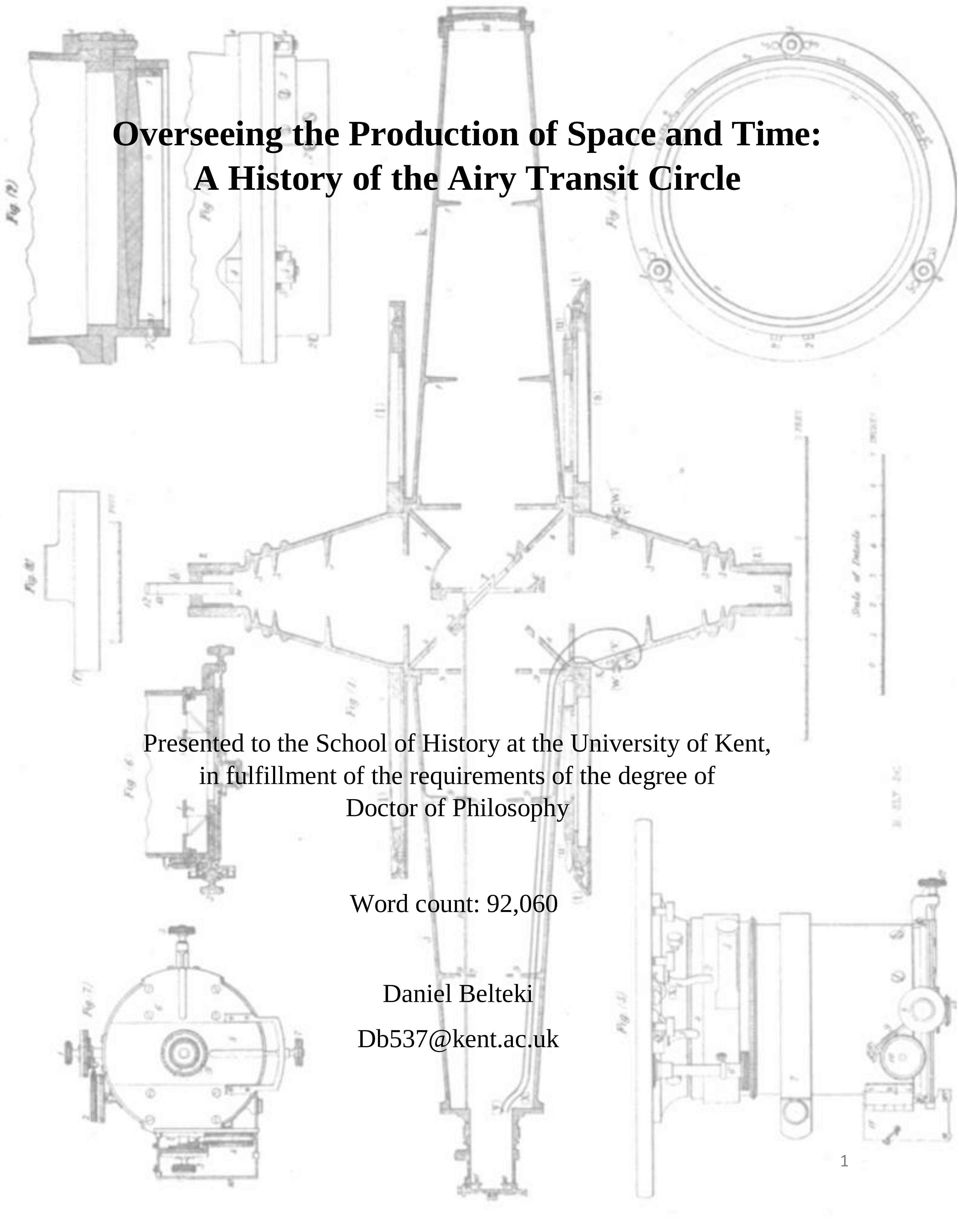

Overseeing the Production of Space and Time: A History of the Airy Transit Circle

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I was sure that the sun would some day regulate itself by my watch!

- Jean Passepartout in Jules Verne’s *Around the World in Eighty Days*

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Contents

Introduction

Visitors wishing to see the Airy Transit Circle (figure 1) at the Royal Observatory Greenwich find it in a room that appears too small for the instrument. The space between the walls of the room and the piers of the Transit Circle is so narrow that only one visitor at a time can walk through it. Walter Maunder, a former assistant at the Observatory, noted this problem with the statement that the Transit-Circle Room is 'not well adapted for representation by artist or photographer.'[1] In light of this, those who visit the Transit Circle are not only looking at the instrument, but they are also constantly engaging with the space that surrounds it with all of its obstacles.

The curators of the Observatory oversee the taming of this instrument. Yet, even in their hands, it refuses to be easily displayed to the visitors. The method of observation, and the precision achieved with the instrument has been long surpassed by other instruments. Systematic errors of the instrument were found in the early 20th century, which led to halting observing programmes with it in the 1930s. The Airy Transit Circle was also much larger than other transit circles, which led to a relatively complex design that consists of a multitude of smaller parts and instruments. Communicating transit circles and their principles has been a challenge since the nineteenth century, and disagreements arose among Airy and his assistants about how they should be described to different audiences. Such problems pose major difficulties in communicating the Transit Circle to visitors of the Observatory in our time. The current solution

[1] Walter Maunder, *The Royal Observatory Greenwich: A glance at its history and its work* (London: The Religious Tract Society, 1900), p. 147.

is to connect the history of the instrument to the wider history of finding longitude.[2] This can easily be achieved as the Transit Circle was selected by the delegates of 22 nations in 1884 as the instrument to define the International Prime Meridian.[3] But such framing of the instrument's history both hides and simplifies its wider contributions to star catalogues and to time-keeping within everyday life.[4] To sum up, curators inherited the struggle of how to both tame and exhibit the instrument.

