The British Journal for the History of Science (2023), **56**, 65–81
doi:10.1017/S0007087423000018

RESEARCH ARTICLE

The winter of raw computers: the history of the lunar and planetary reductions of the Royal Observatory, Greenwich

Daniel Belteki*

Royal Museums Greenwich, UK
*Corresponding author: Daniel Belteki, Email: daniel.belteki@gmail.com

Abstract

In 1839 the working hours of the computers employed on the lunar and planetary reductions of the Royal Observatory, Greenwich were reduced from eleven hours to eight hours. Previous historians have explained this decrease by reference to the generally benevolent nature of the manager of the reductions, George Biddell Airy. By contrast, this article uses the letters and notes exchanged between Airy and the computers to demonstrate that the change in the working hours originated from the computers as a reaction to their poor working conditions. Through the exploration of these archival materials, the article shifts the focus of the analysis to the working experience of the computers, rather than to the administrative history of the project that inevitably tends to highlight Airy's actions. By doing so, the article shows how the computers were treated as a disposable low-skilled workforce, as opposed to aspiring astronomers with considerable mathematical talent. Through this reframing, the article takes a step towards a working history of the observatory.

In January 1839 the computers working in the Great Room of the Royal Observatory, Greenwich, rejoiced at the news that their daily working hours were going to be reduced from eleven to eight hours. Further good news soon followed: their monthly salaries would remain the same. This alteration of the working hours was hailed by historian Arthur Jack Meadows as an example of George Biddell Airy's (the observatory's director and Astronomer Royal) goodwill, in contrast to his traditional image as a 'Victorian ogre'.[1] Mary Croarken similarly argued that Airy reduced the working hours after he noticed that the 'productivity [of the computers] in the second half of the day was poor and that some of the computers' health was suffering'.[2] On this reading, the decision to reduce the hours was taken in order to increase the efficiency of the work by keeping the computers healthy.[3] More recently, Scott Alan Johnston has argued that the computers worked long hours of their own volition, and that Airy 'convinced' them to agree to

[1] Arthur Jack Meadows, 'The Airy era', *Vistas in Astronomy* (1976) 20, pp. 197–201, 198.

[2] Mary Croarken, 'Human computers in eighteenth- and nineteenth-century Britain', in Eleanor Robson and Jacqueline Stedall (eds.), *The Oxford Handbook of the History of Mathematics*, Oxford: Oxford University Press, 2008, pp. 375–406, 391.

[3] The term 'factory mentality' to characterize Airy's directorship was introduced in Allan Chapman, 'Sir George Airy (1801–1892) and the concept of international standards in science, timekeeping and navigation', *Vistas in Astronomy* (1985) 20, pp. 321–8.

the reduced hours.[4] Such arguments were used by historians to counter Airy's depiction as a despotic director, initially popularized by Walter Maunder's early (1900) history of the observatory.[5] The episode received its closest examination yet from David Aubin, who used it to illustrate the use of mathematics as a tool and to depict computers as mathematical artisans.[6] But unlike previous historians, Aubin also noted that while Airy was receptive to the idea of reducing the hours, the proposal originated from the superintendent of the computers. In Aubin's framing of Airy's intentions, the reduced working hours were adopted to decrease the chances of computers making errors due to fatigue and any error going unnoticed by the superintendent checking the computations. Therefore the working conditions were inseparable from the efficiency of the project. At the same time, Aubin's work only examined one of the three volumes of archival materials related to the computations. The additional two volumes provide more detailed information about the working conditions of the computers and how their recruitment was tied to the financial management of the project. This article re-examines the working conditions of the computers in question by expanding on the archival materials used by Aubin. This re-examination will demonstrate three key points about the working conditions of computers at the Royal Observatory, Greenwhich, which have not been fully appreciated by existing historical scholarship about the computers, namely that

1 the computers were not employed by the Royal Observatory, Greenwich;
2 the proposal to reduce the working hours originated from the superintendent of computers as a response to the harsh working conditions faced by the computers;
3 Airy only decided to reduce the working hours after the threat of computers potentially leaving the project.

Human computers were employed in a variety of industries that required processing large amounts of numerical data.[7] They were the 'invisible technicians' of data processing and the mathematical artisans of computing work.[8] Within the context of the history of astronomy during the nineteenth century, computers were regularly employed at institutions that handled large amounts of data daily. Two key examples of this were the Nautical Almanac Office and the Royal Observatory, Greenwich. Historically, computers were the lowest-ranking workers in the latter establishment's hierarchy. However, the features of the role have been widely debated in the context of the historiographical framings of the observatory's organization. Was it a site ruled by a 'factory mentality' given the increased division of labour, the surveillance of work and the introduction of 'machine-like' scientific instruments?[9] Was it a site governed by naval discipline, given its strict hierarchy, its ties to navigation and the fact that its funding originated with the

[4] Scott Alan Johnston, 'Managing the observatory: discipline, order and disorder at Greenwich, 1835–1933', *BJHS* (2021) 54(2), pp. 155–75, 166.

[5] Walter Maunder, *The Royal Observatory Greenwich: A Glance at Its History and Work*, London: The Religious Tract Society, 1900.

[6] David Aubin, 'On the epistemic and social foundations of mathematics as tool and instrument in observatories, 1793–1846', in Johannes Lenhard and Martin Carrier (eds.), *Mathematics as a Tool: Tracing New Roles of Mathematics in the Sciences*, Cham: Springer, 2017, pp. 177–96.

[7] David Alan Grier, *When Computers Were Human*, Princeton, NJ and Oxford: Princeton University Press, 2005.

[8] For an overview of the various ways in which the concept of invisible technician was deployed, see Iwan Rhys Morus, 'Invisible technicians, instrument-makers and artisans', in Bernard Lightman (ed.), *A Companion to the History of Science*, Chichester: John Wiley & Sons Ltd, 2016, pp. 97–110.

[9] Robert W. Smith, 'A national observatory transformed: Greenwich in the nineteenth century', *Journal for the History of Astronomy* (1991) 22(1), pp. 5–10; Simon Schaffer, 'Astronomers mark time: discipline and the personal equation', *Science in Context* (1988) 2(1), pp. 115–45; Holly Rothermel, 'Images of the sun: Warren De la Rue, George Biddell Airy and celestial photography', *BJHS* (1993) 26(2), pp. 137–69; Lee T. Macdonald, 'The origins and early

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

Admiralty?[10] Was it a site reliant on a clerical workforce given the dominance of paperwork and the strenuous record-keeping?[11] Was it an expansion of the domestic space of the Astronomer Royal, given that Airy lived on site?[12] Or is it misleading to place the observatory within any of these frameworks, as they cannot account for observatory practices as a whole?[13]

This article takes as its starting point the view that each one of the approaches cited above focuses on a different operation of the observatory taking place at different stages of Airy's directorship. Therefore the starting assumption of this article is that the historical scholarship highlights not the homogeneous nature of the observatory, but rather the variety of different types of labour that coexisted within it at different levels of its hierarchy.[14] Within this framing, previous scholarship shows that the observatory under Airy's directorship was not an unchanging monolith during his forty-six years as Astronomer Royal. Instead, Airy actively responded to the changes within science and society that occurred over this period.[15] With these points in mind, this article aims to examine the origins of the first group of computers who worked within the observatory grounds under Airy's directorship, in order to demonstrate the principles that later guided Airy's hierarchical vision for observatory staff organization.

