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PRECISION EXPLORATION: MATHEMATICAL PRACTICE AND 18TH CENTURY BRITISH VOYAGES OF SCIENTIFIC EXPLORATION

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Abstract: This paper looks at the role of 18th-century mathematical practitioners in establishing precision observation as a key element of crown- and state-funded voyages of scientific exploration. This was characterised by the careful use of a suite of mathematical instruments and texts by skilled individuals travelling to uncharted lands. Initially, these were men of precarious employment, creating piecemeal mathematical careers, but they developed an approach that in the 19th century could be taken on by career naval officers.

I. As Stephen's paper has shown, practical mathematicians were long connected to maritime voyages. However, it was in the 18th century that we find more regular, state-funded attempts to embed such skills on elite voyages of scientific exploration. This **first image** is a detail from a print of one such voyage: the third circumnavigation of Captain James Cook, showing the ships *Resolution* and *Discovery* in the Society Islands in the 1780s. Just visible in the background is their land camp, including what are probably observing tents, marking the location of the practical mathematician observers and their precision instruments. These voyages were relatively small in number but widely publicised and influential, paving the way for the more consistent support of survey voyages in the 19th century.

By practical mathematician, I include those applying, as well as teaching or writing in support of the application of, mathematics to activities such as navigation, survey, architecture, engineering, ballistics, gauging and instrument making. Such skills were developed within the navy and army, and by the 19th century underpinned two groups – Practical Mathematicians and Scientific Servicemen – that David Miller has identified as core to the disciplinary and institutional development of the physical sciences.[1] However, in the second half of the 18th century, the mathematicians on board ships, pioneering what I call precision exploration, were supernumeraries. They were not mariners or naval officers, but land-based civilians with skills that brought them a range of irregular opportunities. In this talk I will ask who they were, how they became expeditionary astronomers and what the results of this move were. I should note that this was by no means only a British phenomenon – there were Russian, Spanish and, especially, French voyages of scientific exploration too – but this is the context I will focus on today.

II. There were earlier examples of including, and attempts to encourage, mathematicians and mathematics on board ships. There was **Edmond Halley**, a natural philosopher, astronomer and mathematician who voyaged

[1] David Philip Miller, 'The Revival of the Physical Sciences in Britain, 1815-1840', *Osiris* 2 (1986), 107-134.

abroad to make observations of the southern stars and a transit of Mercury from the island of Saint Helena in 1677. He was, during a brief interlude of peace in 1690s after the end of the Nine Years' War, also very unusually made a captain in order to take charge of a naval voyage to investigate terrestrial magnetism in the Atlantic.

There were several initiatives to increase the number of skilled individuals within the navy. Attempts in the 1670s to encourage the use of astronomical methods to find longitude at sea – relying on precision instruments, astronomical tables and calculation – were supported by the creation of the **Royal Observatory, Greenwich**, and the foundation of the Royal Mathematical School, intended to teach boys before being apprenticed to a sea captain. The first Astronomer Royal, John Flamsteed, was rather dismissive of the abilities of most seamen – blaming "Ignorance" and "the Poverty of the braine, proceeding from an Obstinate Laziness" – but he offered advice on the school's curriculum and taught boys and young men intended for sea service privately.[2] He suggested that the right combination of sober pupil and skilled Master would, after practical apprenticeship at sea, produce inventive and diligent navigators. He is shown here on the ceiling of the Painted Hall at the Royal Hospital for Seamen at Greenwich, as master to his apprentice Thomas Weston, himself later a teacher of mathematics for navigation.

Another of Flamsteed's former assistants was his nephew-in-law, **James Hodgson**. Hodgson had been assistant at Greenwich from 1695 to 1702, became a mathematical teacher and author, and natural philosophical lecturer, in London before being appointed mathematical master at the Royal Mathematical School in 1709. If the textbook he produced for his pupils and wider public in 1723, *A System of the Mathematics*, is anything to go by, his hope was that boys trained in mathematics and the theory of astronomy and navigation before undertaking a practical apprenticeship, had the potential to apply astronomy to improve navigation. They might, he suggested, make the lunar-distance method of finding longitude a practical proposal: "I cannot help thinking, that if Men would set about it in good Earnest, they would not fail to meet with Success at Sea."