The members of the museum's conservation department face challenges through the maintenance and repair of the Transit Circle. Despite being a precision instrument, its precision is no longer maintained to an extent that would allow for making useful measurements with it.[5] However, the abilities to raise and lower the telescope tube, and to turn it around its horizontal axis are still preserved. Furthermore, the microscopes attached to the western pier can still be used to view the graduations of the large divided circle on the other side of the pier. To maintain the instrument in such a state requires specialist knowledge which was passed down by the last Observatory assistants and mechanics who used and repaired the instrument.[6] However, due to the infrequency with which those practices are carried out, the knowledge is no longer embodied, but rather followed through text-based instructions. This way, every time the general

[2] For the challenges connected to presenting the complicated history of the museum as a curator, see Gloria Clifton, 'The Royal Observatory, Greenwich, London: Presenting a Small Observatory Site to the Public', *Monuments and Sites*, 18 (2009), 177-187.
[3] For more on the International Meridian Conference in Washington, see Derek Howse, *Greenwich Time* (Oxford: Oxford University Press, 1980), pp. 138-151; and Charles J. Withers, *Zero Degrees: Geographies of the Meridian*, (London: Harvard University Press, 2017), pp. 185-218.
[4] For the contribution of the Airy Transit Circle to astrometry see Michael Perryman, 'The history of astrometry', *The European Physical Journal H*, 37:5 (2012), 745-792 (pp. 27-28).
[5] For a published report of the last major conservation of the ATC, see C. M. Lowne, 'The Object Glass of the Airy Transit Circle at Greenwich', *The Observatory*, 101 (1981), 43-50.
[6] These documents are held at the Curatorial Office of the Royal Observatory, Greenwich, now forming part of the Royal Museums Greenwich.

maintenance of the instrument takes place, the tacit knowledge required for its use is rediscovered once again.

The challenge that historians of the Observatory face takes a different form. Documents relating to the Transit Circle are distributed unevenly among the large number of manuscripts held among the Royal Greenwich Observatory archives at Cambridge University Library.[7] Despite this, previous historians of the Observatory compiled the history of the Transit Circle from the official publications of the Observatory (the *Annual Reports of the Astronomer Royal to the Board of Visitors*, the *Greenwich Observations*, and the instrument's two official technical descriptions), which were easily accessible in libraries.[8] Unfortunately, the official documents only included discussions about the final products and results of scientific and technical projects, as opposed to discussing the various challenges that arose during the projects. As a result, the histories of the Transit Circle based on the official documents have not called attention to the recurring negotiations that influenced both its design and everyday use within the operations of the Observatory.[9] This way, if historians want to reconstruct how the Transit Circle was integrated into the work of the Observatory, they have to consult the 12 cubic meters of records that Sir George Biddell Airy (the seventh Astronomer Royal, and designer of the Airy Transit Circle) left behind, and where records of these negotiations can still be found. This thesis is an attempt at re- assembling its life-story in a way that highlights the various interpretations and meanings associated with the instrument.

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[7] To illustrate how scattered these documents are, it is worth naming a few of the titles of the folders within which references to the Transit Circle appear: 'Papers on Government Superintendence' (RGO 6/1-7), 'Visitation papers' (RGO 6/8-20), 'Occasional orders to assistants' (RGO 6/33-41), 'Papers concerning occasional observers' (RGO 6-42-43), 'Papers on buildings and grounds' (RGO 6/44-52), 'Correspondence about Estimates' (RGO 6/64-71), 'Correspondence on instruments' (RGO 6/159-179), 'Correspondence with tradesmen' (RGO 6/725-758) etc.

[8] The official descripts of the instrument (titled '*Description of the Transit-Circle*') were published as appendices to the Greenwich Observations of 1852 and 1867. The latter description included all the modifications implemented into the design and use of the instrument since the first official description.

[9] See Gilbert E. Satterthwaite, 'Airy's transit circle', *Journal of Astronomical History and Heritage*, 4 (2001), 115-141.

Fig. 1. The Airy Transit Circle in 2013 (photo by Danilo Pivato)

1. Scholarship on the Airy Transit Circle

This dissertation is not the first time that the history of the Airy Transit Circle and its parts have been examined. The last person to make an official observation with the instrument, Gilbert Satterthwaite, wrote a master's dissertation and an article about the history of the instrument. His writings provide insights into how the instrument was used, what research programs it contributed to, and brief descriptions of the various parts of the instrument.[10] However, a major part of his history of the instrument is told through collated extracts and summaries from the *Annual Reports*, thereby providing little historical analysis on how and why changes were implemented. His article on the Transit Circle (based on the dissertation) similarly focuses on the technical description and changes made to the instrument as opposed to placing the instrument within the historical and scientific context within which it emerged.[11] Despite these shortcomings, his dissertation and the article serve as essential guides to anyone interested in the history of the Transit Circle. Moreover, since Satterthwaite spent a considerable amount of time using the instrument, his publications provide unique insights into how one of the instrument's users interpreted its materiality, and the close connection that the user and the instrument formed. This will be explored in this dissertation through an analysis of maintenance practices, as well as through seeing the instrument as an assemblage of multiple external and internal instruments working in harmony. In addition, he saw the instrument through the eyes of its users, which specific approach considers it as an assemblage. In chapters 5 and 6 of this dissertation, we will see how other users of the Transit Circle approached it in a similar manner.

[10] Gilbert E. Satterthwaite, 'The History of the Airy Transit Circle at the Royal Observatory, Greenwich' (Unpublished MA dissertation, University of London, 1995).
[11] Satterthwaite (2001).

The first comprehensive account of the instrument was written by Arthur Jack Meadows. He contextualised the instrument within nineteenth-century positional astronomy and its contributions to the field by the Observatory. He briefly mentioned Airy's family connections to the engineering firm Ransome & May that made the large parts of the Transit Circle, and highlighted the major modifications made to the instrument. Specifically, Meadows discussed the impact of the electric chronograph, which changed the recording of observations from the eye-and-ear method to the chronographic eye-and-touch method.[12] Shorter accounts of the instrument have also been written by other people. When the object glass of the Transit Circle was cleaned in the late 1970s by C. M. Lowne, he wrote a short paper on the quality of the glass.[13] The historical account of the object glass was brief, and once again based exclusively on the official publications of the Observatory. Carole Stott took a different approach by placing the Transit Circle within the long line of meridian instruments used at the Observatory.[14] Her account contextualised the Transit Circle as part of the Observatory's historical aim on the ever-more precise determination of longitude. More recently, a group of historians and physicists compared the instrument and the Coimbra Transit Circle.[15] Their work paid close attention to the materiality of the two instruments to demonstrate how the defects of the original instrument were improved in copies of it. Their article also showed, how the instrument helped in the dissemination of technical knowledge between the two observatories. Since the Transit Circle defined the Prime Meridian, it frequently appears in books discussing the history of longitude. This is due to one of the resolutions of the International Meridian Conference of 1884 held in

[12] Arthur Jack Meadows, *Greenwich Observatory: The Royal Observatory at Greenwich and Herstmonceux 1675-1975, vol. ii: Recent History (1836-1975)* (London: Taylor and Francis, 1975), pp. 36-40.
[13] Lowne, 'The Object Glass of the Airy Transit Circle at Greenwich'.
[14] Carole Stott, 'The Greenwich Meridional Instruments: up to and including the Airy transit Circle', *Vistas in Astronomy*, 28:1 (1985), 133-145.
[15] Vitor Bonifacio, I. Malaquias, and J. Fernandes, 'The Troughton & Simms transit circle of Coimbra Astronomical Observatory from the 1850s: An example of the dissemination of technological developments', *Astronomische Nachrichten*, 330:6 (2009), 544-551.

