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Finding longitude: The *Investigator* expedition, 1801–1803

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Abstract
This article analyses the methods deployed for finding longitude on the *Investigator*'s expedition to circumnavigate Australia, made under the command of Matthew Flinders in the period 1801–1803. Timekeeping and astronomy were complementary methods for ascertaining longitude; they were carried out using chronometers and by taking lunar observations. The article explains who was responsible for handling the astronomical readings on the expedition; the performance of the chronometers used; Flinders's comparisons of the longitudinal readings with the work of previous navigators; and the reasons why dissemination of the longitudes taken during the voyage was delayed. The article shows how the combined use of chronometers and lunar observations helped Flinders to achieve scientific accuracy in his charting of coastal Australia in the atlas to his major work entitled *A Voyage to Terra Australis*.

Keywords
Australia, longitude, maritime exploration, Matthew Flinders, navigation, scientific instruments

During the eighteenth century, important improvements in determining longitude enabled navigators to establish clearly their position and time relative to a given meridian. Navigators needed to know precisely their east–west position on the globe in relation to an initial prime meridian (based on Greenwich time in the Anglophone world) in order to sail safely across the oceans.[1] Finding latitude at sea presented fewer technical and

1. Richard Dunn and Rebekah Higgitt, *Finding Longitude* (Glasgow, 2014); Charles W. J. Withers, 'The Longitude Question', *Journal of Historical Geography*, 47, No. 1 (2015), 1–5.

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mathematical challenges than calculating longitude. The widespread use of Hadley's sextant from the 1730s onwards enabled latitude to be determined accurately and expeditiously. Using the equator as a natural reference point, latitude could be calculated fairly precisely from the angular height of the Sun at noon.[2] It was not until the 1770s, however, that new technology, in the form of chronometers, became available to determine longitude at sea. Such timekeepers were machines for carrying local time throughout a voyage. They needed to remain accurate over several months, and had to be checked by lunar observations, a method for calculating longitude devised by the English astronomer Nevil Maskelyne in the 1760s.[3] The deployment of chronometers was stimulated by the British state's demand for robust astronomical and navigational instruments for long-distance voyages, but their diffusion occurred gradually over many decades.[4] It took time for them to be manufactured on a mass scale, and it was not until the 1850s that they were issued to all British naval vessels.[5]

Despite the importance of lunar observations and chronometers for navigation, relatively few studies have investigated their deployment on long-distance voyages in the late eighteenth and early nineteenth centuries.[6] The complexity of determining longitude meant that overlapping methods were used to check for accurate results. Thus on Cook's third Pacific voyage in the *Resolution* (1772–1775), longitude was recorded by lunar observations, by timekeeper, by lunar observations combined with dead reckoning and by lunar observations combined with the use of the timekeeper.[7] George Vancouver, on his Pacific voyage of 1791–1795, used both lunar observations and chronometers to determine meridians.[8]

2. Rebekah Higgitt, 'The Longitude Problem', in Rebekah Higgitt, ed., *Maskelyne: Astronomer Royal* (London, 2014), 50.
3. Andrew S. Cook, 'Surveying the Seas: Establishing the Sea Routes to the East Indies', in James R. Akerman, ed., *Cartographies of Travel and Navigation* (Chicago, IL, 2006), 78. The best brief overview of how to calculate longitude by lunar distances and by chronometers is Jim Bennett, *Navigation: A Very Short Introduction* (Oxford, 2017), 78–92.
4. Richard Sorrenson, 'The State's Demand for Accurate Astronomical and Navigational Instruments in Eighteenth-century Britain', in Ann Bermingham and John Brewer, eds., *The Consumption of Culture 1600–1800* (London, 1995), 263–71.
5. Alun C. Davies, 'The Life and Death of a Scientific Instrument: The Marine Chronometer, 1770–1920', *Annals of Science*, 35, No. 5 (2006), 509–25; Alun C. Davies, 'The Rise and Decline of Chronometer Manufacturing', *Antiquarian Horology*, 12, No. 3 (1980), 285–99.
6. Alun C. Davies has published three relevant studies dealing with one voyage: 'Vancouver's Chronometers', in Robin Fisher and Hugh Johnston, eds., *From Maps to Metaphors: The Pacific World of George Vancouver* (Vancouver, 1993), 70–84 and 305–11; 'Horology and Navigation: The Chronometers on Vancouver's Expedition, 1791–1795', *Antiquarian Horology*, 21, No. 3 (1994), 244–55; and 'Testing a New Technology: Captain George Vancouver's Survey and Navigation in Alaskan Waters, 1794', in Stephen Haycox, James Barnett and Caedman Liburd, eds., *Enlightenment and Exploration in the North Pacific 1741–1805* (Seattle, WA, 1997), 103–15.
7. Eóin Phillips, 'Captain Cook's Journal of Voyage to the South Seas', www.cudl.cam.ac.uk/view/MS-RGO-00014-00060/1 [accessed 16 August 2017]; Cambridge University Library (CUL), RGO 14/60–1, Observation Book kept by James Cook and James King giving the day's work and observations, Board of Longitude Papers.
8. Davies, 'Horology and Navigation', 244–55.

This article advances knowledge of this topic by explaining the use of chronometers and lunar methods on the first circumnavigation of Australia in HMS *Investigator*, under the command of Matthew Flinders. This important expedition lasted from July 1801, when the ship left Portsmouth, until July 1803, when the *Investigator* was decommissioned at Port Jackson (i.e. Sydney).[9] Two main themes are addressed. First, by analysing how longitude was calculated on this important voyage, this article adds to the recent argument, made by David Philip Miller, that chronometers by themselves cannot be regarded as determining longitude accurately at sea.[10] Second, the article shows that the utility of the longitudinal readings taken on voyages depended on the reliability of the instruments used, the accuracy of the nautical tables consulted, and the checking of data on meridians undertaken after the end of voyages. The broad context for the article lies in the advancement of scientific knowledge on voyages of exploration in the late eighteenth and early nineteenth centuries.