Some of these pupils became commanders but others applied for the rather lowly position of naval schoolmaster. Since 1702, they were placed on ships to instruct "not only in the theory but the practical part of Navigation" and "the Art of Seamanship". Their competence, like that of the Mathematical School pupils, was certified by the maritime guild Trinity House after being grilled by their mathematical examiner. **Hodgson suggested** that the naval schoolmasters might take on an augmented role, if given the means:

> let every one of His Majesty's Ships of War be provided with a good *Telescope*, a small *Quadrant*, and a good *Time-keeper*, and let the Teacher of *Mathematicks* appointed for that Ship, be obliged in every Port he comes into, to make all the Observations that happen during the time of his stay there; and let him be obliged at his return home, to bring them to the *Royal Society*, or to any Person or Set of Men whom the Government shall think fit to appoint for this Purpose....[3]

in order to add to and improve charts. This would be as effective as "sending Two or Three Ships abroad, to put these and other Methods that have been proposed in Practice", which he said that others unnecessarily called for. However, schoolmasters were poorly paid and had little status on board ships. Flamsteed, Hodgson and others lamented that mathematical skills were not more appreciated or recognised.

[2] Quoted in Rob Iliffe, 'Mathematical Characters: Flamsteed and Christ's Hospital Royal Mathematical School', in Frances Willmoth (ed), *Flamsteed's Stars: New Perspectives on the Life of the Astronomer Royal, 1646-1719* (Woodbridge: The Boydell Press, 1997), pp. 115-144, p. 141.

[3] James Hodgson, *A System of the Mathematics*, vol 1 (London: 1723), p. 385.

III. Those two or three ships Hodgson mentioned were, of course, to be set to work in the second half of the century and had considerably more than a schoolmaster and the **three key instruments** on board. The 18th century was to see a succession of naval conflicts, but the voyages of scientific exploration were to find their moment after the end of the Seven Years' War (1763) and before the beginning of the Napoleonic Wars (1803).

The first of the Royal Navy's scientific voyages is usually identified as that of the *Dolphin*, which carried out two circumnavigations after the end of the Seven Years' War. This certainly signals the Admiralty's burgeoning interest both in ambitious voyages and the use of skilful navigators and surveyors. On board the 1766-68 voyage was John Harrison – not the clockmaker but the ship's purser – who was capable of making lunar-distance observations to fix positions, though not necessarily the hard mathematical work to fully process his observations.[4] However, crucial to the story of expeditionary astronomers and mathematicians that I want to tell is a voyage preceding that, more in the mould of Halley's trip in 1677. Again, to **Saint Helena**, and again involving a man subsequently to become Astronomer Royal, this was to observe to the 1761 transit of Venus. Nevil Maskelyne and this voyage were to be an important – and I've argued too much overlooked – contribution to what was to become a tradition.

While Maskelyne's role as observer and organiser undoubtedly helped him become Astronomer Royal, that was not a given. Although he was a Cambridge graduate and Fellow of the Royal Society, and a curate, he was also a jobbing astronomer and mathematician. The Royal Society paid him as an observer with a grant from George III (suitably convinced by the Society that transit of Venus observations would benefit the nation by demonstrating scientific prowess and by improving the accuracy of astronomy and, therefore, of navigation). Maskelyne again took on such paid work for the Board of Longitude in 1763, acting as both chaplain and astronomer on a voyage to Barbados to trial three methods of finding longitude. In between he published the ***British Mariner's Guide***, supporting the practical use of the lunar-distance method, which he had used with some success on his first voyage. He suggested that this could become a practical method if the kind of pre-computed tables that he presented (borrowed from ones published by the French astronomer Nicolas-Louis de Lacaille) could be regularly calculated and published in advance. This was, perhaps, a prospectus for potential employment, whether as a teacher, expeditionary astronomer or author of such tables. He could not know that the new Astronomer Royal, Nathaniel Bliss, would die after only two years in post.