Washington, D.C. referring to 'the transit instrument at the Observatory of Greenwich as the initial meridian for longitude.'[16] Despite this close connection, histories of longitude only briefly mention the instrument, as opposed to analysing why the instrument served as a reliable tool for defining the Prime Meridian.[17] Within histories of time dissemination, the presence of the Transit Circle is even less frequent: its crucial role in determining time based on the movement of celestial bodies is almost always overlooked, with the task simply described as one of the general roles of the Observatory.[18]

In summary, previous histories of the Transit Circle have offered brief or technical accounts of the instrument. They offered little historical and critical analysis about how the instrument was made, how it was maintained, and what led to its transformation over time. This dissertation aims to fill this gap by examining the recorded interactions of the individuals using the instrument. Another major shortcoming of previous histories is their reliance exclusively on official publications. This is surprising given the abundance of documents that survived within the RGO Archives that relate to the instrument. This dissertation's key strength is the use of the correspondence with instrument makers and other astronomers as well as the internal notes written by Airy and his assistants related to the instrument. From these 'new' documents the Transit Circle's history appears as one complicated by the relationships between astronomers and instrument makers and providing a continuous source of anxiety for the people who oversaw its maintenance. Finally, expanding on the works of Meadows and Stott, this dissertation aims at

[16] Quoted in Howse, *Greenwich Time*, p. 139.
[17] See for example, Howse (1980), Charles J. Withers, *Zero Degrees: Geographies of the Meridian*, (London: Harvard University Press, 2017), pp. 185-218.
[18] See for example Iwan Rhys Morus, ''The nervous system of Britain': space, time and the electric telegraph in the Victorian age', *The British Journal for the History of Science*, 33:4 (2000), 455-475; and David Rooney & James Nye, 'Greenwich Observatory Time for the public benefit': standard time and Victorian networks of regulation', *The British Journal for the History of Science*, 42:1 (2009), 5-30.

contextualising the history of the instrument by placing it within the debates about precision of instruments, reliability of instrument makers, and management of large-scale astronomical data processing.

2. The Airy Transit Circle as an astronomical and scientific instrument

Most of the documents related to the Airy Transit Circle survive within the 'Airy papers' section of the Royal Greenwich Observatory Archives at the Cambridge University Library. While the relevant documents are scattered around in different folders, most of initial plans and descriptions of the instrument can be found in the folders that Airy labelled as 'Correspondence on instruments' and 'Astronomical methods and instruments'.[19] These labels call attention to the fact that Airy categorised the Transit Circle among instruments commonly found at nineteenth-century observatories: clocks, galvanic wires, telescopes, and smaller parts of instruments such as micrometers, object glasses, and threads used in the eye-pieces of telescopes. In this light, we need to consider what role the Transit Circle played in the development of nineteenth-century astronomical instruments. Histories of the subject have highlighted three important aspects of their nineteenth-century developments: an increase in size of telescopes and object glasses, an increase in their precision, and their amalgamation with emerging technologies such as electricity, photography, and spectroscopy. The increase in the size of the instruments reflected the new technical possibilities, the changing manufacturing techniques, and the wider cultural contexts. With the new artisanal techniques of the opticians at Benediktbeuern's Optical Institute, astronomical instruments could be supplied with object glasses of larger sizes.[20]

[19] These can be found under RGO 6/160 to 166.
[20] Myles Jackson, *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics* (Cambridge, Massachusetts; London, England: The MIT Press, 2000).

Keeping the Benediktbeuern methods a secret, both opticians and nations began to support research into the production of high quality glasses.[21] However, as the history of the Transit Circle will demonstrate, the decisions about which optician to employ as a supplier went beyond the simple considerations of the quality of the final product. Instead, personal preferences, national sentiments, questions regarding costs and testing of the product, and problems of trust all played important roles in choosing an instrument maker.

New mounting structures and the use of new techniques for casting the bodies of instruments allowed the increase in the size of telescopes to be complemented with lighter materials and uniformity of their wear.[22] However, adapting the new materials and techniques was not a straightforward process. In the case of the Transit Circle, the use of a new technique for casting its body as well as its large size faced oppositions from other astronomers and Airy's close circle of friends. At the same time, the gigantic size of instruments also formed part of 'the history of the sublime and the gigantic in Victorian science, arts, and society.'[23] The large size of the instruments, objects and buildings attracted audiences through overwhelming their sensory experiences.[24] Incorporating the issues of power and reputation into the large telescope size and the culture of spectacle, Lankford demonstrated how the size of telescopes within astronomy also

[21] For British efforts into producing object glasses of similar quality see Melvyn C. Usselman, 'Michael Faraday's Use of Platinum in His Researches on Optical Glass', *Platinum Metals Review*, 27:4 (1983), 175-181. For the transfer of European opticians and their work to Britain through the case study of the Chance Brothers in Smethwick, Birmingham see Isobel Armstrong, *Victorian Glassworlds* (New York: Oxford University Press Inc., 2008). For a discussion on the Glass Tax and on the socio-political meanings of glass in Britain during the first half of the nineteenth-century see Jenny Bulstrode, 'Riotous assemblage and the materials of regulation', *History of Science*, 56:3 (2018) 278-313.

[22] For a history of improvements made to the mountings of telescopes see Henry C. King, *The History of the Telescope* (Mineola, NY, Dover Publications Inc., 2003) pp. 182-184. For a history of the English Mounting see Wayne Orchiston, 'The English Equatorial mounting and the history of the Fletcher Telescope', *Journal for the History of Astronomy*, 4:1 (2001), 29-42.

[23] Simon Schaffer, 'On Astronomical Drawing', in Caroline A. Jones and Peter Galison, *Picturing Science, Producing Art* (New York, NY and Abingdon, England: Routledge, 2013), 441-474 (p. 461).