Chronometers and lunar observations were complementary methods for ascertaining longitude. Both procedures had to be tried and tested 'to become trusted elements of maritime practice'.[11] Timekeepers enabled navigators to obtain a reliable average from a large number of lunar observations taken at different times.[12] Chronometers were dependent, however, on various factors: their condition, the care with which they were looked after during a voyage, the accuracy of their rates, the reliability of lunar observations in checking them, and details on local time. The accuracy of chronometers was also dependent on changes in temperature, humidity, barometric pressure, metal fatigue and the quality of the lubricating oil used. Lunar observations were especially useful where more than one chronometer was taken on a voyage, in order to determine the accuracy of the timekeepers.[13]

Even when timekeepers were commercially available, their efficacy needed to be tested for several decades against prior ways of calculating longitude, such as the method of taking lunar observations. The lunar distance procedure was based on deriving local time and a meridian from the Moon's rapidly changing position relative to fixed stars. Great accuracy was needed in observation and long calculations of great exactitude were required. Naval officers trained in the period c.1770–1820 needed to be familiar with the technologies of calculating longitude by lunar distances and using chronometers.[14] These two methods of finding longitude overlapped before the chronometer became the preferred *modus*

9. For a recent assessment of this voyage, see Kenneth Morgan, *Matthew Flinders, Maritime Explorer of Australia* (London, 2016), 45–142.
10. 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, 2016), 223–47.
11. Rebekah Higgitt and Richard Dunn, 'Introduction', in Dunn and Higgitt, eds., *Navigational Enterprises*, 3.
12. Eric G. Forbes, *The Birth of Scientific Navigation: The Solving in the 18th Century of the Problem of Finding Longitude at Sea* (Greenwich, 1974), 17.
13. Miller, 'Longitude Networks', 226; Davies, 'Testing a New Technology', 105.
14. Davies, 'Horology and Navigation', 247, 255; David Waters, 'Navigational Problems in Captain Cook's Day', in Antoinette Shalkop, ed., *Exploration in Alaska: Captain Cook Commemorative Lectures June–November 1978* (Anchorage, AL, 1980), 53.

operandi by the mid-nineteenth century.[15] By that time, three chronometers were usually issued to Royal Navy ships to compare for accuracy.[16] The eventual ascendancy of chronometers over lunars for determining meridians was based on the fact that they could reduce the margin of error tenfold, from 60′ to 30′ of arc to 6′ to 3′.[17]

Flinders's voyage, supported by his patron Sir Joseph Banks, the President of the Royal Society, and sponsored by the Admiralty, undertook a meticulous maritime survey of Australia's coasts and offshore islands with a scientific group of gentlemen. Flinders's associates included a professional astronomer equipped with nautical instruments, including various chronometers, supplied by the Board of Longitude, the British government body formed in 1714 to encourage new methods for determining longitude at sea. The *Investigator* expedition carried a larger set of scientific instruments than any previous British voyage of exploration. These instruments and the astronomer on board the voyage were intended to improve navigation, charting and observation through the creative interaction of trained personnel and precision objects.[18]

Flinders needed accurate readings of longitude not just to determine his position at sea during a long oceanic voyage but also to sail around a continent whose entire coastline had never been charted – a continent, moreover, that was only established as one landmass as a result of his expedition. Flinders spent over 18 months in Australian waters (December 1801–July 1803) carrying out his circumnavigation. During the voyage, he took regular bearings to determine geographical features and distances to compile nautical charts: without accurate geographical coordinates, this would have been impossible to achieve. The charts were vital for accurate navigation in the future. During daylight, astronomical calculations were made with sextants from the altitude of the Sun; at nighttime, the altitudes of a fixed star were used to calculate longitude.[19] Flinders drew many charts and checked astronomical data after the voyage ended before publishing in 1814 an account of his expedition in *A Voyage to Terra Australis* accompanied by an atlas of his charts of Australia's coasts.[20] Flinders also compiled a lengthy unpublished 'Memoir'

15. A. R. T. Jonkers, *Earth's Magnetism in the Age of Sail* (Baltimore, MD, 2003), 144.
16. J. E. D. Williams, *From Sails to Satellites: The Origin and Development of Navigational Science* (Oxford, 1992), 103.
17. Waters, 'Navigational Problems', 54.
18. Claire Warrior and John McAleer, 'Objects of Exploration: Expanding the Horizons of Maritime History', in Fraser MacDonald and Charles W. J. Withers, eds., *Geography, Technology and Instruments of Exploration* (Farnham, 2015), 102–4.
19. Kenneth Morgan, ed., *Australia Circumnavigated: The Voyage of Matthew Flinders in HMS Investigator 1801–1803*, Hakluyt Society's Publications, series III, 28–9 (2 vols., London, 2015), II, 410. This scholarly edition does not reproduce the lengthy computations for longitude that Flinders included on almost a daily basis in his ship journal. Those calculations can be found in the manuscript of his fair journal at the National Archives, Kew, ADM 55/76-8, Flinders, Journals in HMS *Investigator*.
20. Matthew Flinders, *A Voyage to Terra Australis; undertaken for the purpose of completing the discovery of that vast country, and prosecuted in the years 1801, 1802, and 1803, in His Majesty's Ship The Investigator, and subsequently in the Armed Vessel Porpoise and Cumberland Schooner. With an account of the shipwreck of the Porpoise, arrival of the Cumberland at Mauritius, and imprisonment of the Commander during six years and a half years in that island*, 2 vols., and Atlas (London, 1814).

in which he explained in detail the navigational and geographical challenges of the expedition. Nearly a third of this document dealt solely with the difficulties of determining longitude.[21]

The *Investigator* expedition was one in which the technology of timekeepers was tested against lunar readings; as my analysis shows, both were needed in a practical sense to provide accurate calculations of longitude, but both were also beset with problems for establishing longitude with certainty. The discussion below explains who was responsible for handling the astronomical readings on the expedition; the performance of the chronometers used; Flinders's comparisons of the longitudinal readings with the work of previous navigators; and the reasons why dissemination of the longitudes taken during the voyage was delayed for several years. Testing a new technology in the form of chronometers, as we will see, was fraught with many hurdles that needed to be surmounted.[22]

During preparations for the *Investigator* expedition, Sir Joseph Banks, who was closely involved with initiating the voyage, was adamant that a professional astronomer should be appointed and that the most up-to-date scientific instruments should be provided.[23] He contacted Maskelyne, the Astronomer Royal, who sought a suitable astronomer and identified the scientific instruments needed for the voyage. Maskelyne had spent much of his career as an advocate for 'precision exploration' in the use of scientific hardware on maritime expeditions involving hydrography, coastal surveying and mapping.[24] Maskelyne quickly arranged to acquire chronometers by the leading instrument makers John Arnold and Thomas Earnshaw, who were great rivals.[25] The Board of Longitude granted awards to Arnold and Earnshaw for their improvements to chronometers.[26] It selected John Crosley as the astronomer for the voyage, following Maskelyne's advice.[27] Crosley was an experienced astronomer who had served for three years (1789–1792) as Maskelyne's assistant at the Royal Observatory.[28] In 1795–1798 he sailed on a