This article is divided into two parts. First, it retells the overall history of the lunar and planetary reductions.[16] This history demonstrates that the need to improve methods for finding longitude continued to be a key justification used by the British government for funding astronomical research during the nineteenth century. In addition, it shows that the financial management of the project was inseparable from the financial remuneration and working conditions of the computers, since almost all project expenses remun to covering the costs of their employment. The second half of the article examines the experiences of the computers who worked on the reductions. It showcases their harsh working conditions, the precarious nature of their jobs and the power struggles among themselves. By combining these two approaches, the article demonstrates how the reductions were experienced and communicated differently among different social groups (astronomers, government officials and computers), and how their interests often clashed.

years of the Magnetic and Meteorological department at Greenwich Observatory, 1834–1848', *Annals of Science* (2018) 75(3), pp. 201–33.

[10] Philip S. Laurie, 'The Board of Visitors of the Royal Observatory – II: 1830–1965', *Quarterly Journal of the Royal Astronomical Society* (1967) 8, pp. 334–53; Jessica Ratcliff, *The Transit of Venus Enterprise in Victorian Britain*, London: Pickering & Chatto, 2008.

[11] Croarken, op. cit. (2); Grier, op. cit. (7); William J. Ashworth, 'The calculating eye: Baily, Herschel, Babbage and the business of astronomy', *BJHS* (1994) 27(4), pp. 409–49; William J. Ashworth, 'John Herschel, George Airy, and the roaming eye of the state', *History of Science* (1998) 36(2), pp. 151–78.

[12] Johnston, op. cit. (4).

[13] Omar Nasim, 'Observatorium', in Marianne Sommer, Staffan Muller-Wille and Carsten Reinhardt (eds.), *Handbuch Wissenschaftsgeschichte*, Stuttgart: J.B. Metzler, 2017, pp. 180–92.

[14] Nasim, op. cit. (13); Daniel Belteki, 'The spring of order: Robert Main's management of astronomical labor at the Royal Observatory, Greenwich', *History of Science* (2021), OnlineFirst, at https://doi.org/10.1177/00732753211028434.

[15] Once again, a systematic assessment of how Airy's vision of astronomy and science has changed over time would be useful, but such research has not yet been undertaken and is beyond the scope of this article. For initial attempts that incorporate such an approach see Rothermel, op. cit. (9); Lee Macdonald, *Kew Observatory & The Evolution of Victorian Science 1840–1910*, Pittsburgh: University of Pittsburgh Press, 2018; Daniel Belteki, '"The grand strategy of an observatory": George Airy's vision for the division of astronomical labour among observatories during the nineteenth century', *Notes and Records of the Royal Society* (2021), [AheadOfPrint], at https://doi.org/10.1098/rsnr.2021.0034.

[16] The two projects collectively will be referred to as 'the reductions' for the rest of the article. The article will also delineate between the lunar reductions and the planetary reductions when necessary.

Longitude and astronomical tables

The history of 'finding longitude' has long been divided between approaches that focus on John Harrison's heroic figure and those that focus on the more complex emergence of various solutions to the problem.[17] The Royal Observatory, Greenwich, was established in 1675 with the aim of deploying both theoretical and empirical methods to solve the problem of longitude. Successive Astronomers Royal focused their efforts on making regular and systematic observations of celestial bodies, data that were also crucial for the improvement of lunar and planetary theories. Unfortunately, however, their observations were published in a variety of different formats, which also required the reader to perform additional calculations before the data could be used effectively.

When George Airy became the director of the Cambridge Observatory in 1828, he considered this lack of standardization to be laborious and inefficient, developing a new publication format for his own observations that decreased the computational labour demanded from readers, freeing them to direct their energies to other calculations.[18] In an ambitious plan Airy proposed to apply the same approach to reduce the historical observations of the Moon, the Sun and the planets 'on a uniform plan' to render 'nearly useless' observations into useful ones.[19] This call to action prompted the British Association for the Advancement of Science (BAAS) to form a committee in 1833 to discuss the potential of reducing the observations made at Greenwich by applying a uniform system of calculation, and to lobby the government for a grant to support this work. This committee was the beginning of a fifteen-year project that resulted in recalculating nearly all the observations of the Moon and the planets made at Greenwich between 1750 and 1830. James Bradley's observations, as the oldest and most regular series of data at Greenwich, were chosen as the starting point. Lord Althorp (Chancellor of the Exchequer) agreed to fund the project on the basis that it would contribute to 'Astronomy in General, and more especially to Nautical Astronomy by improving the Existing Tables of the Planets'.[20]

Work on the project began in October 1833, and while Airy superintended the project, he did not undertake the computations himself. His role was to standardize and simplify the endeavour, for example by dividing the equations governing the calculations into smaller exercises requiring only basic arithmetic skills, and preparing the standardized forms used for the computations. He employed John Glaisher (the brother of Airy's assistant at the Cambridge Observatory, James Glaisher) to carry out the computations. John Glaisher began work on the computations on 29 March 1834 and continued with the project until 16 January 1836.[21] In 1835 Airy left Cambridge to begin his new position as Astronomer Royal at Greenwich, but this relocation did not halt work on the reductions. Glaisher was replaced by John William Thomas and John Hartnup, while at the 1837 meeting of the BAAS a deputation was formed to lobby the government for extra funding to support the reduction of the lunar observations made at Greenwich, resulting in a further two thousand pounds for the project from the Treasury.[22] As a result, the number of

[17] For an overview of the debate see Rebekah Higgitt, 'Challenging tropes: genius, heroic invention, and the longitude problem in the museum', *Isis* (2017) 108(2), pp. 371–80.

[18] George Biddell Airy, *Astronomical Observations made at the Observatory of Cambridge*, Cambridge: J. Smith, 1829, pp. v–vii.

[19] George Biddell Airy, 'Report on the progress of astronomy during the present century', in *Report of the First and Second Meetings of the British Association for the Advancement of Science*, London: John Murray, 1833, pp. 125–89, 187.

[20] RGO 6/524 6, Lord Althorp to John Herschel, 25 July 1833.

[21] It is not known why Glaisher stopped working on the project. For the last payment made to Glaisher see RGO 6/524 29–30, Accounts relating to the Expenditure for Reduction of Greenwich Planetary Observations, 2 August 1833.

[22] RGO 6/524 162, Airy to the Marquis of Breadalbane, 11 May 1841.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

computers increased from two to nine by the end of 1838.[23] However, this group of computers were not members of the observatory's workforce, despite working in the Octagon Room of the observatory. Their salaries were provided directly by the Treasury as part of the project. In contrast, the observatory staff were funded through the Admiralty.