[24] Bernard Lightman, 'Mid-Victorian science museums and exhibitions: 'the industrial amusement and instruction of the people'', *Endeavour*, 37:2 (2013) 82-93 (p. 89).

entailed individual and national competitions. His analysis of the controversy over telescope size during the late nineteenth century highlighted the amateur support for smaller instruments (as it brought forth the skill of its user), while professionals supported the use of larger instruments.[25] Similarly, citing a sense of 'American nationalism', American astronomers defended large telescopes since Alvan Clark's reputation was gained through the making of large telescopes.[26] An analysis of the history of the Transit Circle highlights similar considerations. Airy decided on a large transit circle despite other astronomers advising against it. This opposition was due to transit circles being relatively small (especially in comparison to equatorials), which allowed for their easier adjustment and measurement of their errors. Reflecting on the design and material used for the instruments, Simon Newcomb noted the strength and sturdiness of the instrument, which also showed Airy's transformation of the astronomical instruments into factory-like 'heavy machinery'.[27] This dissertation demonstrates how the size of both the object glass and the complete instrument was highlighted by Airy himself as the largest one used for any transit circle at the time, in order to advance his own proposed design and to maintain the reputation of both the Observatory and the instrument.

Transit circles were classified as precision instruments, since they were used for the precise measurement of the coordinates of celestial bodies. Such instruments underlined both the material and social aspects of nineteenth-century 'culture of precision'.[28] In relation to

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[25] John Lankford, 'Amateurs versus Professionals: The Controversy over Telescope Size in Late Victorian Science', *Isis*, 72:1 (1981), 11-28.
[26] Ibid., pp. 15 & 19.
[27] For the description of the instrument by Newcomb see, Simon Newcomb, *The Reminiscences of an Astronomer* (Boston and New York: Houghton, Mifflin and Company, 1903), p. 287-289. For an overview on the transformation of the Observatory into a 'factory' see Robert W. Smith, 'A National Observatory Transformed: Greenwich in the Nineteenth Century', *Journal for the History of Astronomy*, 22:1 (1991), 5-20.
[28] For an overview on 'culture of precision' see Norton M. Wise (ed.), *The Values of Precision* (Princeton, New Jersey: Princeton University Press, 1995).

astronomy and time, observations made with transit circles served as the basis for time measurement. In the case of the Airy Transit Circle, measurements with it served as the basis for Greenwich Mean Time.[29] At smaller observatories around the country that devoted their energies to aiding commerce and shipping, transit circles were used for adjusting clocks and rating chronometers.[30] Within nineteenth-century British society, the culture of precision played the role of regulating everyday life and offering order through periodicity.[31] Airy's transformation of the Greenwich Observatory reflected these principles through their embodiment within the division of labour,[32] the disciplining of the astronomical assistants,[33] and the maintenance of the instruments. Among nineteenth-century astronomers and instrument makers, the question of how precision could be attained served as another dimension through which social hierarchies were reproduced. Two key figures of nineteenth-century astronomy John Herschel (figure 2) and Friedrich Bessel (figure 3), both argued that the works of instrument makers were made better with the aid of disciplined astronomers.[34] Their ideas incorporate a hierarchy between astronomers and instrument makers, where the astronomers brought the instruments even closer to perfection through accounting for their errors in their calculations. As Bessel stated: 'every instrument is made twice […], once in the shop of the master from brass and steel, a second time, however, by the astronomer on paper, through the application of necessary corrections, which he

[29] For a nineteenth-century description of the time signal system set up at the Observatory, see William Ellis, 'The Greenwich Time Signal System', *Nature*, 14:342 (May 18, 1876) 50-52 and 14:344, (June 1, 1876) 110-113.
[30] For an example in the context of the Liverpool Observatory, see Yuto Ishibashi, 'In Pursuit of Accurate Timekeeping: Liverpool and Victorian Electrical Horology', *Annals of Science*, 71:4 (2014), 474-496.
[31] Mark W. Turner, 'Periodical Time in the Nineteenth Century', *Media History*, 8:2 (2002), 183-196.
[32] Smith (1991).
[33] Simon Schaffer, 'Astronomer Mark Time: Discipline and the Personal Equation', *Science in Context*, 2:1 (1988), 115-145.
[34] For Herschel's ideas on the hierarchy between astronomers and instrument makers see John Herschel, *Outlines of Astronomy* (New York: Sheldon & Company, 1869), p. 78.

obtains in the course of his investigations.'[35] As this dissertation will demonstrate, Airy's engagement with the maintenance and use of the Transit Circle reflected such principles, by considering the mathematical understanding of the instrument attained by his astronomical assistants to be better than that of the instrument makers.

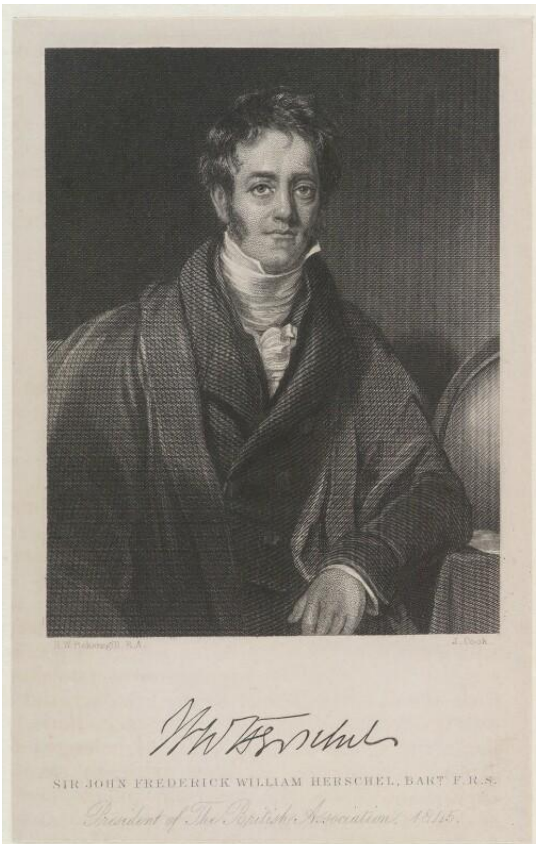

Fig. 2. Portrait of John Herschel (c. 1845, NPG, D16022)

Fig. 3. Portrait of Friedrich Wilhelm Bessel (undated)

The maintenance of instruments highlights that precision is never inherent exclusively in the materiality of instruments themselves, but always has to be complemented with their management by individuals. To put it in differently, precision is always performative: it is

[35] Quoted in Dieter B. Hermann, *The History of Astronomy from Herschel in Hertzsprung* (Cambridge: Cambridge University Press, 1984), p. 35.

performed through the interaction between the human and the material. This approach to precision highlights that instruments never stay the same, but rather constantly change their materiality. In essence, the instruments are in a constant state of flux, which poses another limit on the achievable precision, and necessitates performing its maintenance.[36] Within this framing, even the instruments are set free,[37] by considering them as active participants in the performativity of precision as opposed to being passive objects upon which humans exert a one-sided influence.