21. The 'Memoir' is transcribed and annotated in Morgan, ed., *Australia Circumnavigated*, II, 402–505. The chapter on longitude is included at 421–56.
22. David Mackay, *In the Wake of Cook: Exploration, Science and Empire, 1780–1801* (Beckenham, 1985), 4–8.
23. Banks to Flinders, 19 February 1801, in Neil Chambers, ed., *The Indian and Pacific Correspondence of Sir Joseph Banks, 1768–1820. Volume 5. Letters 1798–1801* (London, 2012), 279.
24. Rebekah Higgitt, 'Equipping Expeditionary Astronomers: Nevil Maskelyne and the Development of "Precision Exploration"', in MacDonald and Withers, eds., *Geography, Technology and Instruments of Exploration*, 15–36.
25. Maskelyne to Banks, 23, 24 December 1800, in Chambers, ed., *Indian and Pacific Correspondence*, V, 229–31.
26. Rupert T. Gould, *The Marine Chronometer: Its History and Development* (London, 1923), 116–28. For the achievements of Arnold and Earnshaw, see Jonathan Betts, 'Arnold and Earnshaw: The Practicable Solution', in William J. H. Andrewes, ed., *The Quest for Longitude* (Cambridge, MA, 1996), 312–28.
27. CUL, RGO 35/55, fols. 342–3, Maskelyne to Banks, 23 January 1801, and RGO 14/6, Minutes of the Board of Longitude, 7 March 1801.
28. Mary Croarken, 'Astronomical Labourers: Maskelyne's Assistants at the Royal Observatory, Greenwich, 1765–1811', *Notes and Records of the Royal Society of London*, 57, No. 3 (2003), 291.

surveying voyage in the *Providence* to the North Pacific, under the command of William Broughton.[29] Crosley was employed by the Board of Longitude, which set down detailed instructions for his work.[30]

At the time of the *Investigator* expedition, the Admiralty, via the Board of Longitude, mainly supplied chronometers for voyages of exploration.[31] The Board of Longitude furnished a 'large and expensive set' of scientific instruments to Crosley, which included several chronometers already used on voyages of discovery in the 1790s.[32] The *Investigator* took Arnold's box timekeepers nos. 82 and 176; Earnshaw's box timekeepers nos. 520 and 543 suspended on gimbals (pivots); and a highly accurate long-case clock by Earnshaw, built in 1791, which was needed to check the timekeeping of the chronometers. Hanging Earnshaw's timekeepers in gimbals in a deep brass bowl provided a low centre of gravity that prevented them from accidentally turning over.[33] The Arnold chronometers had already been used; the Earnshaw timekeepers were new.[34] Taking four chronometers on the voyage would enable inaccurate readings to be identified with confidence. The Navy Board supplied Flinders with a pocket chronometer by Arnold (no. 1736) for use in the whale boat taken in the *Investigator*, for exploring rivers and other inlets.[35] Crosley had a pocket chronometer (Earnshaw no. 465) for his own use.[36]

Flinders would have been familiar with Arnold no. 176 from sailing with Bligh in the second breadfruit voyage in the *Providence* in the period 1791–1793.[37] Arnold no. 82 and no. 176 had been taken on Vancouver's Pacific expedition between 1791 and 1795, as had Earnshaw's long-case clock.[38] Banks was a long-serving patron of Arnold's

29. Mary Croarken, 'Nevil Maskelyne and his Human Computers', in Higgitt, ed., *Maskelyne*, 143; Andrew David, ed., *William Robert Broughton's Voyage of Discovery to the North Pacific 1795–1798*, Hakluyt Society's Publications, series III, 22 (London, 2010), xxx.
30. Board of Longitude to John Crosley, 7 March 1801, in Chambers, ed., *Indian and Pacific Correspondence*, V, 287–91.
31. W. E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology*, 9, No. 6 (1976), 638.
32. Entry for 17 July 1801 in Morgan, ed., *Australia Circumnavigated*, I, 138.
33. Entry for 4 November 1801 in Morgan, ed., *Australia Circumnavigated*, I, 211; Christopher Wood, 'Some Historic Earnshaw Chronometers: The Work of His Pupils and One of his Rivals', *Antiquarian Horology*, 14, No. 5 (1984), 469–70.
34. Denis Shephard, 'This Excellent Timekeeper', in *Mapping our World: Terra Incognita to Terra Australis* (Canberra, 2013), 213.
35. Entry for 17 July 1801 in Morgan, ed., *Australia Circumnavigated*, I, 138; Mitchell Library, Sydney, Flinders to Maskelyne, 25 May 1802, Matthew Flinders letterbook (1801–6).
36. May, 'How the Chronometer went to Sea', 638.
37. Nigel Rigby, '"The Whole of the Surveying Department Rested on Me": Matthew Flinders, Hydrography and the Navy', in Marc Serge Rivière and Kumari R. Issur, eds., *Baudin-Flinders dans l'Océan Indien: Voyages, Découvertes, Rencontre: Travels, Discovery, Encounter* (Paris, 2006), 265. For further information on this chronometer, see David Harries, 'A Late 18th Century "Expedition" Marine Chronometer: The John Arnold no. 176', *Timecraft*, 2, No. 1 (1982), 5–10.
38. Davies, 'Vancouver's Chronometers', 73, 75–6; Jonathan Betts, 'Earnshaw, Thomas (1749–1829)', in H. C. G. Matthew and Brian H. Harrison, eds., *Oxford Dictionary of National Biography*, 60 vols. (Oxford, 2004), 17: 576–8. Earnshaw's long-case clock is now on display at the Powerhouse Museum, Sydney. See www.powerhousemuseum.com/

chronometers. Arnold himself had supplied chronometers to the Board of Longitude since the 1770s. It is therefore unsurprising to find that two of his timekeepers were taken on the *Investigator* expedition. They were cleaned and adjusted for that voyage.[39] Prior to his circumnavigation of Australia, Flinders had not used Earnshaw's chronometers. That they were taken on the voyage was partly related to Maskelyne's support for Earnshaw.[40]

Crosley's detailed instructions from the Board of Longitude enjoined him to use both the chronometers and lunar observations to calculate longitude correctly: each method would serve as a check on the other. Crosley's instructions stated that he was to take daily readings of latitude and longitude. Specifically, he was urged to take daily meridian altitudes of the Sun in the morning and afternoon; to wind up the chronometers every day; to compute longitude by comparing the time on the watches with the apparent time inferred from the Sun's altitudes; to observe the variation of the compass and the inclination of the dipping needle; to keep a ship journal; and teach officers on board ship the use of Hadley's sextant to determine the elevation of celestial objects in relation to the horizon.[41] Using the sextant accurately was not always an easy task, given the movement of ships in the ocean and the unpredictability of atmospheric or meteorological conditions.