From 1838 onwards, the same team of computers worked on both the lunar and the planetary reductions, with Airy occasionally using one source of funding to cover the costs of both reductions, and combining their expenses in the accounts sent to the Treasury.[24] However, by 1840, the two projects were beginning to diverge. By April 1840, Airy reported to Robert Gordon that the planetary reductions were at an advanced state, and gave a detailed history of the project to the BAAS meeting in September of that year.[25] In the following year, he claimed that, with the exception of an introduction, they were ready for publication.[26] However, it took another four years before they appeared in 1845.[27]

In contrast, the work on the lunar reductions progressed at a different pace. At the 1840 BAAS meeting, another deputation was formed to lobby the government for extending the project funding by two thousand pounds. The deputation was headed by the Marquis of Breadalbane, who worked closely with Airy and Lubbock to put together the formal proposal to the government.[28] This proposal characterized the labour involved in the reductions as 'immense' and labelled the project 'probably the greatest and the most important that has ever yet been undertaken in Astronomy'. Emphasizing the practical benefits of the project, the proposal further stated that

> it deserves the attention of any scientific nation, for its importance in the sciences of Theoretical and Practical Astronomy, but especially of a maritime nation, for its importance to the improvement of Navigation: and we imagine that the honour of the British Nation and that of its National Observatory are intimately concerned in the complete and useful reduction of its most important observations.[29]

Airy calculated that the work would take thirty-six years for a single individual to complete. To finish the work more quickly, he requested £3,600 to be used for the employment of more computers at the average annual salary of one hundred pounds.[30] This request was granted, increasing the total number of computers from nine to fifteen, enabling Airy to 'carry on the work at a quicker rate'.[31] Efficiency savings here were clearly tied to the speed of production and not to the well-being of the computers. By the end of

[23] This group of computers included John William Thomas, Hugh Breen, Hugh Breen Jr, Edwin Dunkin, Richard Dunkin, Thaddeus Foley, George Withersby, J.H. Bowman and John Putt. For the list of computers employed see RGO 6/524 117–18, Accounts relating to the Expenditure for the Reduction of the Greenwich Lunar and Planetary Observations, [*c.*1839].

[24] RGO 6/524 121, Airy to Spearman, 13 April 1839.

[25] RGO 6/524 132, Airy to Robert Gordon, 18 April 1840. A portion of Airy's statement made to the BAAS still survives. See RGO 6/524 145 [statement by Airy on the planetary reductions], 22 September 1840.

[26] RGO 6/524 153, Airy to Edward Sabine, 27 April 1841.

[27] George Biddell Airy, *Reduction of the Observations of Planets Made at the Royal Observatory, Greenwich, from 1750 to 1830*, London: Palmer and Clayton & J. Murray, 1845.

[28] The brief history of this deputation was described by Airy in RGO 6/524 162, Airy to the Marquis of Breadalbane, 11 May 1841.

[29] RGO 6/524 170–3, draft letter to the First Lord of the Treasury [*c.* June 1841].

[30] RGO 6/524 181, Airy to F.T. Baring, 15 June 1841.

[31] RGO 6/524 188, Charles Trevelyan to the Marquis of Breadalbane, 23 June 1841. This new group included Hugh Breen Sr, Hugh Breen Jr, James Breen, Thomas Downs, Charles Todd, J.M. Britcher, Richard Dunkin, James Mackay, Richard Harris, E. Hanson, Edward Hanson Junior, C.H. Martin, George Fryer, Thomas Eastmure and William Ellis. In 1842, George Withersby, John H. Morgan and B.G. Carter joined, while James Breen,

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1844 Airy informed the Board of Visitors (the body supervising the observatory's management) that the lunar reductions were nearing completion, successfully applying for additional funding to form new and improved lunar tables based on the reductions.[32] However, this task required a smaller workforce, which resulted in the gradual dismissal of almost all the remaining computers.

The published planetary reductions received universal acclaim from the astronomical community. Most prominently, Airy was awarded the Gold Medal of the Royal Astronomical Society in 1846 for completing and supervising the project. Surprisingly, the society did not include any information about the relevance of the observations to nautical astronomy (as claimed in the original funding proposal). Instead, it emphasized that Airy cut 'a broad highway' through the 'wilderness' of paths that former astronomers had taken. Similarly, the task was likened to the 'extraction of ore from the dross of an ancient furnace', and it was described as the Linnaean system for planetary observations.[33] The publication of the lunar observations received a less grandiose reception, but served as the starting point for revising lunar tables: within a year, Airy published a paper demonstrating how the observations corrected elements of these tables.[34]

This overview of the administrative history of the reductions shows that the project was presented to the government as a venture that benefited marine navigation, and consequently the British Empire, through the improvement of lunar and planetary tables. The entanglement of public benefits and astronomical theory was essential for securing funding for the project. The money granted for the reductions by the government was aimed to cover almost exclusively the salaries of computers who undertook the calculations. Although the lunar and the planetary reductions started out as two separate projects, Airy employed the same workforce for both. These computers were not considered members of the observatory, but were instead temporary and disposable workers undertaking calculations for a limited time only. This is an important correction to previous historical works, as it demonstrates that the low rank of the computers originated not only from the type of work they undertook, but also from their employment status. The next section demonstrates the friction in the daily practices of the computers that was caused by such arrangements.

The lives and activities of computers

Since the 1990s there has been a renewed interest in exploring the lives of computers at Greenwich. Mary Bruck examined the contributions of William Christie's 'lady computers' and the life of the Breen family.[35] David Alan Grier provided an overview of the history of computing work at Greenwich.[36] Mary Croarken and David Aubin focused on the lunar and planetary computers. By using the *Annual Reports of the Astronomer Royal* (written by Airy), Croarken placed the experiences of the computers within a wider analysis of

Charles Todd and Edward Hanson Jr were no longer included on the accounts of expenditure. RGO 6/524 189, Airy to Trevelyan, 28 June 1841.

[32] RGO 6/524 232, Extract from the Minutes of the Board of Visitors of the Royal Observatory, meeting of 1844 November 30.

[33] William Henry Smyth, '[Presidential address on the subject of the award of the Medal of the Royal Astronomical Society]', *Monthly Notices of the Royal Astronomical Society* (1846) 7(4), pp. 64–7.

[34] George Biddell Airy, 'Corrections of the elements of the moon's orbit, deduced from the lunar observations made at the Royal Observatory of Greenwich, from 1750 to 1830', *Memoirs of the Royal Astronomical Society* (1849) 17, pp. 21–57.

[35] Mary Bruck and S. Grew, 'A family of astronomers: the Breens of Armagh', *Irish Astronomical Journal* (1999) 26 (2), pp. 121–8.

[36] Grier, op. cit. (7).