Thinking about instruments as active participants in experiments, observations, and in everyday routines opens up the possibility to write about the historical life of instruments. Considering the lives of artefacts has been a prominent feature of business and innovation studies, where products are considered to have life-cycles. However, the concept of a product life-cycle was introduced to make sense of the 'uncertainty about user preferences' and so it focuses solely on how the organisational network (and its members) interacting with product determines the 'life' of a product.[38] As a result, this approach removes the possibility of reciprocal co-production whereby the product also shapes the conditions of the network itself.[39] Within the fields of history and museum studies, object biographies analyse the historical and organisational contexts

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[36] Alexi Baker, '"Precision," "Perfection," and the Reality of British Scientific Instruments on the Move during the 18th Century', *Material Culture Review/ Revue de la culture materielle*, 74 (2012), 14-29.

[37] John Tresch, 'Even the Tools Will Be Free: Humboldt's Romantic Technologies', in David Aubin, Charlotte Bigg, and H. Otto Sibum (eds.), *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture* (Durham and London: Duke University Press, 2010), 253-284.

[38] Steven Klepper, 'Entry, Exit, Growth, and Innovation over the Product Life Cycle', *The American Economic Review*, 86:3 (1996), 562-583 (p. 562).

[39] Jasanoff defined the concept of co-production as 'the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. Knowledge and its material embodiments are at once products of social work and constitutive forms of social life […]', Sheila Jasanoff, 'The idiom of co-production', in Sheila Jasanoff (ed.), *States of Knowledge: the co-production of science and social order* (New York and London: Routledge, 2004), 1-12 (p. 2).

within which object "lived through".[40] The extent to which objects can have *lives* and whether objects and instruments have *agency* still remains a debated topic within these approaches. On the one hand, the approaches of Lorraine Daston and John Tresch highlight the conceptions of things and objects acting out their own lives.[41] On the other hand, Thomas Soderqvist argues that only individuals can have lives,[42] and biography can only be extended as a metaphor and a guiding mechanism for analysing the history of objects and things.[43] In brief, object biographies raise the question whether biographies are only limited to *living* beings, or whether there is a distinct *biographical approach* to examine the history of objects. This dissertation adds to this scholarship by placing as the basis for an instrument's *life* (1) the *interactions* between humans and instruments, (2) the instrument's *state of flux* (i.e. its constantly changing nature), and (3) its participation in the *co-production* of astronomical labour. This way, following Samuel Alberti's work, the dissertation shifts the discussion away from the question of agency of objects towards an analysis of a *life in action*.[44] In relation to the Transit Circle, discussions about the maintenance of precision will demonstrate that changes in the materiality of instruments affect the network by necessitating maintenance or repair. Furthermore, through Tresch's understanding of Humboldtian science, the Transit Circle is seen as an active companion of astronomers as opposed to being a passive tool. In consequence, what is novel about the

[40] For a overview of the object biographies approach through case studies, see the 'Object Biographies' section in Kate Hill (ed.), *Museums and Biographies: Stories, Objects, Identities* (Woodbridge: The Boydell Press, 2014).
[41] Lorraine Daston (ed.), *Things that Talk: Object Lessons from Science and Art* (New York: Zone Books, 2002).
[42] Thomas Soderqvist and Adam Bencard, 'Do Things Talk?', in *Max Planck Institute for the History of Science, Preprint series*, No. 399, 2010, 92-102.
[43] While Soderqvist does not mention object biographies in his edited volume on scientific biographies, he equates biographies with 'life writing', thereby placing the presence of a 'life' as an essential component of any biography. See Thomas Soderqvist (ed.), *The History and Poetics of Scientific Biography* (Aldershot, England; Burlington, VT: Ashgate, 2007).
[44] Alberti argued that 'Objects prompted, changed, and acted as a medium for relationships but were nonetheless inanimate'. It is these actions that the dissertation examines, but at the same time also emphasises that objects do not conform and mediate the intentions of the individuals, which resistance is accentuated in the use of precision instruments such as the Transit Circle. See Samuel J. M. M. Alberti, 'Objects and the Museum', *Isis,* 96 (2005) 559-571 (p. 561).

approach advocated in this dissertation, is the analysis of how the instrument actively participated in the coproduction of the networks within which it operated. This way, the history of the Transit Circle turns into an analysis of its active life.

Instruments do not only interact with humans, but with other instruments too. A focus on their interactions approaches them as *assemblages*.[45] Assemblage-thinking brings forth the multiple entities that take part in a given action. It highlights that instruments are never isolated from other instruments, but instead are always situated in an already existing network. Such networks are especially visible in the case of precision instruments, since the various factors affecting their performances constantly have to be measured and monitored, and other instruments creating the suitable conditions for its performance are similarly relied upon.[46] In the case of the Transit Circle, we can observe this assemblage even within the Transit Circle Room itself. Two collimator telescopes are placed north and south of the Transit Circle (used for measuring its optical misalignments), a third removable collimator can be set up through the western wall of the room, a set of steps around its East-West axis serves as a sun protector, two mercury basins within the observation pit (one visible and one in the ground) allow for observations by reflection and for measuring the error of the instrument, barometers and thermometers placed on the wall provided further measurements that had to be taken into account after observations, while the walls and roof of the room shield the instrument from rain and wind as well as provide

[45] Assemblage was not used by Airy and his assistants as term to describe the Transit Circle. Instead, I use the term to guide the historical analysis of the instrument. This use of the term assemblage is useful in highlighting the multiple parts of the instrument and its constantly changing nature that requires its precision to be "re-assembled". For a discussion of assemblages in relation to objects and their materiality, see Martin Muller, 'Assemblages and Actor-networks: Rethinking Socio-material Power, Politics and Space', *Geography Compass*, 9:1 (2015), 27-41 (pp. 33-35).

