May; 1, 2, 3 June, and *passim*. We can be sure that Haggis was using Harrison's treatise, since he begins the record of his first observation, 25 May, with: 'By the New Logarithmic Solar Tables, Calculated and constructed for determining the Latitude at Sea, by taking two Altitudes …', cf. the title at note 43.

45 Maskelyne, *The British Mariner's Guide*, op. cit. (12), pp. 70–79. Note also the contemporary interest of Henry Pemberton, 'Some considerations on a late treatise intituled, *A New Set of Logarithmic Solar Tables, &c.* intended for a more commodious method of finding the latitude at sea, by two observations of the sun', *Philosophical Transactions* (1759–1760) 51, pp. 910–929. Harrison, op. cit. (43), p. 31v, note also sig. A2. Dodson, who had died in 1757, is not mentioned.

46 Harrison, op. cit. (43), sigs. A2–A2v.

47 Maskelyne, 'A letter', op. cit. (12), p. 560.

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the star, the altitude of the star, and even that of the moon, cannot be taken with sufficient certainty'.[48]

We now appreciate Maskelyne's interest in the longitude by account: it was an essential ingredient in the lunar calculation. It was still important, naturally, for him to emphasize the inadequacy of dead reckoning. Having disembarked on St Helena on 6 April, Maskelyne wrote to Birch on 13 May that 'the different Accounts of the Ship' put her between 7½° and 10½° to the east of the island. This will have been on the basis of the longitude assigned to St Helena by Halley from his observations in 1677, which Maskelyne's 'reckening [*sic*] corrected from my observations of the Moon' missed by only 1¾°, without, he said, the benefit of a lunar determination for the previous eleven days.[49] Maskelyne later refined the longitude of St Helena by observations of Jupiter's satellites and committed himself in print to 'the common reckoning' being in error by 7° 12′ and his own figure being 'only 1d. 28m. from the true longitude'. He now knew that many such reckonings were being kept on board on the basis of the 'common log' maintained by successive officers of the watch: 'Many reckonings kept on board the ship were no less than ten degrees erroneous'.[50]

## Robert Waddington

One of those keeping an account was Robert Waddington: he refers to it in a letter he wrote to Birch on 13 May.[51] He too had become part of a shared routine on board, telling Birch that they were on the equator on 21 February at noon, not only by his own observations but 'Several Others in y$^{e}$ Ship made no Lat[itude] this day'. Maskelyne's *Journal* concurs, showing zero as the observed latitude. Their figures for the longitude by account, however, differ by some 4½ degrees. Waddington says that the captain complimented him on keeping the best account on the ship – at landfall it was indeed slightly better than Maskelyne's.[52]

Moving to longitude by lunars, Waddington gave Birch eleven determinations, beginning with one on 28 February, which is different from Maskelyne's of the same date. Five determinations between 9 and 15 March coincide with Maskelyne's values, after which they again diverge and sometimes occur on different days. The values they give

48 Maskelyne, *The British Mariner's Guide*, op. cit. (12), pp. 53–56.

49 Maskelyne, op. cit. (24), f. 242v. Eleven was a mistake, which he corrected in later accounts to seven or to eight.

50 Maskelyne, *The British Mariner's Guide*, op. cit. (12), p. 107; cf. Maskelyne, 'A letter', op. cit. (12), p. 574. Waddington concurs, reporting as early as 13 May that the accounts kept by the mates were out by between ten and eleven degrees. Waddington, op. cit. (23), f. 83.

51 Waddington, op. cit. (23), f. 83.

52 Maskelyne's determination of the longitude of St Helena by Jupiter's satellites was 5° 44′ west of London (i.e. not Greenwich, which was five minutes to the east of the London meridian, generally taken as St Paul's Cathedral). Maskelyne, *The British Mariner's Guide*, op. cit. (12), p. 107. The final longitude by account in Maskelyne's *Journal* is 1° 28′ east (the prime meridian is not specified but was probably London); the captain's journal 1° 37′ east (surely of London); we do not have Waddington's journal but his letter to Birch of 13 May records his longitudes to, at best, half a degree, the final one being one degree east (though he does specify London). Waddington, op. cit. (23), f. 83.

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throughout for the longitude by account are different; we know already that they were keeping separate accounts. Over the period when their lunar determinations coincide, the outcomes are so close that they must have been collaborating in some way, even if that amounted only to exchanging results. The determinations by lunars recorded by the captain always coincide with Maskelyne's, so not always with Waddington's.