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computing work in Britain from the eighteenth century to the twentieth.[37] Reliance on these reports blurred the boundaries between the roles of assistants and the computers, which resulted in the mistake of considering the computers of the planetary and lunar reductions as members of the observatory staff. By contrast, David Aubin's work on the computers made extensive use of the surviving archival materials, and was able to show how different groups within the observatory were able to deploy mathematical techniques in ways that reflected their professional interests. The computers, for example, used them as their tools of labour in order to perform the tasks assigned to them, while for the assistants they could be used in order to climb the observatory's hierarchy. Airy himself used them 'to assert his authority over his staff and the general public'.[38] This article argues that in the case of the planetary and lunar reductions, mathematical techniques were designed to increase the rate at which calculations were produced by a cheap workforce. To demonstrate this, the article revisits five erroneous assumptions in the works of Aubin and Croarken: (1) the function of the entry exams, (2) the training of computers, (3) the internal promotion and future employment of computers, (4) the role of the superintendent of computers and (5) the function of letters of recommendation and testimonials written by Airy.

Entry exams

A key error of Croarken's analysis was the assumption that the lunar and planetary computers in the 1830s, and the observatory assistants in the 1870s, took the same entry exams. Although the group of computers hired in 1838 underwent trials, these were categorically different from the civil service examinations introduced in the 1870s. The purpose of the trials in 1838 was to measure the daily computing rate of a recruit, and to establish their monthly wages relative to the performance of other computers. This arrangement was in line with Airy's proposal for extra funding that tied the annual salaries to the increased production rates. John William Thomas (the superintendent of the computers) and Airy noted that the trials helped with avoiding the computers being overpaid.[39] For example, when John Oddy Putt began working as a computer, his performance was compared to that of another computer, and Thomas complained that the young boy was only able to work 'one third of the Quantity of work done by Mr Dunkin in the same number of hours'.[40]

This connection between the work rate and the salary was already present in Airy's initial requests for potential recruits, in which he sought the employment of untrained computers at low wages. For example, in his letter to Edward Riddle (master of the mathematical school at the Royal Naval Hospital, Greenwich), Airy specified that he was seeking 'three or four hands – not finished calculators but persons who can add subtract and use common sense' for the purpose of employing them for several years.[41] In another letter sent to William Samuel Stratford, Airy noted his interest in recruiting two or three computers with preference for 'raw' computers over 'trained' ones.[42] These examples

[37] Croarken, op. cit. (2). These *Reports* were annual summaries of the work undertaken at Greenwich, which were sent to the body supervising the observatory's operations (the Board of Visitors). For an overview of the history of the Board of Visitors under Airy's directorship see Laurie, op. cit. (10).

[38] Aubin, op. cit. (6), p. 188.

[39] See RGO 6/525 18, John William Thomas to Airy [undated, *c.* December 1838], and RGO 6/525 28, Airy to Thomas, 12 January 1839.

[40] RGO 6/525 10, Thomas to Airy [undated], original emphasis.

[41] RGO 6/526 51, Airy to Riddle, 9 July 1838.

[42] RGO 6/526 52, Airy to Stratford, 9 July 1838. In response, Stratford recommended three individuals aged twenty-five, seventeen and fifteen. The two younger computers were the Dunkin brothers, whose father (employed by Stratford) had recently died. See RGO 6/526 53, Stratford to Airy, 10 July 1838.

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demonstrate that although mathematical backgrounds could be deployed for a variety of purposes, in the case of the lunar and planetary computers they were designed and deployed to measure the performance of workers relative to each other.

The training of computers

Both Croarken and Aubin relied on the indirect assumption that the computers received training to help with furthering their careers at the observatory. Such an assumption overlooks the point that the computers working on the reductions were not attached to the observatory. Since they were not members of the observatory staff, they were even more restricted in making use of the site than the lowest-ranking members of staff (e.g. the gate porter). For example, they were only allowed to enter the rooms of the observatory allocated to them: the Octagon Room and the kitchen. One of the computers (Thaddeus Foley) was even reprimanded by Airy for entering the observing rooms of the observatory, stating that these were not 'public' and shall not be 'visited by any persons but those concerned in the observations'.[43] Even the superintendent of computers, John William Thomas, had to apply for special permission to inspect and practice with the instruments, and the permission was not granted.[44]

Similar requests by other computers do not appear in the archive until 1846, but even those requests were only partly successful. Surviving documents show that requests by Richard Dunkin and B.G. Carter to practise and to observe with the instruments were rejected. Meanwhile, other computers, such as James Breen, William Ellis and Charles Todd, did gain the opportunity to become observers.[45] As the highest-ranking assistant of the observatory noted, one reason for the promotion of a selected number of computers was to use cheap labour to fill the gap in the increased demand for observing at the observatory.[46] At the same time, the selective rejection of these applications demonstrates that the computers were not automatically trained and then promoted as observers or assistants at the observatory. In addition, these examples show that the original aim of recruiting the computers for the reductions was not to train them to become part of the observatory staff. As this longer-term perspective demonstrates, they remained a distinct and separate group, employed merely as temporary workers valued only for their capacity to provide calculating labour. In the case of the reductions, Airy sought to deploy this computing power without consideration of the long-term training of the individuals who supplied that labour.

Internal promotion and the future employment of computers

Clearly related to the question of training is the issue of the computers' career trajectory.[47] While both Grier and Croarken considered internal promotion to be a general path for the computers, such cases were the exceptions rather than the rule for those working on the planetary and lunar reductions. Since the computers were not employed by the observatory, the only internal promotion they could gain was to the role of the superintendent of computers. This confusion may arise from the fact that historical scholarship has tended to cite Edwin Dunkin's story to demonstrate the 'meritocratic' system of

[43] RGO 6/526 71, Airy to Foley, 10 November 1838.

[44] RGO 6/525 7, Thomas to Airy, 7 August 1838.

[45] RGO 6/526 226, Richard Dunkin to Airy, 2 November 1846; RGO 6/526 218, B.G. Carter to Robert Main, 6 October 1846. For the list of computers who also observed see George Biddell Airy, *Astronomical Observations Made at the Royal Observatory, Greenwich, in the Year 1846*, London: Palmer And Clayton, 1848, p. ii.

[46] Belteki, op. cit. (14), p. 586.

[47] Croarken, op. cit. (2), pp. 391–2.

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the observatory – that a computer had the chance to start out as a computer and work their way up to the position of chief assistant of the observatory. The exact reason why Edwin Dunkin was promoted over others from the group of computers remains relatively obscure. He was first promoted from the post of computer to the post of observer at the newly established Magnetical and Meteorological Department. Edwin's autobiography simply noted that Airy 'had previously expressed a desire to improve my position on the first opportunity' as the reason for the promotion.[48] Unfortunately, there remains no relevant document among the archival materials in which Airy cited the reason for the promotion. However, Dunkin's story, that of an extremely rare computer promoted within the observatory ranks, is very much the exception and not the rule. His brother Richard, for example, started in the same position and at the same time as Edwin, but was never promoted, remaining as a computer for nine years (with very small increments to his salary). Among the archival materials consulted that relate to the computers, there were no documents that compared the performances of the two brothers to each other or expressed any preference for one over the other. Ultimately, when a permanent job opportunity emerged for Richard at the Nautical Almanac Office, he resigned from the reductions, citing the 'great uncertainty attending to the permanency of the situation I now hold'.[49] Richard's case contrasts sharply with his brother's experience, but is much more representative of the experiences of the computers, employed on a temporary basis for the project, rather than with the intention of training them for a job at the observatory.