[46] For an overview of the monitoring of complex precision instruments and their maintenance in a historical context, see Chris J. Evans, 'Precision engineering: an evolutionary perspective', Phil. Trans. R. Soc. A, 370 (2012), pp. 3835-3851.

moderate control of the temperature around it. Assemblages are not limited to the immediate surroundings of an instrument. In the case of the Transit Circle, when the chronographic method of recording observations was introduced, galvanic wires and signals were used to communicate between the Transit Circle and the Barrel Chronograph (placed in a different building at the North-East corner of the Flamsteed House). In brief, thinking about the Transit Circle as an assemblage highlights its inter-reliance between various instruments as opposed to focusing on the performance of a single instrument. While such a network of instruments can be considered as part of the external assemblage of the Transit Circle, the internal assemblage of the instrument can also be opened up for analysis. Micrometers, eyepieces, graduated circles, counterweights, prisms, and electrical wiring all had to work well at the same time in order to make a good observation. These various parts also had their own histories and lives, which the dissertation attempts to explore further show the complex interaction between multiple large and small instruments in order to help the observers achieve good observations with the Transit Circle.

3. The Airy Scholarship

The Airy Transit Circle used to be referred to as the Greenwich Transit Circle in international publications and simply as the Transit Circle within the internal documents of the Observatory. The first reference to an 'Airy transit circle' can be found in an obituary of Sir David Gill published in 1915 (though it was a reference to a modified version of the Greenwich instrument used at the Cape Observatory),[47] and became a more widely used term from the 1970s onward. The reference to Airy in the name of the instrument shows that it has to be understood

[47] *Annual Report of the Board of Regents of the Smithsonian Institution*, 1915, pp. 513 & 514.

not only within the history of astronomical instruments, but also within the context of Airy's directorship.

The scholarship on Airy has focused on three major themes related to his life and work: (1) as the director who introduced 'factory mentality' into the management and instrumentation of the Observatory, (2) as a scientific public servant embedded within bureaucracy of the British government, (3) and as an 'engineer manquée'. These themes are not isolated from each other, and historians refer to works from all three. At the same time, they focus on different sources and draw conclusions that complement each other. A key example to this is the discussions about Airy's personality: whether his dictatorial management of the Observatory was reflected in every aspect of his life, or whether his playful private personality had more impact on the way in which he controlled the Observatory and the staff.[48] The aim of this dissertation is to offer a synthesis of the three major themes, and to demonstrate how it can provide further insights into the history of the Transit Circle.

[48] While there has not yet been an article written about these contrasting understandings of Airy's personality, the 'Observatory Life' exhibition at the Flamsteed House attempts to present both sides of Airy's life.

Fig. 4. Portrait of George Airy (1877, NPG, Ax17526)

4. Airy and the 'factory mentality'

The most dominant theme within the scholarship on Airy has been his characterisation as the person who introduced 'factory mentality' into the organisation and instrumentation of the Observatory.[49] This was most prominently emphasised in Simon Schaffer's analysis of the personal equation.[50] According to his interpretation, Airy disciplined the astronomical assistants making the observations with instruments the same way as factory managers disciplined the factory workers. The assistants and their actions were calibrated the same way as the instruments, because the increased mechanisation of the Observatory required increased control. In essence, 'the observatory became a factory, if not a "panopticon"'.[51] However, this way of organising astronomical labour was not unique to Airy and the Royal Observatory at Greenwich. As Schaffer emphasised, this new division of labour gradually emerged at other national observatories around Europe too during the nineteenth century.[52] Such a 'factory mentality' was fuelled by the underlying culture of precision, and the increased emphasis on processing astronomical data on larger scales. In relation to this dissertation, the article is useful in analysing how technologies of 'surveillance' were implemented into the design and assemblage of the Transit Circle in order to 'calibrate' the observers. However, while Schaffer placed the observers within the instrumental system, he did not detail how the instruments themselves were overseen. Expanding upon this point, this dissertation opens up the question of how the Transit Circle was calibrated, and how such a need for its calibration showed that instruments were considered to be

[49] The term 'factory mentality' was introduced in Allan Chapman, 'Sir George Airy and the Concept of International Standards in Science, Timekeeping and Navigation', *Vistas in Astronomy*, 28 (1985), 321-28.
[50] Simon Schaffer, *Astronomers Mark Time*.
[51] Ibid. p. 119.
[52] Ibid. p. 121.

just as prone to errors as humans.[53] Such an approach raises the question whether the reliability of the culture of precision was based on the instruments themselves or on trust in the reputation of the instrument and its maintainers.[54]

'Factory mentality' is a powerful term for the analysis of the Observatory as it is reflective of the industrialisation and the mechanisation of Britain during the nineteenth century. It is also reflective of the power relations governing both the social and material organisation of the Observatory. As a result, historians were quick to embrace this approach. Ashworth demonstrated the close commercial ties between business and astronomy through an analysis of the founding of the Royal Astronomical Society.[55] Similarly, he showed how the division of mental labour introduced by Airy to transform the observing process and their further corrections (called reducing observations) reflected the centralised system and hierarchy of the British Empire: the data gathered and produced by astronomical labourers were checked by the skilled assistants during production and by Airy himself before publication.[56] This type of division of astronomical labour reflected the application of the ideas of Adam Smith on the division of physical labour to mental labour.[57] While Ashworth focused more on the organisation of the human workforce, the chapters of this dissertation demonstrate how the instruments were placed within a similar system of surveillance.

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[53] Tresch *Even the Tools Will Be Free*.

[54] For a discussion on how reliability is "constructed" by groups and individuals see Carlene Stephens, '"The Most Reliable Time": William Bond, the New England Railroads, and Time Awareness in 19th-Century America', *Technology and Culture*, 30:1 (1989), 1-24.

[55] William J. Ashworth, 'The calculating eye: Baily, Herschel, Babbage and the business of astronomy', *The British Journal for the History of Science*, 27:4 (1994), 409-441.

[56] William J. Ashworth, 'John Herschel, George Airy, and the roaming eye of the state', *History of Science*, 36:2 (1998), 151-178.

[57] See Noah Kennedy, *The Industrialization of Intelligence: Mind and Machine in the Modern Age* (London and New York: Routledge, 1989); Simon Schaffer, 'Babbage's Calculating Engines and the Factory System', *Reseaux: The French journal of communication*, 4:2 (1996), 271-298.