By observing lunar distances from the Sun and fixed stars with the sextant, Crosley could compute the longitude of the ship by the nautical almanacs published for the years 1801–1805 inclusive, which he carried with him. The method used was to measure the altitude of the Sun or Moon or fixed star; to measure the angular distance between the two bodies; and to note and record the precise time of the observation. It was necessary to allow for refraction and parallax when making celestial observations.[42] The nautical almanacs included pre-computed distances of the Moon from one or more bodies selected from the Sun and bright stars. The compilation and calculations of the almanac tables were the work of Maskelyne and a team of associates. The tables were arranged by calendar month. They included tables of the Sun's longitude, the timing of Jupiter's eclipses, the Moon's daily position for noon and midnight, planetary positions, and daily lunar distances from the Sun and stars for every three hours. Longitude was determined from this source by calculating the difference between Greenwich apparent time and local apparent time, converted to units of angle.[43]

Crosley was to wind up the timekeepers each day and to compare and note their times. The current times could then be compared with the time at the Greenwich meridian. Care

collection/database [accessed 16 August 2017]. Arnold no. 176 is now in the possession of the Vancouver Maritime Museum. See www.vancouvermaritimemuseum.com/permanent-exhibit/ [accessed 16 August 2017].

39. Davies, 'Vancouver's Chronometers', 73–5.
40. Rory McEvoy, 'Maskelyne's Time', in Higgitt, ed., *Maskelyne*, 184.
41. CUL, RGO 14/185, fols. 4r–4(b)r, Board of Longitude to Crosley, 1 March 1801, Board of Longitude Papers.
42. M. K. Barritt, 'Matthew Flinders's Survey Practices and Records', *Journal of the Hakluyt Society* (March 2014), 3.
43. Williams, *From Sails to Satellites*, 95–6; Croarken, 'Nevil Maskelyne and his Human Computers', 131, 134. The *Nautical Almanac* published tables in apparent solar time until 1834, after which it included data based on mean solar time.

was needed to check the extent to which the chronometers were affected by changing temperatures and the ocean's motion. On shore Earnshaw's astronomical clock was to be set up in a tent observatory and used in conjunction with Hadley's sextant and Ramsden's universal theodolite to determine the 'going rate' of the clock (i.e. the time lost or gained in relation to the Greenwich meridian, conventionally taken to have longitude zero degrees).[44] Such portable observatories were widely used at the time to enable longitudes to be taken on shore during voyages.[45] Earnshaw's clock, furnished with a weight-powered regulator, was needed on shore to check the settings of the chronometers against the stars.[46]

During the first part of the voyage, from Portsmouth to the Cape of Good Hope, Crosley carried out astronomical observations to check the times recorded by the chronometers. This was necessary to ascertain any errors that occurred on what were expected to be highly accurate timepieces: a slow or fast-running chronometer would invalidate the navigator's longitude readings, which could lead to shipwreck and disaster. Errors from Greenwich apparent time (taken as the prime meridian) were recorded.[47] Arnold no. 82 proved deficient: no rate could be determined owing to its irregularity.[48] In this initial stage of the voyage, Flinders, as well as Crosley, carried out lunar observations to calculate longitude.[49]

Unfortunately, Crosley was seriously unwell with gout when the voyage reached the Cape of Good Hope and so he asked to be discharged from the expedition. Crosley handed over the Board of Longitude's scientific instruments to Flinders, who was obliged to take over the astronomical duties for the rest of the voyage along with his younger brother Samuel Ward Flinders, who was a second lieutenant on the expedition.[50] Crosley set up a tent observatory at the Cape and explained the adjustments of the clocks and universal theodolite to Flinders and his brother.[51] Before returning to England, Crosley spent five days at Cape Town checking the accuracy of all the timekeepers. Flinders continued this work for a further seven days. Earnshaw no. 543 was found to be the most accurate of the timekeepers. Arnold no. 82, on the other hand, gave erratic readings. It was therefore not used after the *Investigator* left the Cape.[52]

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44. Entry for 4 November 1801 in Morgan, ed., *Australia Circumnavigated*, I, 209–10; Higgitt, 'The Longitude Problem', 52–3. See also Brian W. Richardson, *Longitude and Empire: How Captain Cook's Voyages Changed the World* (Vancouver, 2005), 34.
45. Higgitt and Dunn, 'Introduction', in Higgitt and Dunn, eds., *Navigational Enterprises*, 7.
46. Davies, 'Testing a New Technology', 104.
47. For example, the astronomical data taken at Funchal, Madeira, on 7 August 1801: see Morgan, ed., *Australia Circumnavigated*, I, 160.
48. Entry for 4 November 1801 in Morgan, ed., *Australia Circumnavigated*, I, 214.
49. For example, entry for 30 July 1801 in Morgan, ed., *Australia Circumnavigated*, I, 153.
50. Entry for 4 November 1801 in Morgan, ed., *Australia Circumnavigated*, I, 208, 211; Flinders, *Voyage to Terra Australis*, I, 40. To avoid confusion, in the discussion below Matthew Flinders is referred to just by his surname whereas his brother is referred to as Samuel.
51. British Library (BL), Add. MS 32,439, fol. 51, Crosley to Maskelyne, 5 November 1801, Robert Brown Papers.
52. Flinders, *Voyage to Terra Australis*, I, 40–1; the 'Memoir' in Morgan, ed., *Australia Circumnavigated*, II, 423.