Perhaps even more significantly, and in contrast to a historiographical approach focusing on the success stories, not only were computers almost never promoted within the observatory, but also they rarely found employment in observatories elsewhere. The surviving archival materials show that only four out of the twenty-four computers mentioned in the financial accounts were eventually promoted within the observatory. Although four other computers (John Hartnup, Richard Harris, John C. Morgan and Charles Todd) continued working within the field of astronomy, each one of them worked at different institutions. Among them, Charles Todd had one of the most complicated career paths. After his work was first terminated at Greenwich, he was employed in the 'counting house of a wholesale oilman'. A year later, he sought clerkship in the Ordnance Office and asked for Airy's help.[50] Instead of helping with the clerkship application, Airy offered another temporary computing position to Todd. Todd's father (G. Todd, who carried out the negotiations about his son with Airy) was reluctant to accept this offer, unless Airy guaranteed that it was going to lead to a permanent position.[51] Airy did not respond, which prompted the Todd family to make alternative arrangements. Ultimately, the counting house allowed Charles to work for the observatory 'for a short period' while keeping his position at the counting house vacant until his return.[52] Charles was promptly hired by Airy, but after just over a year's work as a computer his work was once again terminated.[53] Unfortunately for Charles, it appears that the counting house did not honour their promise, and G. Todd once again had to write to Airy asking for help in finding a position for his son. Surprisingly, the request was not to return to the observatory, but to work at either 'a Banking house, or Life Annuity Office'.[54] Although

[48] Edwin Dunkin, *A Far-Off Vision: A Cornishman at Greenwich Observatory*, Truro: Royal Institution of Cornwall, 1999, p. 75.

[49] RGO 6/526 269, Richard Dunkin to Airy, 5 August 1847.

[50] RGO 6/526 186, G. Todd to Airy [November] 1845.

[51] RGO 6/526 188, G. Todd to Airy, 19 November 1845.

[52] RGO 6/526 190, G. Todd to Airy, 21 November 1845.

[53] RGO 6/526 243, Airy to Charles Todd, 7 January 1847.

[54] RGO 6/526 250, G. Todd to Airy, 15 February 1847.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

Airy stated that he was only allowed to provide references, Charles was shortly after recommended for a vacant role at the Cambridge Observatory.[55] Through Todd's career path we see that internal promotion was far from being the norm among the computers. Instead, due to the temporary nature of the job, the computers sought computing work and clerkships outside the confines of the observatory.

The superintendent of computers

As noted, the more likely potential route for computer career progression was the role of superintendent of computers. This role was only created in September 1838, once the number of computers had increased from two to eight. Therefore the role of the superintendent arose from the need to manage a group of individuals, rather than from any requirement for greater mathematical expertise. The first superintendent was John William Thomas.[56] Born in Wales, he began his career as a teacher of mathematics and published several mathematical and instructional books. In 1834 he moved to London, but it was not until 1836 that he started work on the reductions. His letter of introduction stated that Thomas was 'a fair hand at calculation'.[57]

Thomas became a superintendent of computers in the autumn of 1838, resulting in a significant change in his duties. He provided Airy with reports on any calamities that occurred in the Octagon Room, on the performance of the computers, on any late arrivals and on proposals for the distribution of work.[58] Clearly, the role of the superintendent was not to improve and modify the calculations and the standard forms prescribed by Airy. Instead, the role involved ensuring the orderly conduct of the computers and managing the workflow. For example, Thomas provided Airy with a suggestion on how to terminate the work of George Withersby, whom Thomas characterized as 'extremely lazy' and having 'no Brains'. On the rare occasion when Thomas proposed alterations to working practices, these were suggestions relating to monitoring the progress made by the computers.[59] Sharing Airy's fondness for order and efficiency, Thomas reported that he was having trouble keeping 'all hands at full work' due to the lack of standard forms being prepared.[60] At the same time, he still faced the severe limitations arising from the status of a computer: as noted earlier, when Thomas applied to learn how to use the equipment, he was denied that opportunity. Thereby, even though he was the highest-ranked of the computers, he did not enjoy any privileged participation in the work of the observatory, or any opportunities to further his interest in mathematics. He was assigned more duties and responsibilities than the ordinary computers, but he gained the position of superintendent through his love of order, not his ability as a mathematician or an astronomer. This was made clear in Airy's response to an inquiry about an obituary of Thomas:

> [Thomas] was a man with a strong feeling of order, and most perfectly trust-worthy. His natural disposition was inclined to the pursuit of mathematics, but beyond this, and a general ability in subjects of a mathematical nature and in calculations, he did not possess the high mathematics which would have been useful if he had the absolute direction of the calculations entrusted to him. These however were arranged in almost every part by myself and his business was to keep the calculations in proper

[55] RGO 6/526 251, Airy to G. Todd, 16 February 1847.

[56] For an overview of the life of John William Thomas in Welsh, see R. Elwyn Hughes, 'Arfonwyson: Uchelgais A Siom', Llyfrgell Genedlaethol Cymru, *National Library of Wales Journal* (1999) 31(2), pp. 149–72.

[57] RGO 6/526 8, Griffith Davies to E. Riddle, 5 April 1836; RGO 6/526 9, E. Riddle to Airy, 12 April 1836.

[58] RGO 6/526 11, Airy to Thomas, 30 November 1838.

[59] RGO 6/525 10, Thomas to Airy [undated]; RGO 6/526 18, Thomas to Airy [undated].

[60] RGO 6/525 45, Thomas to Airy [undated], original emphasis.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

> order. The qualities which I have mentioned above were for this purpose particularly valuable, and I therefore placed him above several who were better mathematicians than himself.[61]

After the death of Thomas in 1840, Hugh Breen was appointed the next superintendent. Similarly to Thomas, Hugh Breen had previously worked as a teacher of mathematics. He was born in Ireland and lived there until 1838. In 1837 he had begun to face increased political and religious persecution from the established church after voting in the elections for the local Whig candidate, William Curry, eventually leading to his ousting from his teaching role, and creating barriers to further local employment. Breen did, however, enjoy the patronage of the Caulfield family, who assisted him in making contact with Airy. A letter of introduction was sent to Airy, which included testimonies from Thomas Romney Robinson, William Rowan Hamilton, John Brinkley and Dionysius Lardner.[62] Airy responded joyfully to the prospect of employing someone like Breen, while simultanously noting the low pay attached to the job, making it clear that the only prospect of promotion or salary increase would come through management, and not mathematics. Breen agreed to the conditions and he began working as a computer at the end of the summer of 1838.