In a letter of 26 March to Nathaniel Pigott, Waddington associated himself with Maskelyne's lunar determinations: 'The Rev. M$^{r}$. N. Maskelyne & I made several Observations viz 18 In Order to find y$^{e}$. Longt$^{d}$ of y$^{e}$ Ship', using only a Hadley quadrant and a 'stopwatch' and reliably achieving an accuracy of one degree.[53]

It seems likely that Waddington was, at least sometimes, a member of Maskelyne's 'team', along with ship's officers. Maskelyne notes trying out Waddington's quadrant.[54] It seems also that Waddington made independent determinations and we cannot be certain whether he assembled a team of his own on such occasions, though it seems likely.

In 1763 Waddington published *A Practical Method for Finding the Longitude and Latitude of a Ship at Sea*, wherein we find a determination for 18 March, a date with a measurement also in Maskelyne's *Journal*, where Maskelyne finds a mean longitude value from two determinations, one from a measurement to Pollux, the other (some two hours later) to Spica, on either side of the moon.[55] Waddington also records distances to Pollux and to Spica – three each, plus the moon and star's altitudes in all six cases, and in addition two altitudes of Spica for finding the time (i.e. as a substitute for a solar altitude the previous day). It is difficult to see how all this could have been done without assistance. None of Waddington's results coincides with any of Maskelyne's and, of course, his longitudes by account are also different. They both believe that consistency between the results from two stars speaks for the soundness of the method and the accuracy of a particular result; for Maskelyne the difference between them is thirty-three minutes of arc, for Waddington twelve minutes.

The captain also records the two determinations from measurements to Pollux and to Spica; as always his values coincide with those of Maskelyne. It seems that 18 March may have been a memorable night for navigational activity on board the *Prince Henry*. Maskelyne and Haggis both note it was calm and fair.[56]

We can be more definite about Waddington's role on his homeward voyage: he was no longer with Maskelyne, so any initiatives for lunar determinations of longitude were due to him. He took ship on 29 June in another East Indiaman, the *Oxford*, Captain William Webber. *A Practical Method* has a table of nineteen determinations of longitude by lunars between 6 July and 4 September.[57] Two are mentioned in the captain's journal – on 23

53 Waddington to Pigott, 26 May 1761, Royal Astronomical Society, RAS MSS Pigott, 84.

54 Maskelyne, op. cit. (10), ff. 39v–40r.

55 Robert Waddington, *A Practical Method for Finding the Longitude and Latitude of a Ship at Sea by Observations of the Moon*, London, 1763, pp. 25–26; Maskelyne, op. cit. (10), ff. 7v–8r. See also Maskelyne, 'A letter', op. cit. (12), p. 577.

56 Maskelyne, op. cit. (10), f. 8r; Haggis, op. cit. (17), 18 March 1761.

57 Waddington, op. cit. (55), p. 11, note also pp. 12–23. See also Waddington to Pigott, 7 January 1762, Royal Astronomical Society, RAS MSS Pigott, 85.

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August a 'Long$^{de}$: by M$^{r}$. Waddingtons Obs$^{n}$:' is noted separately from the usual record, and on 2 September: 'Long$^{de}$. from London at Noon by Observ$^{n}$: of Dist$^{ce}$. of ye Sun and Moon'.[58] Webber uses this longitude result to reset his account, or rather to begin a new account that he maintains every day, separate from the standard entries in the journal, until he is within sight of the English coast. The observation itself was to be important, at least symbolically, as it became the first full longitude determination to appear in print.

After Waddington's return to London on 21 September, with Maskelyne still on St Helena, notices began to appear in London news-sheets mentioning Waddington's success in determining longitude at sea. An advertisement for 4 November announced his 'New Mathematical Academy' near the Monument, equipped with an observing platform for learning the method recently used on the St Helena voyages, for which the advertisement claimed an accuracy generally to less than half a degree and always to less than a degree.[59] These figures were, of course, significant in relation to the rewards at the dispensation of the Board of Longitude: £10,000 for a method accurate to within one degree, £20,000 if within half a degree.

The first published lunar distance calculation arising from the St Helena expedition came from Waddington's return voyage. It appeared in what may seem an unlikely place, but for a mathematical practitioner such as Waddington it was perfectly appropriate. Over three successive issues of Benjamin Martin's *Miscellaneous Correspondence* (a section of his monthly *General Magazine of Arts and Sciences*), from June 1762, he gave first the observation made on the *Oxford* on 2 September, which, as the captain noted, was a distance between the moon and the sun.[60] Waddington sets out nine times for lunar distances in three groups, each group having measured altitudes for sun and moon.