Flinders had some experience of nautical astronomy from the *Providence* voyage with Bligh in 1791–1793, from his voyage out to New South Wales in the *Reliance* in 1795, and from his voyage in the *Norfolk* towards the Furneaux Islands in 1798. On the latter voyage, he had used a timekeeper and had taken lunar observations to calculate longitude. Flinders had had several years' practice of getting the rates of the timekeepers in harbour by checking the artificial horizon.[53] His brother, however, had little such experience. Flinders used his leisure time at the Cape of Good Hope to improve his knowledge of nautical astronomy, with Crosley's help, and to familiarise himself with the larger instruments supplied by the Board of Longitude. The loss of an astronomical expert before the voyage had reached Australia, of course, was a serious impediment. Flinders knew he would be pressurised to fulfil his new role because of the time needed to attend to his other duties as commander of the voyage.[54] But, as no replacement astronomer was available at the Cape, there was no alternative to his overseeing the astronomical observations. He decided to share the work with his younger brother Samuel. Responsibilities were divided. Flinders took charge of the land-based astronomical surveying while Samuel undertook the lunar observations on board ship.[55] The two brothers liaised fairly well in carrying out these tasks even though tensions between them flared up on occasions when Samuel forgot to wind up the timekeepers.[56]

Flinders conducted the circumnavigation of Australia in a semi-clockwise direction, making landfall in early December 1801 at Cape Leeuwin, the south-western point of the continent. He proceeded along the 'unknown south coast',[57] and continued sailing before taking a couple of months' stopover at Port Jackson, then the only British settlement in Australia. After leaving Port Jackson in late July 1802, the *Investigator* headed northwards up Australia's east coast, sailing through the Great Barrier Reef and Torres Strait to the Gulf of Carpentaria, which was surveyed meticulously. After finding that the ship was leaking water badly and needed repairs and that the crew were succumbing to dysentery and fevers, Flinders sailed expeditiously around the remainder of the continent to Port Jackson. In July 1803, the expedition was terminated there owing to the unseaworthiness of the *Investigator* and the lack of a suitable replacement vessel. During this long voyage, Flinders and his brother Samuel assiduously took readings for longitude via the timekeepers and lunar observations. Three eight-inch sextants, with stands manufactured by the

53. Geoffrey C. Ingleton, *Matthew Flinders: Navigator and Chartmaker* (Guildford, 1986), 23–4; BL, Add. MS 32,439, fols. 47–8, Flinders to Banks, 29 October 1801, Robert Brown Papers.
54. Entry for 4 November 1801 in Morgan, ed., *Australia Circumnavigated*, I, 208.
55. CUL, RGO 14/65, 'Reduction of the Astronomical observations made in the voyage of the *Investigator* 1801-1805 by Samuel Ward Flinders, second lieutenant', Board of Longitude Papers.
56. For Flinders's acknowledgement of his brother's assistance, see entry for 13 September 1802 in Morgan, ed., *Australia Circumnavigated*, I, 85. The failure to wind up the chronometers is mentioned in entries for 17, 25 September, 12 December 1802, 21 January 1803 in Morgan, ed., *Australia Circumnavigated*, II, 88, 93, 202, 253.
57. This was the contemporary phrase used for the uncharted south coast of Australia from the islands of St Peter and St Francis to Van Diemen's Land.

instrument maker Thomas Troughton, were used to observe lunar distances. Ramsden's Universal Theodolite was used for the accurate determination of latitude. The east coast was the only section of the voyage where Flinders and his brother regularly had existing information on longitude, which had been gathered by Cook in the *Endeavour*. Elsewhere the Flinders brothers had to calculate longitude without reference to prior authorities or accurate charts. During the entire voyage, Flinders regularly applied his coordinate findings from nautical astronomy to drafting charts of coastal Australia: his longitude calculations would only be useful for future navigators if applied to accurate charts.[58]

After making landfall in south-western Australia in early December 1801, Flinders took available opportunities to deduce longitudes by checking the chronometers with lunar observations.[59] During nearly a month anchored at King George Sound, in a deep-water harbour, he was able to begin his astronomical calculations. He set up the tent observatory on shore with the astronomical instruments. Thirty-one sets of lunar observations were taken for comparison with the mean longitude values obtained from the chronometers; the daily rates of the timekeepers were deduced; and errors from Greenwich apparent time were recorded. Further observations for equal altitudes of the Sun were taken, in order to test the rates of the timekeepers at various points along Australia's south coast: at Lucky Bay and Goose Island Bay, in the Recherche Archipelago; at the head of the Great Australian Bight; near Port Lincoln; at the head of Spencer Gulf; at Kangaroo Island; and at Port Phillip.[60] All the calculations were made carefully, with as much checking between the timekeepers as possible. At Kangaroo Island, for example,

> the rates of the timekeepers were obtained, for the sake of expedition, from single altitudes of the Sun's upper and lower limbs, taken from a quicksilver horizon with a sextant fixed on a stand; the time being noted from Arnold's watch, compared with Earnshaw's time keepers before going on shore and immediately after returning.[61]

The only three navigators who had previously sailed along Australia's south coast for whom Flinders had access to astronomical data were Vancouver during his stay at King George Sound in 1791; Charles Beautemps-Beaupré at Port L'Esperance on Bruni D'Entrecasteaux's expedition of 1792 in search of the lost explorer La Pérouse; and Nicolas Baudin's expedition near King Island, Bass Strait in December 1801.[62] Flinders's

58. Details of the voyage as it proceeded around Australia are presented in K. A. Austin, *The Voyage of the Investigator 1801–1803: Commander Matthew Flinders, R.N.* (Adelaide, 1964), and Morgan, ed., *Australia Circumnavigated*, I and II. For the use of Troughton's sextants and Ramsden's Universal Theodolite, see Barritt, 'Matthew Flinders's Survey Practices and Records', 3. For the relationship between longitude readings and charts, see Miller, 'Longitude Networks', 229.
59. Geoffrey Badger, *Explorers of Australia* (Roseville, NSW, 2001), 84, 86–7, 89.
60. Entries for 13 December 1801; 5, 10, 16, 28 January; 4, 12 March; 5 April and 2 May 1802 in Morgan, ed., *Australia Circumnavigated*, I, 246, 253–6, 266, 269–71, 274–5, 285, 323–5, 334–5, 357–8, 391.
61. Flinders, *Voyage to Terra Australis*, I, 185.
62. The evidence for D'Entrecasteaux's expedition had been supplied by Alexander Dalrymple to Flinders. Archibald Day, *The Admiralty Hydrographic Service, 1795–1919* (London, 1967), 18–19.

longitudinal readings for Cape Chatham and Termination Island were only 1′ different from those taken by Vancouver, but there was a difference of 10′ between Flinders's and Vancouver's longitudes from Greenwich. Flinders found his longitudes differed between ½′ and 6′ west at several points between Cape Leeuwin and the head of Spencer Gulf from those recorded on D'Entrecasteaux's voyage. He only had one place, King Island, where he could compare his longitudes with those taken on Baudin's expedition; the difference was 13′.[63] Flinders adjusted his charts to take account of these readings for longitude.