Breen's duties as a computer were initially limited to computations. Despite this, he instructed (of his own volition) other members of the computing team on how best to carry out the calculations.[63] By the end of the year 1838, Hugh Breen's son, Hugh Breen Jr, had also begun working as a computer.[64] Father and son worked next to each other in the Octagon Room on the computations, and in some cases the father even scolded his son for misbehaving at work.[65] The surviving archival materials also reveal a power struggle between Thomas and Breen. This possibly arose from Thomas sensing that Breen, as the eldest member of the computing team, was a constant threat to his position as superintendent. It was partly this threat that induced Thomas to write disparaging comments about Irishmen in general and to refer to incidents between father and son as 'Irish row'.[66] However, their power struggle ended with Thomas's early death, and Breen's promotion to the role of superintendent.

Breen's first request as superintendent was to move the computers from the Octagon Room, as he complained about it being 'so very uncomfortable'.[67] Unlike Thomas, his future reports were less punctuated with stories about calamities. Instead, he usually praised the work carried out by the computers, with statements such as 'all the persons employed have conducted themselves in the most agreeable manner, and unremittingly attended to the work pointed out to them to perform'.[68] In terms of his personal development, he requested a copy of the Astronomer Royal's paper on magnetism and to borrow the Greenwich Observations for 1838 'to be better acquainted' with their contents. Probably resulting from other similar requests, Breen was then granted the use of the observatory's library in December 1841.[69] In his letter thanking Airy for this act, he

[61] RGO 6/526 96, Airy to Edward Jones, 17 June 1840, original emphasis.

[62] Although only referred to as Mrs Caulfield in the letters, the use of the initials E.M. Caulfield in a letter suggests that it was Elizabeth Margaret Browne, wife of Henry Caulfield (an MP for Armagh several times), who wrote the initial request. For this letter see RGO 6/526 42, E.M. Caulfield to Airy, 7 June 1838. For the letter mentioning references see RGO 6/526 20, Robert Hutton to Airy, 10 February 1838.

[63] RGO 6/525 54, Hugh Breen to Airy, 9 June 1839.

[64] RGO 6/525 12, Airy to Thomas, 30 November 1838.

[65] RGO 6/526 19, Thomas to Airy [undated].

[66] RGO 6/525 78, Thomas to Airy, 1 November 1839.

[67] RGO 6/525 90, Breen to Airy, 22 January 1840.

[68] RGO 6/525 91, Breen to Airy, 3 April 1840.

[69] RGO 6/525 94, Breen to Airy, 16 April 1840.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

noted that he had been mistakenly borrowing books from it for private use, and apologized for his misunderstanding of the library's rules.[70] For the next years, Breen continued in the same role, hardly ever complaining about the working conditions of the computers. Unfortunately, his life also ended abruptly, and he did not live to see the reductions being published. Nevertheless, Airy considered it an appropriate honour to acknowledge Breen's contributions as an 'Addition to the Introduction' in the final publication: '[Breen died] a few hours after the last Supplementary Tables [of the lunar reductions] had been sent to press'.[71]

Letters of recommendation and testimonials

Previous historians have used Airy's letters of recommendation to demonstrate his good intentions towards the computers and observatory staff.[72] The surviving testimonials are divided into two types: one relating to employment at observatories, and one relating to employment at non-observatory sites.[73] Roger Hutchins previously showed that Airy used his testimonials to promote the Greenwich-centric organization of astronomical work around Britain.[74] However, the testimonials produced by Airy for computers, which tended to be sent to non-scientific employers, were rather different. These documents have not yet been fully examined by historians, but they tended to be both formulaic and distant, reflecting the relationship between Airy and the computers. For example, after Hugh Breen had become the superintendent, he asked Airy to provide testimonials to Martin and Withersby as Breen knew 'nothing of them except during their working hours [and] to these they attended very punctually'.[75] The testimonials to both were produced on the same day, and were almost entirely identical without any reference to their characters: 'Mr. George Withersby has been employed under my superintendance, as Computer, from the 9th of May 1842 to the present day. During this time I have had every reason to be satisfied with his steadiness and regularity'.[76] Martin's testimonial included an extra half-sentence which clarified that Airy parted with him only because 'the work on which he has been employed is drawing to a clear': in other words, coming to an end.[77]

The testimonials had the potential to serve the applicant or the prospective employer. This was shown by Airy making references to the limitations of the computers within the documents. For instance, after Francis Waters left his position as a computer, he asked Airy for a testimonial to support his application for a clerkship at the Royal Naval School, New Cross.[78] Airy noted in his response that due to the way in which Waters left his position at the observatory, he was tempted to withdraw the testimonial and reminded the computer that 'Mr. Waters will not in any case be received again at the Observatory'.[79] Waters's application to the Royal Naval School was possibly unsuccessful as Airy sent another testimonial in April next year to the Guarantee Society. In this letter, he stated, 'I determined that I would never take him into employment again', and, '[m]y

[70] RGO 6/525 101, Breen to Airy, 11 December 1841.

[71] George Biddell Airy, *Reductions of the Observations of the Moon Made at the Royal Observatory Greenwich, from 1750 to 1830*, London: Palmer & Clayton and J. Murray, 1848.

[72] Croarken, op. cit. (2), p. 392.

[73] The former can be found among the 'Correspondence on observatories' and 'Letters from observatories' volumes (RGO 6/140–55), while the latter can be found among the 'Correspondence of computers' volume (RGO 6/526).

[74] Rogert Hutchins, *British University Observatories 1772–1939*, Abingdon and New York: Routledge, 2016.

[75] RGO 6/526 153, Hugh Breen to Airy [undated].

[76] RGO 6/526 162, testimonial of George Withersby, 29 February 1844.

[77] RGO 6/526 161, testimonial of C.H. Martin, 29 February 1844.

[78] RGO 6/526 226, Francis Waters to Airy, 2 November 1846.

[79] RGO 6/526 236, Airy to Francis Waters, 13 November 1846.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

general impression is, that in most circumstances he will conduct himself well, but that in difficult circumstances no dependence can be placed on him. I would not become [surety?] for him myself'.[80] It is unknown what the effect of Airy's testimonial was. Years later, however, the Guarantee Society asked Airy for further clarification about the testimonial. Airy responded by quoting his original testimonial and stating, 'I answered them [i.e. the Guarantee Society's questions] as I should have answered a private friend'.[81] After this answer, no further letters arrived from either Waters or the Guarantee Society.