Since Waddington offers little by way of explanation, these printed calculations would have been of scant help in introducing a seaman to Waddington's method and they were perhaps intended more to assert a claim for a promising method for longitude at sea. He gives a fuller account of this example in *A Practical Method*, where he refers to this earlier derivation as having been 'by a more Lax Calculation made at Sea, as published in the General Magazine for July [*sic*] 1762'.[61] A second determination, in Martin's July issue, has six measurements for 4 September, again with three altitudes of the moon and sun. On the latter occasion, the times of all the individual measurements are different and never closer to one another by less than two minutes, so Waddington may have been working alone. He mentions the two possibilities we noted with Maskelyne – finding altitudes by observation or by calculation:

58 Captain William Webber, journal of the *Oxford*, British Library IOR/L/MAR/B/588D.

59 Bennett, op. cit. (4), pp. 67–80.

60 On this aspect of Martin's confusing output of publications see John R. Millburn, *Benjamin Martin: Author, Instrument-Maker, and 'Country Showman'*, Leiden: Noordhoff, 1976, pp. 69–71; Robert Waddington, 'To find the longitude of a ship at sea, by observations of the distance of the sun and moon, or of the moon and a known fixed star of a small latitude', in Benjamin Martin, *Miscellaneous Correspondence in Prose and Verse* (June–August 1762) 4, pp. 879–881, 895–897, 911–912.

61 Waddington, op. cit. (55), pp. 12–23.

> it frequently happens (in Cloudy-weather) that the Observer has occasion for two Assistants, *viz*. one to take the Altitude of the Sun and the other the Altitude of the Moon, at the same Time that the Distance of the ⊙ and ☽ is taken; which will (oftentimes) save the Trouble of having their Altitudes to compute, but when the Weather is pretty clear then one Person may make all the Observations necessary.[62]

So having assistants taking altitudes is particularly valuable in cloudy weather and will save computation, though in clear weather it is possible for one person to make all the observations. Looking at the times in these two cases, it seems that Waddington had assistant observers on 2 September but was probably working alone on 4 September. The captain's journal records 'A Pleasant Gale and fair weather'.[63]

In the concluding episode of Waddington's paper, published in Martin's August issue, he reports three measurements of the moon from the sun, made from the observing platform at his academy by the commander of an East Indiaman. The seaman also made the computation, which included computing the altitudes of the sun and moon, presumably because there was no horizon. Finally Waddington gives a determination from 14 June 1761, i.e. on St Helena, with computed altitudes.[64]

In *A Practical Method* Waddington gives two determinations with altitudes of the sun and moon taken by assistants. These were on 9 July and 23 August, on his homeward voyage, so we can be sure that, like Maskelyne, he was collaborating with officers on the ship. [65] We also learn that, again like Maskelyne, he used, on different occasions, the *Connaissance des temps*, and tables from Gael Morris at Greenwich.[66]

## Conclusion

What of Maskelyne's return voyage? He departed St Helena on 19 February 1762 on board the *Warwick*, Captain James Dewar. He kept a journal that does not survive, but again he extracted a table of longitude determinations for *The British Mariner's Guide*.[67] Dewar noted Maskelyne's measurements of longitude by lunars in the official journal, though for this voyage only five of them.[68] Maskelyne's published extract contained nineteen observations on sixteen dates. One of these provided him with the measurements for the first fully worked longitude by lunars he published, based on 'a set of actual observations, taken by myself, and the officers of the ship … on our return from St. Helena'.[69]

Following their voyages, Maskelyne and Waddington pursued separate but parallel strategies for promoting the lunar method, involving publishing a practical textbook, followed by tables for the moon (in Maskelyne's case the lunar distance tables in the

62 Waddington, op. cit. (60), p. 897.

63 Webber, op. cit. (58), 2 September 1761.

64 This example is repeated in *A Practical Method*, Waddington, op. cit. (55), pp. 27–28.

65 Waddington, op. cit. (55), pp. 23–25.

66 Waddington, op. cit. (55), p. 13.

67 Maskelyne, *The British Mariner's Guide*, op. cit. (12), pp. 108–110.

68 Captain James Dewar, journal of the *Warwick*, British Library IOP/L/MAR/B/585H, ff. 149 (21 April 1762), 150v (26 April and 27 April), 151 (28 April), 152 (2 May).