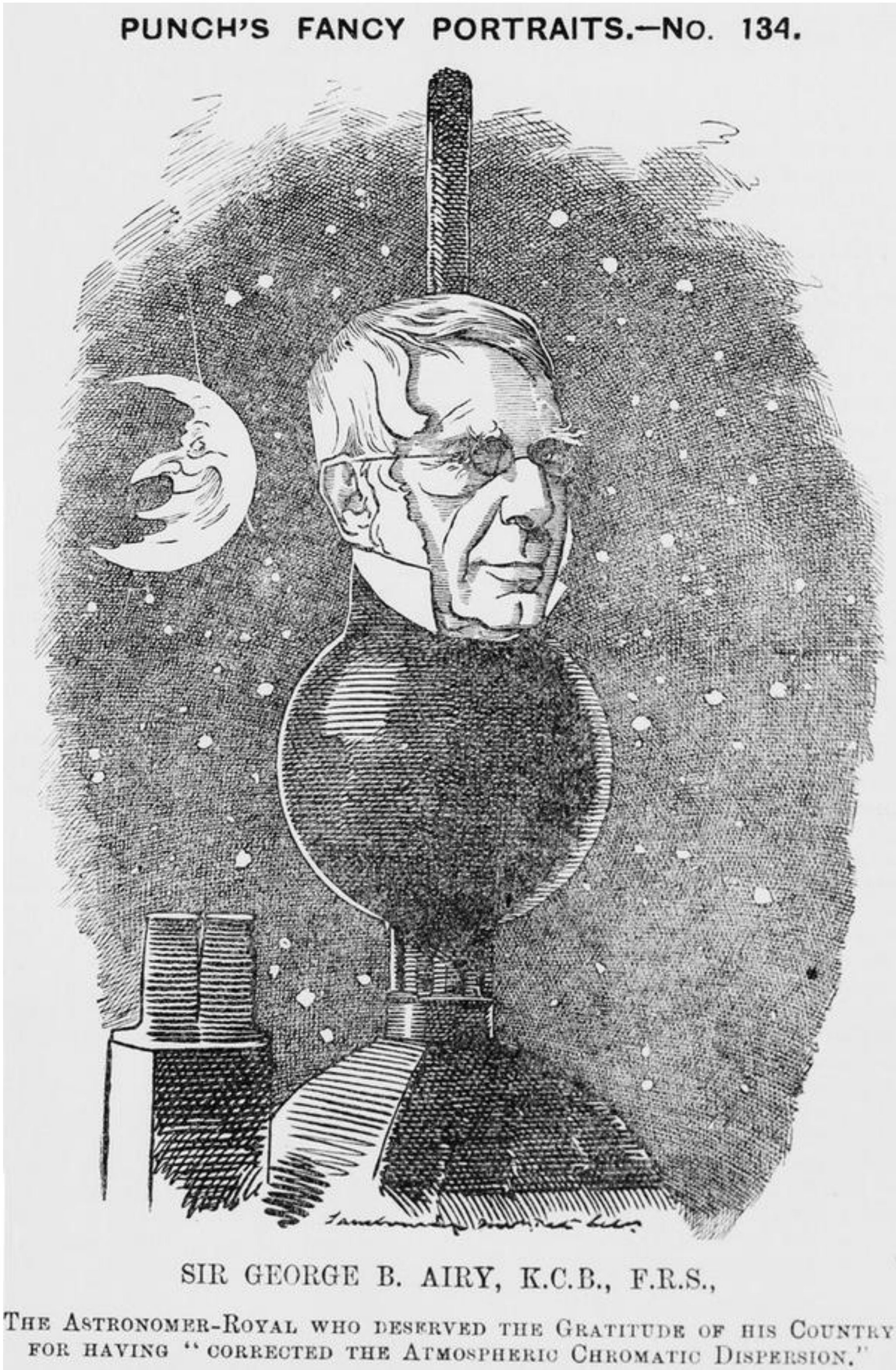

Fig. 5.Cartoon depicting Airy as the Greenwich Time Ball (Punch, 1883)

The theme of centralisation of astronomical work is a similarly important point in histories of nineteenth-century time systems. Morus argued that Greenwich Observatory became the central node within the nervous system of time distribution around Britain.[58] The regulatory implications of this centralisation were explored further by Rooney and Nye, but they similarly maintained the defining power of the Observatory.[59] Edward Gillin's work on the rebuilding of the Palace of Westminster challenges these assumptions.[60] It tells the story of how Airy's attempt at controlling the time service distributed to the building was challenged by both clock makers and politicians, prompting Airy to withdraw from advising on the project. Through this example, Gillin's work shows the attempts to establish new centres (or at least "independent" nodes) within what previously has been seen as a centralised time distribution network. Moving away from time service to organisation of astronomical research at national and international levels, Macdonald raises a similar criticism. By analysing the history of the Kew Observatory, he demonstrates how Kew was considered by the Astronomer Royal as a serious threat to his Greenwich-centred vision of observatory sciences within Britain.[61] In his concluding paragraphs, Macdonald even calls for more histories that show how the centralisation of observatory sciences was challenged by astronomers.[62] This has the potential to lead to accounts of nineteenth-century British astronomy that are decentralised from Greenwich-dominated approaches. Since this dissertation discusses the history of an astronomical instrument that has never left the Greenwich, it decentralises the role of the Observatory in a different manner. It demonstrates how the instrument makers and artisans influenced the design of the final instrument, and how

[58] Morus, *The nervous system of Britain*.
[59] Rooney and Nye, *Greenwich Observatory Time for the public benefit*.
[60] Edward J. Gillin, *The Victorian Palace of Science* (Cambridge: Cambridge University Press, 2017).
[61] Lee T. Macdonald, *Kew Observatory and the Evolution of Victorian Science*, 1840-1910 (Pittsburgh, PA: University of Pittsburgh Press, 2018).
[62] Ibid. p. 245.

their availability determined whether the instrument could be used or not. Similarly, while Ashworth and Schaffer approached the astronomical work at the Observatory through Airy's system of division of labour, this dissertation attempts to decentre it by focusing on the interactions of individuals with the Transit Circle and the data it produced. From this bottom-up approach, the Observatory's (both human and non-human) workforce appears in constant conflict with its established regulations and disciplinary regime. By doing so, the dissertation demonstrates that the strict discipline and regulations did not remove human error and the breakdown of instruments from the operations. Instead, the surveillance was implemented because astronomical work and astronomical instruments often went 'awry'.[63]

5. Airy as a 'scientific public servant'

Airy described himself as an 'Astronomical Officer of the Government'.[64] Due to his position as an Astronomer Royal, he was often consulted in matters related to science and technology.[65] This point was emphasised by Chapman, who argued that Airy needs to be contextualised within his role as a scientific public servant, as it highlights the assignments and projects that he decided to prioritise over others.[66] Furthermore, by approaching Airy as a bureaucrat representing the Government, Chapman's approach offers explanations about why he insisted on continuing the historical mission of the Observatory (i.e. pursuing positional