The working conditions of the computers

Edwin Dunkin's success story has dominated the image of a computer during Airy's early directorship: a computer who rose from the lowest ranks to the highest-ranking assistant at the observatory. By contrast, this section has demonstrated that additional archival materials depict the working conditions of the computers in a different light. Airy's interest in employing young 'raw' computers was influenced by the temporary nature of the project and by his attempt to reduce labour costs. Thereby, the organization of the reductions reflected the same emphasis on economy and efficiency that the organization of the observatory did. Breaking down the equations used so that 'raw' computers were also able to solve them was an essential material manifestation of a system built upon temporary disposable labour. The implementation of such a system does not reject claims for Airy's acts of benevolence in general. However, it does demonstrate that labour was not organized with the aim of benefiting computers. Airy's vision of efficiency was not achieved simply by new standardized procedures and the reorganization of the work based on heightened divison of labour. It was also tied to the employment of a disposable workforce at low wages. As the archival materials demonstrate, within Airy's design of the reductions these elements were inseparable from each other.

If Airy's computers formed a machine, then Airy let it run until it started making unusual noises. The surviving archival documents appear to have been compiled to record mostly these instances of breakdown. By using what historians identified as the benevolent elements of Airy's directorship, this section has demonstrated how benevolence played very little role in the organization of labour during the early stages of the reductions. The entry exams were used to set salaries, not as a method to measure one's competency as an astronomer. The post of the computer was not a traineeship to become an astronomer. Even when computers wanted to be trained in the use of instruments, Airy did not provide the opportunity for everyone. Progression within the observatory ranks was not the norm. Although Edwin Dunkin succeeded, most of his contemporaries did not. Airy's testimonials were not written with the distinct aim of helping individuals find work. Instead, writing these testimonials was one of his duties as an employer. Moreover, the testimonials helped prospective employers too to make decisions about the applicant. Finally, when the computers left the observatory, they were employed at a variety of jobs, not just at other observatories. Therefore the post of computer was not a training ground for jobs at other observatories.

Revisiting the alteration of the working hours

With the working conditions of the computers in mind, it is worth returning in the concluding section to the main example set out in the introduction: the alteration of the working hours of the computers. The working hours were closely connected to the salaries of the

[80] RGO 6/526 260, Airy to secretary of the Guarantee Society, 10 April 1847.
[81] RGO 6/526 263, Airy to secretary of the Guarantee Society, 31 May 1854.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

computers. The salaries of two computers working from the summer of 1836 to the summer of 1838 included additional remuneration for performance-based overtime work. This created the incentive for the two computers working on the reductions (John William Thomas and John Hartnup) to work overtime by taking the skeleton forms home. According to the surviving financial accounts, Airy assented to such request from Thomas, but Hartnup continued being paid the same amount on a quarterly basis.[82] When Hugh Breen was hired as the third computer during the summer of 1838, his first salary reflected a similar arrangement, including a component for regular working hours and a component for working overtime.[83] The system of payments changed a month after Breen's arrival due to recruitment of multiple new computers. The new computers were paid the same amount every month, and the individual salaries were determined based on the amount of work they were able to carry out in comparison to each other.[84] With the creation of the role of the superintendent of computers, Thomas became responsible for the monitoring of the work rate and the adjustment of the salaries according to the performances of individuals. For instance, based on their performances, the salary of Richard Dunkin was decreased from £9 11*s* to £7 3*s*, while the salary of his brother, Edwin Dunkin, remained the same.[85] Although a new system of payment was put in place, there were no alterations made to the working hours, which remained at eleven hours a day (i.e. eleven hours and an extra hour for break).

As Dunkin's autobiography also noted, the working conditions were detestable. A similar view was expressed by another computer, Thaddeus Foley, who according to Thomas characterized the Octagon Room and the conditions as 'a beastly place, a slavery, and that no one but a half starved beggar would stop in it'.[86] Foley's views may reflect the fact that he came to the job of computer already in possession of significantly more skills than his colleagues, and would in fact leave after five months to take up the position of mathematical master at the Royal Naval School at Camberwell.[87] Even being in receipt of the second-highest salary amongst the computers could not compensate a skilled and experienced mathematical labourer for the conditions in the Octagon Room.[88]

Foley's comments and his determination to leave did not induce Airy to change the working practices, and the eleven hours of daily work continued for several weeks afterwards. Alarms were raised once again about the working conditions when Airy attempted to recruit J. Henry Bowman as a new computer. Bowman told Thomas that 'if he were to work so many hours every day that he could not possibly live long'.[89] This encounter prompted Thomas to write a lengthy account, including the comments made by both Bowman and Foley, about the working conditions and their effect on the health of the computers.[90] It also noted that Foley had informed Lieutenant Stratford about the poor working conditions. According to Thomas, Stratford's reaction was alarming:

> Lieut Stratford was very much surprised how Professor Airy could think of binding persons to long time if he were only to consult himself on the matter and the health

[82] RGO 6/526 15, John Hartnup to Airy, 1837 November 9; RGO 6/526 49, John William Thomas to Airy [undated, *c.* June 1838].

[83] RGO 6/524 37–8, account relating to the expenditure for the reduction of the Greenwich planetary observations.

[84] RGO 6/524 117–18, accounts relating to the expenditure for the Greenwich lunar and planetary reductions.

[85] RGO 6/524 119–20, accounts relating to the expenditure for reduction of the Greenwich lunar and planetary observations.

[86] Dunkin, op. cit. (48), pp. 71–3; RGO 6/525 15, Thomas to Airy [undated, *c.* December 1838], original emphasis.

[87] RGO 6/526 57, Airy to Stratford, 21 July 1838.

[88] RGO 6/526 83, Foley to Airy, 31 December 1838.

[89] RGO 6/525 29, Thomas to Airy, 21 January 1839.

[90] Thomas to Airy, op. cit. (88).

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

> of the computers as well and besides that he (Professor Airy) could never expect to have the work done well by working too many hours at a time.[91]

Besides alerting Airy to Stratford's disapproval, Thomas described his own experiences with the long working hours. In particular, he pointed out, they made him 'stupified' and led to committing more errors during calculations. In relation to matters of health, Thomas noted that Hugh Breen complained about his chest 'on account of being too long in the same position'. In addition, Thomas warned that there were persons on the 'look out to take the two Dunkins away on account of the long time for fear of their health'. To remedy these issues, Thomas proposed revising the working hours to 8 a.m. to 5 p.m. (with a one-hour break) or to 8 a.m. to 4 p.m. (without a break).[92]