69 Maskelyne, *The British Mariner's Guide*, op. cit. (12), pp. 14–52, 14.

*Nautical Almanac*) to save much of the calculation at sea, and working on more efficient means of clearing the distance. They both sought to make use of the contacts they had made with East India Company officers. Waddington had some success with a training programme using the observing platform at his academy. When Maskelyne presented a memorandum on lunars to the Board of Longitude in February 1765, he produced written endorsements from two East India Company captains, Charles Mears and James Dewar, and brought forward in person four other officers, who had recently served as first, third, fourth and sixth mates, to be questioned on their experience of the method.[70] These were not empty testimonies: both captains had been on voyages since Maskelyne's return, Mears to China and Dewar to India. Both their journals for these voyages have frequent determinations of longitude by lunar distance.[71] We should remember that this was before navigators had the considerable assistance of the *Nautical Almanac*. Mears affirmed that determinations 'were found very useful & not difficult, each Observation not taking up more than four hours to find the result'.[72]

It was, of course, a vital part of the case for the lunar method that it was within the abilities of ships' officers, just as the chronometer method depended on a successful timekeeper being within the abilities of many skilled watchmakers.[73] In summing up his success on the voyage home, Maskelyne was anxious to disavow any special skills of his own:

> I would not be understood … to arrogate any particular merit or skill to myself in making these observations, which others may not equally attain with the same care and experience; since I am satisfied, from the near agreement of many observations, taken by the officers of the Warwick, with my own, taken at the same instant, that mariners properly instructed in making the observations … and moderately exercised in the practice of them … will be able to determine their longitude … within the limits [of] … about a degree.[74]

Here too is further evidence, if any were needed, of Maskelyne recruiting a team.

We can conclude that there were 'mathematicians on board' in more than one respect: Maskelyne and Waddington brought their mathematical culture on board but they encountered a mathematical practice to which they accommodated and aspects of which they would assimilate to their methods for finding longitude.[75] Maskelyne realized that he was able to find the skills required for the teamwork characteristic of

70 Cambridge University Library, Board of Longitude Confirmed Minutes RGO 14/5, pp. 78–81.

71 Captain Charles Mears, journal of the *Ermont*, British Library IOR/ L/MAR/B/535D, see longitude determinations in 1763: 5 March, 3, 16 June; in 1764: 19, 22 April, 20, 22 May, 19, 20, 21, 22, 23 June, 6, 7 July. Mears also tries finding the latitude by two altitudes of the sun 'According to the Revd Mr Maskelyn's [*sic*] method' on 9, 10, 11, 12, 13 July 1764. Captain James Dewar, journal of the *Speaker*, British Library IOR/ L/MAR/B/548 A, see longitude determinations in 1764: 22 May, 6, 8, 21, 22 June, 5, 12, 16, 17, 23 July, 2, 4, 5, 31 August, 5, 7, 21 September, 1, 3, 29 October, 1 November.

72 Cambridge University Library, Board of Longitude Confirmed Minutes RGO 14/5, p. 80.

73 For a discussion of the challenges of making such judgements see Bennett, op. cit. (9).

74 Maskelyne, *The British Mariner's Guide*, op. cit. (12), p. 117.

75 For a slightly earlier case of significant and innovative navigational skill on the part of a lifelong seaman and Hudson's Bay captain, Christopher Middleton, see Jim Bennett, 'Adventures with instruments: science and seafaring in the precarious career of Christopher Middleton', forthcoming in *Notes and Records: The Royal Society Journal of the History of Science*.

Lacaille's method, and so did Waddington. The present study supports a positive view of the navigational competence of East India Company officers, as well as their interest in the potential for innovation and improvement.

At the end of this experience of life on board, Maskelyne described the final observation on the last of the three voyages, his own homecoming. On 13 May 1762 at about 2 a.m. on a night that he recorded was very fine, he could see the lights on the two towers erected on the Lizard in Cornwall in 1751. He took five lunar distances to Antares. We have noted the skill Maskelyne developed of rocking the quadrant, so that the star appeared to sweep by the limb of the moon. On this occasion he says, 'the sea was almost perfectly calm, the motion thereof being very gentle and regular, so that it was rather an advantage to the observations in causing the star to sweep the moon's limb, than of any prejudice'.[76] For this final observation the regular movement of the ship provided the rocking the observer needed, as he held the quadrant steady and called out the moment of contact. This story has been one of accommodation of a mathematical culture to the routines and resources of life on board and it ends well with an image of the mathematician in harmony with the sea.

76 Maskelyne, *The British Mariner's Guide*, op. cit. (12), p. 104.