Maskelyne's assistant on the St Helena voyage was Robert Waddington, whose career, as Jim Bennett has shown, is a kind of shadow to that of Maskelyne; an alternative and more precarious one, lacking Maskelyne's university education and London contacts and also, perhaps, luck.[5] Waddington had likewise made successful longitude observations and **published a book** that demonstrated the practicality of the lunar-distance method, but his career was to remain what Maskelyne's might have been: the mathematical practitioner teaching mathematics and navigation, selling and improving instruments and publishing navigational textbooks. His hopes that he might receive a reward from the Board of Longitude or some more permanent position, or patronage came to naught. His patchwork, piecemeal career is, however, more typical than Maskelyne's of the expeditionary astronomers.

[4] Richard Dunn, 'John Harrison, pioneer of lunar distances', Longitude Project Blog (2013) https://www.rmg.co.uk/discover/behind-the-scenes/blog/john-harrison-pioneer-lunar-distances.

[5] Jim Bennett, '"The Rev. Mr. Masklyne, F.R.S. and Myself": The Story of Robert Waddington", in Rebekah Higgitt (ed.), *Maskleyne: Astronomer Royal* (London: Robert Hale, 2014), pp. 59-88.

IV. As Astronomer Royal, and thus chief authority on astronomy and navigation within the Royal Society and a Commissioner of Longitude, Maskelyne was in a position to exercise patronage on behalf of such individuals by inserting them – plus a suite of scientific instruments and instructions for their regular use – on board voyages of exploration. Between 1761 and 1765 he had learned directly about the practicalities of using instruments at sea and in temporary observatories, and about how to maximise the opportunities afforded by travelling with instruments and skilled individuals. This meant not just fulfilling one observing project, but contributing to several: as well as attempting to observe the transit of Venus, he had proposed a project to measure stellar parallax, and used his stay on land to determine longitude and latitude precisely, investigate the effects of local gravitation and make magnetic and tidal observations. He also, of course, used the voyage to trial the lunar distance method of finding longitude and gained experience of collaborating with the ship's officers in making the relevant observations – a learning process that went both ways.

Maskelyne put these lessons to use when he became an organiser rather than participant in expeditionary astronomy. A hugely important opportunity was the **1769 transit of Venus**. Working between the Royal Society and the Board of Longitude, and with significant funding from the King and Admiralty, Maskelyne appointed observers, directed the purchase of instruments and wrote instructions for five expeditions. For most, the focus was on the transit of Venus, requiring the precise astronomical determination of the observing location as well as the careful observation, measurement and timing of the transit itself. However, for the most famous of these expeditions, on the *Endeavour*, under the command of Lieutenant James Cook, also included extended exploration of the South Seas (reaching New Zealand 250 years ago last week). The appointed observer was the Royal Observatory assistant Charles Green, with Cook in support, who put a whole suite of precision instruments to use in support of astronomy, navigation, geodesy, survey, hydrography, geomagnetism and more. It was a physical science complement to the gathering of botanical, zoological, ethnographic, geographical and geological information that this voyage also supported.

Maskelyne made a crucial step in ensuring that this – that is, the placement of skilled, Board of Longitude-appointed observers, supplied with a wide range of instruments on board ships – would become a pattern and not a 1769 one-off. Within months of his return on the *Endeavour*, Cook was appointed to command another voyage of scientific exploration. While this was to include naturalists and artists, it did not initially have more observational and mathematical expertise than that provided by Cook and his officers. However, Maskelyne **wrote to Lord Sandwich**, who was then First Lord of the Admiralty and Commissioner of Longitude, suggesting that the planned voyage:

> may be rendered more serviceable to the improvement of Geography & Navigation than it can otherwise be if the ship is furnished with Astronomical Instruments as this Board hath the disposal of or can obtain the use of from the Royal Society and also some of the Longitude Watches; and, above all, if a proper person could be sent out to make use of those Instruments & teach the Officers on board the ship the method of finding the Longitude.[6]

The Board supported this idea and Maskelyne was asked to appoint two suitable observers and to "prepare a Draft of Instructions proper for the said Persons and also a **List of the necessary Instruments**". This became the pattern, and all the 18th-century voyages of exploration – Cook's third, Phipps's to the Arctic, Vancouver's to the north-west coast of America and more – went on to carry observers appointed and paid for by the Board,

[6] Maskelyne to Lord Sandwich, in Board of Longitude Minutes, 28 Nov 1771, Cambridge University Library, RGO14/5 http://cudl.lib.cam.ac.uk/view/MS-RGO-00014-00005/211.

along with the large but increasingly standardised **suite of instruments**, supporting mathematical texts and instructions from the Astronomer Royal.

Given Maskelyne's role in appointing these mathematical practitioners as **observers**, it is not surprising that he personally knew many of them through his other routes to patronage. This was principally through appointing astronomical assistants to the Royal Observatory and computers for the *Nautical Almanac* (marked in red) as well as, on a more ad hoc basis, other computing and observational work paid for by the Board of Longitude or, occasionally, Royal Society. Expeditionary astronomer was one appointment among a possible series of such pieces of work and Maskelyne hired some individuals repeatedly, both because they had proved their skill and trustworthiness and because he felt an obligation of support and patronage. There are cases where, for example, a former assistant or computer in financial difficulty was offered paid work by way of help.

V. Such regular opportunities, and support, as well as a degree of fame earned by connection to well-known voyages, led some to the relatively few secure roles for mathematicians. This was particularly the case for the two observers earmarked by Maskelyne for Cook's second voyage: William Wales and William Bayly.

It is not known how **William Wales**, of humble Yorkshire origins, gained his mathematical expertise but he demonstrated it in the pages of the chief periodical supporting mathematics for leisure, the *Ladies' Diary*. His introduction to Maskelyne came after his move to London and his marriage to the sister of Charles Green in 1765 – a relationship suggesting the social connections among mathematicians in London. Within months he was appointed as one of the first *Nautical Almanac* computers, then in 1769 as a transit of Venus observer at Hudson's Bay, and in 1772 as observer on Cook's second voyage. In between and after he undertook computational work for the *Nautical Almanac* and Board of Longitude, including of his own observations. However, he also secured the position of Master of the Royal Mathematical School. In his final years he became secretary to the Board of Longitude. When in the south Pacific he had named the Maskelyne Islands, calling them "by the name of a person to whom I owe very much indeed; one who took me by the hand when I was friendless, and never forsook me when I had occasion for his help."[7]

William Bayly was the son of a farmer in Wiltshire but took the opportunity to learn mathematics from an exciseman living nearby and went on to teach at schools in the west country. In 1766 he was appointed as an assistant to Maskelyne, who had family connections to Wiltshire, and received the practical training that allowed him to be appointed as a transit of Venus observer. He went to observe in Norway with Jeremiah Dixon – the son of a coal mine owner and a veteran of the 1761 expeditions and the surveying of the Mason-Dixon line between Pennsylvania and Maryland, which Maskelyne had helped organise and equip. Bayly returned to his position at Greenwich but was then appointed to both Cook's second and third voyages. The Board of Longitude paid him for computing and publishing the expeditions' observations in 1782, and in 1785 he was appointed headmaster of the Royal Naval Academy in Portsmouth. There were disciplinary troubles and personal health and family problems, but he stayed in position until pensioned off in 1807, when the institution was transformed into the Royal Naval College.

Those not known to Maskelyne were introduced by acquaintances. **William Gooch**, a keen young mathematician who, sadly, was killed in Hawaii, en route to a rendezvous with Vancouver's expedition, was suggested by a friend, and fellow Commissioner of Longitude, the Cambridge mathematician Samuel Vince.