Airy's short response arrived on the same day. It began by stating that he 'has always been of opinion that it would be impossible for the Computers to work the present number of hours'.[93] The reason for delaying such a decision was due to Airy waiting 'for an expression of this opinion before proposing an alteration, of the necessity of which, and the advantage for the accuracy of the calculation, he [i.e. Airy] has been long convinced'. Airy's hesitancy in delaying the alterations is rather unconvincing in light of other surviving letters, but it makes one wonder: to what extent had the reduction of working hours been in Airy's mind? We find that Airy's initial letters dating from 1836 sought computers to work for eight hours per day.[94] By contrast, the exchanges of letters between Thomas and Airy dating from 1837 refer to a different system: an eleven-hour standard workday (from 8 a.m. to 8 p.m. with an hour for break) with the possibility to work overtime.[95] This was reflected in the salary received by Thomas, too, from August 1836. The financial accounts noted that the payments to Thomas to include a regular element of £7 4*s* (and later six pounds), followed by a plus sign, indicating additional small sums that usually fluctuated between one pound and four pounds. Therefore the system of regular working hours and the performance-based remuneration for working overtime were two systems built on top of each other, and there was a discordance between what Airy proposed and how it was put into effect. As outlined at the beginning of the section, this was partly due to the salary system incentivizing working as many hours as possible, rather than allocating work within set times. In June 1838 Airy continued supporting the eleven working hours, writing to Thomas that working during the regular eleven hours instead of the overtime system would allow the computer to earn more.[96] Therefore, by the middle of July 1838, we see that that Airy advised his main computer on the reductions to work fixed hours. This system of fixed working hours became a standard after the new wave of recruits commenced work in August 1838. As a result, the same pattern of working hours was mentioned in the letter in which Airy sought to hire Foley.[97] Airy then remained silent about the eleven-hour workday. However, just three weeks before the working hours were changed, Airy still described in a letter to a potential new computer the eleven-hour workday as the standard.[98] Finally, as has already been mentioned, Bowman was reluctant to take on the position precisely due to the long working hours promoted by Airy. So even if Airy entertained the possibility of changing the working hours, he continued to advertise the role of computers with the requirement

[91] Thomas to Airy, op. cit. (88).
[92] Thomas to Airy, op. cit. (88).
[93] RGO 6/525 30, Airy to Thomas, 21 January 1839.
[94] RGO 6/526 7, Airy to Riddle, 10 March 1836; RGO 6/526 10, Airy to Lord Wrottesley, 9 June 1836.
[95] RGO 6/526 14, Thomas to Airy, 23 August 1837.
[96] RGO 6/525 5, Airy to Thomas, 2 July 1838.
[97] RGO 6/526 57, Airy to Stratford, 21 July 1838.
[98] RGO 6/526 82, Airy to James Mackay, 29 December 1838.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

for eleven hours of daily work. Therefore it is inaccurate to state either that Airy actively sought to alter the working hours or that he initiated the changes to them.

When Thomas announced the alterations of the working hours, the computers received it with great satisfaction. They agreed that 'the time [i.e. the existing working hours] was too long'. Prior to the announcement they had also already become aware of the working arrangements at the Nautical Almanac Office: 'attendance from 9[a.m.] to 4[p.m.] salary from [£]100 to [£]200 – no over work allowed to any except to the person that has the care of the whole which increases his salary to about [£]250 a year'. Greater awareness of the regulations and working conditions at similar roles at other sites encouraged computers to voice their own demands for similar treatment. At the same time, however, the most established computers (Thomas and Breen) were afraid that the new arrangements were going to reduce their salaries. Thomas argued that Breen was only going to accept the assumed reduction to his salary if his son's salary was increased, thereby making their combined salary the same as under the previous arrangements. Meanwhile, Thomas asked Airy not to diminish his salary, citing as justification his managerial role – in particular his capacity to help Airy reduce expenses by cutting his colleagues' wages.[99] Airy's response must have come as a relief to Thomas: 'It was not Mr. Airy's idea to make any deduction from Mr. Thomas's salary, whatever alteration may be made in the arrangement of hours'.[100] Prior to officially introducing the new working hours, Thomas reported that the computers 'are extremely pleased with the arrangement and they seem to be in high spirits and as determined to do their utmost – The new arrangement will certainly give the Astr[onome]r Royal a great credit in general'.[101]

The letters between Thomas and Airy demonstrate that the reduction of the working hours usually described by historians as an example of Airy's generosity was not an act initiated by the Astronomer Royal. Instead, it arose from a threat to Airy's workforce decreasing its productivity due to the deteriorating health of the computers and the possibility of the key computers leaving employment. In addition, it hindered Airy's ability to recruit new computers: new hires began to voice their concerns as early as the first day of their employment. When the computers became aware of the higher salaries and better working conditions of similar labourers at the Nautical Almanac Office, they began demanding better arrangements for themselves. These findings show that the poor working conditions that Airy created and their serious effects on the computers were the driving forces behind the changes implemented in the working hours. Such a reversal of the story, from Airy's perspective to the experience of the computers, helps in reinstating the active presence of the labourers and their awareness of the harsh conditions that they were placed under. It counters the assumption that the labourers were overworked of their own volition and that they were unaware of the effects of the poor working conditions. Examining the working experiences of the computers demonstrates that Airy was primarily concerned about cutting the costs of employment, while at the same time maximizing the productivity of the workforce. This was a rationale that he labelled economic and efficient during his time at the Cambridge Observatory.[102] It was also the same sentiment that Airy displayed in his approach towards the working hours of the computers. It further shows that the concerns and experiences of the mathematical labourers were different from those of the managers of mathematics. The division of labour implemented by Airy for astronomical labour did not abolish the boundaries between social classes. Instead, it reproduced them. The factory mentality that transformed Greenwich brought

[99] RGO 6/525 32, Thomas to Airy, 22 January 1839.
[100] RGO 6/525 33, Airy to Thomas, 23 January 1839.
[101] RGO 5/525 34, Thomas to Airy, 23 January 1839.
[102] RGO 6/157, Airy to the Duke of Northumberland, 4 September 1834.

https://doi.org/10.1017/S0007087423000018 Published online by Cambridge University Press

with it both the efficiency and the inequalities embedded within the organization of the workforce.

This article has also attempted to take the necessary first step to clarify the type of labour that took place within the observatory. It has considered the various previous approaches to the nature of work at the observatory as providing useful glimpses into aspects of its work. However, rather than applying any of those frameworks, the article's analysis has been driven by the surviving archival materials that relate directly to the experiences of the computers. By using such an approach, instead of the creaking sounds of machine-like instruments or the rustling of skeleton forms, it is the growing disquiet of the computers that emerges. Future research would greatly benefit from an analysis of how the changing labour laws during the 1830s impacted the views of the computers. A crucial difficulty will be the lack of substantial records left behind by the computers. Alternatively, one could research further Airy's thoughts on politics and labour law – an area that has been severely neglected by historians despite Airy's demand for political independence upon his appointment to the role of Astronomer Royal. The scholarship would also benefit from comparing the lunar and planetary reductions to later computing projects (such as the meteorological reductions of the 1870s). Such an analysis would be able to examine Airy's changing attitudes towards the employment of computers and the working conditions that were experienced at the observatory decades apart.

Acknowledgements. Research for the article was undertaken while working as an ROG350 Sackler Research Fellow at the Royal Museums Greenwich. I am thankful for the comments and guidance received by Graham Dolan, Louise Devoy and Lee Macdonald while writing the article. I am also thankful for the comments received from the participants of the Observatory Networks workshop series.

Cite this article: Belteki D (2023). The winter of raw computers: the history of the lunar and planetary reductions of the Royal Observatory, Greenwich. *The British Journal for the History of Science* **56**, 65–81. https://doi.org/10.1017/S0007087423000018