Arriving at Port Jackson in May 1802, Flinders wrote to Maskelyne to enclose the lunar observations made so far on the expedition and to comment on the performance of the timekeepers. He expressed an underlying worry that, as he had no official training in astronomy and had been absorbed in surveying Australia's coasts, Maskelyne would find fault with his findings. Flinders noted that only two out of the five timekeepers in the *Investigator* were providing the correct longitude. Arnold no. 82 altered its losing rate from 2″ to 1′18″ at the Cape of Good Hope, so nothing could be deduced from it. A few weeks later it stopped altogether. Arnold no. 1736 had been used since King George Sound, but Flinders had no rate for it. At Port Lincoln it was found to be 'not steady enough to connect its longitude with [Earnshaw] No 543 and 520'. Arnold's watch no. 1736 varied in its rate from 7.81″ to 1.90″, so it was used only as a back-up when necessary.[64] Arnold no. 176 worked well until 1 March 1802 when its rate altered; it then stopped within a few hours and did not work after that time. Flinders later explained that he ignored this chronometer because it deviated too much from the mean. On the other hand, Earnshaw nos. 520 and 543 had worked regularly throughout the voyage. However, the smallness of the tent observatory was 'a great obstruction to our operation' in taking readings on shore.[65]

As the circumnavigation was intended to begin and end at Port Jackson, Flinders set up the astronomical clock on shore when arriving there in May 1802 to take the rates of the timekeepers through daily comparisons.[66] As the *Investigator* proceeded up Australia's east coast, Flinders and his brother regularly took astronomical observations to check the 'going rate' of the timekeepers. Detailed readings for longitude were taken at Upper Head and among the Cumberland Isles.[67] At Broad Sound Flinders insisted that accurate longitudes were need before proceeding to Torres Strait, and that a week was needed for accurate readings to be recorded.[68] Flinders was well aware of the navigational hazards of sailing in the treacherous waters of the Great Barrier Reef

63. These details are provided in the 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 436–7.
64. Entry for 4 March 1802 in Morgan, ed., *Australia Circumnavigated*, I, 324 (quotation), and 'The Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 426; Flinders, *Voyage to Terra Australis*, I, 149.
65. CUL, RGO 14/68, fols. 17r–18v, Flinders to Maskelyne, 25 May 1802, Board of Longitude Papers.
66. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 438.
67. Entries for 26 September, 17 October 1802 in Morgan, ed., *Australia Circumnavigated*, II, 96, 98, 104.
68. Entry for 17 September 1802 in Morgan, ed., *Australia Circumnavigated*, II, 88.

and Torres Strait, with their shoals, rocks, reefs and complex tidal variations. He needed accurate longitudes to chart his position to select a preferred route through Torres Strait. Without this information, the coral rocks in that vicinity could not be avoided with certainty.[69]

Flinders found that Earnshaw no. 543 was more accurate in its timekeeping than Earnshaw no. 520 in sailing between Upper Head and Torres Strait.[70] After passing through the Strait, further lunar observations were taken in the Gulf of Carpentaria at Inspection Hill, on Sweers Island, and at Observation Island, Groote Eylandt and Finch's Island.[71] After leaving the Gulf of Carpentaria, Flinders had fewer opportunities for taking astronomical observations on shore as the leaking *Investigator* needed to return promptly to Port Jackson. Owing to the poor state of the vessel and the sickness of the crew, Flinders abandoned plans to correct the longitudes along the north coast of Van Diemen's Land and to connect them with observations made of King Island and the north side of Bass Strait when sailing in the *Norfolk* in 1798.[72]

Despite these practical difficulties, further lunar observations were taken at Kupang, Timor, and at Goose Island Bay, in the Recherche Archipelago, and compared with timekeeper readings.[73] At Kupang, Flinders was able to compare his longitudinal readings with those of John McCluer in the East India Company cruiser *Panther*, as represented on a chart published in 1792 by Alexander Dalrymple, the Admiralty hydrographer. Flinders's longitude readings here confirmed McCluer's findings.[74] In his 'Memoir', Flinders noted that Arnold no. 1736 had been broken and damaged in Goose Island Bay. It was therefore not used again on the voyage, being 'too unsteady to be united with the other two time keepers in finding the longitude'.[75]

For his voyage up Australia's east coast from Port Jackson to Torres Strait, Flinders had detailed survey material and longitudinal readings from Cook's voyage in the *Endeavour* in 1770. Cook had sailed on that voyage without a chronometer, for timekeepers were then 'in their infancy' and 'he was not then furnished with them'.[76] Flinders wanted to test his readings for longitude with those taken by Cook based solely on dead reckoning and lunar observations. This would be helpful for future navigators in those waters, and was necessary to correct some of the coordinates in Cook's charts. Cook had sailed expeditiously during his running survey along Australia's east coast. He did not

69. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 489–90; Kenneth Morgan, 'From Cook to Flinders: The Navigation of Torres Strait', *International Journal of Maritime History*, 27, No. 1 (2015), 41–60.
70. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 478.
71. Entries for 17, 18 November 1802; 7, 11, 16 January 1803 in Morgan, ed., *Australia Circumnavigated*, II, 170, 172–3, 234–5, 238, 244–5.
72. Morgan, ed., *Australia Circumnavigated*, I, 43.
73. Entries for 8 April and 19 May 1803 in Morgan, ed., *Australia Circumnavigated*, II, 346–8, 373.
74. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 456, 485.
75. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 427, 431 (quotation). For Flinders's detailed observations on the 'going rates' of the timekeepers on Australia's south coast, see entry for 13 May 1802 in Morgan, ed., *Australia Circumnavigated*, I, 401–6.
76. Flinders, *Voyage to Terra Australis*, I, vii.

have time to take a large number of duplicate observations, and could only calculate longitude with certainty from the few fixed stations he was able to establish.[77]