[7] William Wales and William Bayly, *The Original Astronomical Observations, Made in the Course of a Voyage towards the South Pole, and Around the World* (London: 1777), p. lv.

Nevertheless, Gooch had to spend several weeks under Maskelyne's eye to show that he had the necessary practical skills. He reported that the Astronomer Royal "attended closely to everything I undertook for Practice; and observ'd the accuracy of my observations by seeing what they were and calculating what they should be & then seeing how near they agreed". He was asked to compute the rate of going of the Observatory's clock from his own observations, a task that an expeditionary astronomer would have to perform regularly when on shore to establish the going of the portable regulator with observations beneath the portable tent observatory. This letter to his mother was written while at Greenwich, and he records Maskelyne raising a toast after dinner: "success to your Expedition, Mr. G."[8]

The majority of the observers that Maskelyne appointed could be classed as mathematical practitioners, who often moved from the provinces to London to take the opportunities their skills could bring them in a capital and port city. Some, like **Cook** himself, were naval officers with mathematical and observing skills. Typically, these were developed by dint of personal interest but – as the fame of Cook's and other voyages of exploration grew – could lead to opportunities for promotion. Thus, James King was second lieutenant on the *Resolution* during Cook's third voyage but also, having been granted leave to study various scientific subjects in the 1770s, was recommended as a suitable observer for the voyage. William Dawes was in the Royal Marines but was noted and recommended as Board of Longitude observers to the voyage of the First Fleet in 1787 by William Bayly.

All of the Board of Longitude observers were charged with teaching while on expedition as well as carrying out the whole host of observations and calculations required. In particular they were to help familiarise officers with the instruments and techniques of longitude determination by lunar distance and timekeeper, both for navigation and for position-fixing as a basis for surveys. Some of the renowned naval navigators, such as George Vancouver and William Bligh, benefitted from their early experiences on expedition with Wales and Bayly as well as, of course, Cook himself.

VI. By the end of the 18th century, the navy was able supply much of what had been solely the province of Maskelyne, the Board of Longitude and Royal Observatory, including the range and quality of instruments. The foundation of a Hydrographic Office in 1795, and increased focus on a higher level of education at naval colleges in the 19th century, meant that surveying voyages of the 1820s onwards could be entirely naval affairs. The **markers of precision exploration**, the observing tent designed by William Bayly for Cook's second voyage, the suite of precision instruments, were no longer only the provenance of supernumerary expeditionary astronomers.

These sketches were produced in the 1830s-40s by the naval officer, **Owen Stanley**. He had been educated at the Royal Naval College in the 1820s – where James Inman, once a Board of Longitude-appointed observer on Matthew Flinders's Australian circumnavigation, was Professor of Nautical Mathematics. In 1830 Owen joined a survey voyage to South America, in 1836 he was a scientific officer on HMS *Terror* in the Arctic and in 1846 was commander of HMS *Rattlesnake*, the survey voyage to Australia on which the young T.H. Huxley was assistant surgeon and naturalist. His sketches show the extent to which mathematical practice in the form of observation with large amounts of precision instrumentation – and the concomitant use of mathematical and astronomical tables and much pen and paper calculation and notation – was a continuation of the approach of Maskelyne and the other expeditionary mathematical practitioners, but now the business of naval officers alone.

[8] William Gooch to his parents, 20 April 1791, and to his mother, Sarah Gooch, 29 April 1791, Mm.6.48 (Cambridge University Library) https://cudl.lib.cam.ac.uk/view/MS-MM-00006-00048.

Further reading

Rebekah Higgitt, 'Equipping Expeditionary Astronomer: Nevil Maskelyne and the Development of "Precision Observation"', in Fraser MacDonald & Charles W.J. Withers (eds) *Geography, Technology and Instruments of Exploration* (Farnham: Ashgate, 2015), pp.15-36.

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