Flinders found that Cook's longitudes closely approximated his own on the east coast as far north as Mount Dromedary.[78] But continuing northwards he noticed that his longitude 'was getting more eastward from captain Cook as we advanced along the coast'.[79] Flinders's new readings for longitude were necessary because incorrect observations could lead to ships approaching 'rocks or shoals, as near even as half a mile, which might prove fatal'. His revised tables of longitude showed corrections of between 20½′ and 58½′.[80] These distances, measured at the equator, were between 28 and 68 nautical miles.[81] While sailing through Torres Strait, Flinders found that Cook's longitudes needed correction. He realised this after comparing Bligh's chart, based on his passage in 1789 through Torres Strait in the *Bounty*'s launch, with Cook's chart from the *Endeavour* voyage.[82] Cook's measurement of the difference in longitude between the flat-topped island off Cape York to Booby Island was 73′ whereas Flinders's and Bligh's figures were 44′ and 39′ respectively.[83]

Flinders was so respectful of Cook's reputation as a navigator that he found it difficult to reconcile the discrepancy in these readings: 'I confess my judgement to have been altogether confounded by such unexpected differences', he wrote in his 'Memoir', adding that 'considering myself to be a mere tyro in nautical science, in comparison of captain Cook, was inclined to believe, that our log, compasses, time-keepers, sextants and myself were all in the wrong, rather than that such errors were made by him'.[84] Flinders was correct in supposing that it was uncommon for Cook to have made such errors in calculating longitude. It has been explained, however, that the erroneous readings might have resulted from the ill health of Charles Green, the astronomer on the *Endeavour*.[85] Flinders thought Cook's longitudinal errors stemmed from 'an error in the line of collimation of the telescope in his sextant'.[86]

When Flinders arrived in the *Investigator* at Port Jackson in July 1803 he met the astronomer and Cambridge mathematician James Inman, who had been sent out by the Board of Longitude to replace Crosley, the astronomer who had left the expedition at the Cape of Good Hope in November 1801. Inman was Professor of Mathematics at the Royal Naval

77. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 483; Badger, *Explorers of Australia*, 89.
78. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 455.
79. Flinders, *Voyage to Terra Australis*, II, 54–5.
80. Flinders, *Voyage to Terra Australis*, I, v and vii.
81. James Bowen and Margarita Bowen, *The Great Barrier Reef: History, Science, Heritage* (Cambridge, 2002), 64.
82. Entries for 1–3 November 1802 in Morgan, ed., *Australia Circumnavigated*, II, 145–50.
83. Andrew C. F. David, 'The Surveyors of the *Bounty*: A Preliminary Study of the Hydrographic Surveys of William Bligh, Thomas Hayward and Peter Heywood and the Charts Published from Them', Unpublished typescript, Royal Navy Hydrographic Department, Ministry of Defence Archives (Taunton, 1982), 22.
84. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 479.
85. Andrew C. F. David, 'Cook and the Cartography of Australia', *The Globe*, 22 (1984), 49–50.
86. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 482–3.

College, Portsmouth.[87] He had arrived at Sydney in July 1802, and had waited nearly a year for the *Investigator* to appear there. Flinders handed over to Inman the scientific instruments, charts and books issued by the Board of Longitude.[88] Inman began checking the survey data gathered on the voyage by setting up an observatory at Garden Island in Sydney Harbour.[89] He found the universal theodolite was virtually useless and the astronomical clock was not performing: both needed repairs and there was no-one available in Port Jackson with the professional skill to restore them to working order. However, Inman did pay for the repair of some of the other astronomical instruments at Port Jackson.[90] After it was cleaned and rust, dirt and oil removed, Inman managed to get the clock to work.[91] As for the timekeepers, Earnshaw no. 543 kept very bad time, but Earnshaw no. 520 gave better results.[92] The availability of Inman's expertise was timely and necessary: no on-board repair and maintenance systems were available for adjusting poorly functioning astronomical instruments on voyages of exploration.[93]

There was no possibility of mending the universal theodolite in New South Wales. Inman had arrived at Port Jackson with a famous chronometer designed by Larcum Kendall. This was K3, which had been taken on Cook's third Pacific voyage and on Vancouver's world expedition of the 1790s. Unfortunately, K3 performed erratically.[94] As Inman could not carry out his checks correctly and the *Investigator* expedition had been suspended, he sailed home in the *Rolla* via China to England.[95] Flinders also set out for England on a different vessel, the *Porpoise*, which was wrecked off the Queensland coast. The *Rolla* had to stop at the site of the wreck to pick up most of the scientific instruments from Flinders.[96]

87. Flinders, *Voyage to Terra Australis*, II, 273.
88. CUL, RGO 14/68, ff. 173r–174v, Schedule of Instruments, Books and Charts belonging to the Board of Longitude, delivered by Captain Flinders to Mr James Inman at Port Jackson, New South Wales, 26 July 1803, Board of Longitude Papers.
89. Flinders, *Voyage to Terra Australis*, II, 272.
90. CUL, RGO 14/68, fols. 175r–181v, James Inman, Account of his work as astronomer at Port Jackson, 1803, Board of Longitude Papers.
91. CUL, RGO 14/68, fol. 211v, Inman to Maskelyne, 8 August 1803, Board of Longitude Papers.
92. Details of the readings taken by these chronometers are provided in National Maritime Museum, Record of longitude by Earnshaw's chronometers kept by Flinders in HMS *Investigator*, November 1801–December 1803, Flinders Papers, FLI/10. John Aken, the *Investigator*'s master, noted that Earnshaw no. 520 was the most dependable chronometer he had used: see Wood, 'Some Historic Earnshaw Chronometers', 471.
93. On this point, see two studies by Simon Schaffer: 'Easily Cracked: Scientific Instruments in States of Disrepair', *Isis*, 102, No. 4 (2011), 706–17; and 'In Transit: European Cosmologies in the Pacific', in Kate Fullagar, ed., *The Atlantic World in the Antipodes: Effects and Transformations since the Eighteenth Century* (Newcastle upon Tyne, 2012), 78–9, 83.
94. Dunn and Higgitt, *Finding Longitude*, 150; Davies, 'Vancouver's Chronometers', 72.
95. CUL, RGO 14/68, fols. 175r–181r, Account by James Inman of his work as astronomer, 1803, Board of Longitude Papers.
96. CUL, RGO 14/68, fol. 174v, List of instruments belonging to the Board of Longitude put into the hands of James Inman on Wreck Reef by Captain Flinders, 8 October 1803, Board of Longitude Papers.

Disseminating the findings on longitude in charts of Australia's coastal geography proved time-consuming for Flinders, and subject to unfortunate delays. Not realising that war had been resumed between Britain and France after the short-lived Peace of Amiens, Flinders was detained as a suspected spy at the Ile de France (i.e. Mauritius) for six-and-a-half years (1803–1810) after putting in there on the voyage back to England from Australia.[97] He worked extensively on his charts while in captivity, but did not know that his coordinates had serious errors caused by mistakes in the places of the Sun and Moon in issues of the *Nautical Almanac* that he had used.[98] After returning to England in 1804, Samuel Ward Flinders, who had played an active part in helping his brother Matthew compile astronomical observations during the *Investigator*'s expedition, had difficulty in his attempts to persuade the Admiralty to award him remuneration for these duties. He eventually received a modest payment for his services.[99] Flinders had problems with his brother when Samuel withdrew the astronomical record books and refused to hand over the materials, but eventually the volumes were returned.[100]

There were additional problems to sort out. After beginning to compile his voyage account and charts for publication in London in 1810, Flinders found it necessary to have all of the geographical coordinates recalculated according to correct updated versions of the *Nautical Almanac*. An investigation by the Royal Observatory had found that the predicted astronomical calculations (which Flinders had taken from the volumes in the *Investigator*) included significant errors. This laborious process of correction, supported by the Board of Longitude, was undertaken largely by Crosley. It took over two years to complete the recalculations, which required 1365 entries for each month to be checked.[101] Flinders wanted the work done to preserve his own reputation as a navigator, hydrographer and mapmaker. The longitudes used in his charts were taken from the timekeeper readings, regulated by his lunar observations.[102] Precise, accurate data on longitude were vital for Flinders to demonstrate that his mapping of the east, north and south coasts of Australia would 'rest on a basis not easy to be shaken'.[103] Flinders's revised charts formed the basis for the atlas that accompanied his book *A Voyage to Terra Australis*, published when he was on his deathbed in 1814.[104]

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97. Aken took Earnshaw no. 520 back from the Ile de France to England in 1805. May, 'How the Chronometer Went to Sea', 638.
98. Flinders, *Voyage to Terra Australis*, I, iii.
99. CUL, RGO 14/68, fol. 33r–v, Memorial of Samuel Ward Flinders to the commissioners of Longitude, April 1806, and fols. 62r–63r, Petition of Samuel Ward Flinders to the Commissioners of Longitude, 2 December 1812, Board of Longitude Papers.
100. Eóin Phillips, 'Instrumenting Order: Longitude, Seamen and Astronomers, 1770–1805', in MacDonald and Withers, eds., *Geography, Technology and Instruments of Exploration*, 48–51.
101. Morgan, ed., *Australia Circumnavigated*, I, 78; Croarken, 'Nevil Maskelyne and His Human Computers', 134; CUL, RGO 14/68, fol. 67r, John Crosley to the Commissioners of Longitude, 3 March 1814, Board of Longitude Papers.
102. Flinders, *Voyage to Terra Australis*, I, 255.
103. CUL, RGO 14/68, fol. 54r, Flinders to Captain Hurd, 15 July 1811, Board of Longitude Papers. Flinders provided a detailed explanation of the methodology he used to calculate longitude in *Voyage to Terra Australis*, I, 256–61.
104. Morgan, *Matthew Flinders*, 190–1.

Flinders once remarked that 'longitude is one of the most essential, but at the same time least certain data in hydrography'.[105] He was convinced, from his experience on the *Investigator* expedition, that chronometers were essential instruments for determining longitude. He wrote about this eloquently in his 'Memoir':

> Such is the importance of time keepers in marine surveying that whoever thinks to make the chart of a coast, of any extent, without them, which shall stand the test of future examination, will be deceived; its errors may probably not be found by those who sail along the coast no better provided than was the surveyor, or if found, they will still be doubtful; but immediately that a good time-keeper is brought to bear upon it, its fancied accuracy will shrink back to the few points that may have been fixed by a series of astronomical observations; and in the intermediate parts, errors in longitude of greater or less magnitude will start into view, as mountains and hills become distinctly visible in the mist, which obscured them, is cleared away by the rays of a morning's sun.[106]

Flinders's experience on the *Investigator* expedition had given him an extended opportunity to test lunar observations with timekeepers in order to chart his track and his longitudinal position. Flinders found, as did French voyagers in the late eighteenth and early nineteenth centuries, that it was important to average the results of longitudes taken from different methods and impossible to conclude that chronometers gave better results than lunar observations. This was not a case of polarised methods of determining longitude, but rather a situation in which the different methods were necessarily undertaken in order to complement one another.[107] Chronometers by Arnold, Earnshaw and other instrument makers did not supersede other methods of calculating longitude, notably the calculation of lunar distances pioneered by Maskelyne. For, as Flinders found, and as East India Company captains confirmed, chronometers were dependent on their condition, the care with which they were looked after at sea, the accuracy of their rates, and the reliability of lunar observations used to cross-check longitudinal readings.[108] Chronometers offered a technologically superior way of calculating longitude than other methods, but exclusive reliance on chronometers was risky.[109] Flinders combined the results of his lunar observations and chronometer readings to produce a set of longitudes for Australia's coastal geography that stood the test of time. Flinders's charts and atlas for *A Voyage to Terra Australis*, incorporating his longitudinal calculations, were widely used by navigators for over a century, and were not superseded until the era of aerial surveys.[110]

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105. Flinders, *Voyage to Terra Australis*, I, iv–v, (original emphasis). Details of longitude readings by Flinders on Australia's south, east and north coasts are presented in Morgan, ed., *Australia Circumnavigated*, I, 262–8 and II, 499–505.
106. The 'Memoir', in Morgan, ed., *Australia Circumnavigated*, II, 483.
107. John Gascoigne, 'Navigating the Pacific from Bougainville to Dumont d'Urville: French Approaches to Determining Longitude, 1766–1840', in Higgitt and Dunn, eds., *Navigational Enterprises in Europe and its Empires*, 181.
108. Miller, 'Longitude Networks', 226.
109. Davies, 'Horology and Navigation', 255.
110. Morgan, *Matthew Flinders*, 199.

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