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[63] The term 'awry' is a reference to Alison Winter's study on compasses and iron ships, see Alison Winter, '"Compasses All Awry": The Iron Ship and the Ambiguities of Cultural Authority in Victorian Britain', *Victorian Studies*, 38:1 (1994), 69-98.
[64] Letter from Airy to E. J. Lowe, 7 February 1853, RGO 6/144: 36.
[65] For an overview of Airy's involvement in issues of science and technology see Adam Perkins, '"Extraneous government business": the Astronomer Royal as government scientist: George Airy and his work on the commissions of state and other bodies, 1838-1880', *Journal of Astronomical History and Heritage*, 4 (2001), 143-154.
[66] Allan Chapman, 'Private research and public duty: George Biddell Airy and the search for Neptune', *Journal for the History of Astronomy*, 19:2 (1988), 121-139.

astronomy to support navigation and time determination), and why he compared the problems of the Observatory to the problems of bureaus of clerks.[67] In relation to the history of the Transit Circle, this approach (along with that of Ashworth) frames it as an instrument used within an office environment, as opposed to being an industrial machine within a "factory". As the dissertation demonstrates, through the connection of the Transit Circle to a chronograph, the astronomical instrument was turned into a machine that engaged in "paper work" like the other astronomical clerks of the Observatory. Such an approach also demonstrates how the instrument was connected to the historical aim of the Observatory (by being a meridian instrument), and how Airy's other responsibilities as an Astronomer Royal delayed and defined his management of the construction and maintenance of the instrument. Chapman's contribution was also important for relying on the primary sources found in the RGO Archives. Rather than using Walter Maunder's history of the Observatory and the official publications of the Observatory, he used extracts from the Astronomer Royal's Journal and the correspondence between Airy and other astronomers.[68] By doing so, Chapman managed to demonstrate how these documents can provide a new, "administrative" framing for Airy's directorship.

[67] George Airy, *Report of the Astronomer Royal to the Board of Visitors* 1837, p. 2.
[68] These journals can still be found among the 'Airy papers'. See 'Astronomer Royal's Journal' from 1836 to 1888 RGO 6/24-27.

Fig. 6. Cartoon of Airy as "Astronomy" (Vanity Fair, 1875, NPG, D43718)

Airy as a scientific public servant has been explored in various other histories of the astronomer. Doron Swade closely analysed what role Airy's position as an Astronomer Royal served in the discussions relating to halting government funding for Babbage's difference engine.[69] Cawood's discussion on the Magnetic Crusade demonstrated the importance of Airy's voice as a representative of a government funded institution.[70] Hoskin's analysis of the Astronomers at War episode during the nineteenth-century showed how Airy's position as the Astronomer Royal aided in both the South vs Sheepshanks legal battle and the ensuing personal clashes afterward.[71] Research by Kennedy and Kershaw demonstrated Airy's role at an international dimension through his cooperation with other observatories in longitude determination and boundary surveys.[72] Similarly, Jessica Ratcliff described Airy's leading role in the training of observers and management of the British Transit of Venus expeditions taking place in 1874.[73] The challenge of this dissertation is to incorporate the history of the Transit Circle within Airy's various responsibilities as Astronomer Royal, and to demonstrate the obstacles that he faced in the maintenance and operation of the instrument as a result of his role as a scientific public servant.

[69] Doron David Swade, 'Calculation and Tabulation in the Nineteenth Century: Airy versus Babbage' (unpublished PhD dissertation, University College London, 2003).
[70] John Cawood, 'The Magnetic Crusade: Science and Politics in Early Victorian Britain', *Isis*, 70:4 (1979), 492-518.
[71] Michael Hoskin, 'Astronomers at War: South vs Sheepshanks', *Journal for the History of Astronomy*, 20:3 (1989), 175-212.
[72] J. E. Kennedy, 'Airy and the survey of the Maine-New Brunswick boundary (1843-1845)', *Journal of Astronomical History and Heritage*, 2:1 (1999), 33-37; and Michael Kershaw, ''A thorn in the side of European geodesy': measuring Paris-Greenwich longitude by electric telegraph', *The British Journal for the History of Science*, 47:4 (2014), 637-660.
[73] Jessica Ratcliff, *The Transit of Venus Enterprise in Victorian Britain* (London and New York: Routledge, 2016).

6. Airy, instrument makers, and engineers

An important theme within the scholarship on Airy has been his engagement with instrument makers. Such researches have demonstrated Airy's interest and knowledge in technology. The three-volume history of the Observatory used the label 'engineer manquée' to explain his interest in designing and making various mechanical contrivances found around the buildings.[74] Jim Bennett demonstrated Airy's interactions with horologists, and the improvements he introduced into the design of clocks.[75] Chaldecott similarly described the collaboration of Airy with Charles Vincent Walker related to the introduction of platinum into the Greenwich time-signals system.[76] Gillin's book expanded upon these accounts by demonstrating the underlying political affiliations and the power relations implied by the different designs.[77] Hoskin's work on the South vs Sheepshanks debate highlighted the close connection between Airy, Edward Troughton, and William Simms.[78] The relationship between Simms and Airy was further detailed by Eleanor Mennim's biography of the former, and Thomas Ginn's dissertation on how nineteenth-century artisans and men of science interacted with each other.[79] By drawing upon such works, this dissertation adds a more analytical dimension to interpreting Airy's interaction with instrument makers. It asks why instrument makers such as Troughton & Simms were preferred by the Astronomer Royal over others, even though their competitors offered products and services that were supported by the nineteenth-century British

[74] Meadows, *Recent History*, p. 6.
[75] Jim Bennett, 'George Biddell Airy and horology', *Annals of Science*, 37:3 (1980), 269-285.
[76] John A. Chaldecott, 'Platinum and the Greenwich system of time signals in Britain', *Platinum Metals Review*, 30:1 (1986), 29-37.
[77] Gillin (2017).
[78] Hoskin (1989).
[79] Eleanor Mennim, *Transit Circle. The Story of William Simms (1793-1860)*, (York: William Sessions, 1992); and Thomas W. Ginn, 'Philosophers and artisans: The relationship between men of science and instrument makers in London 1820-1860 (unpublished PhD thesis, University of Kent, 1991).

astronomical community. In doing so, the dissertation provides an analysis of what principles served as the basis for a 'good instrument' among nineteenth-century British astronomers.

The dissertation also explores Airy's interaction with the firm Ransome & May, who contributed in the construction of the heavy and large parts of the Transit Circle. Even though most of the information related to the construction of the instrument survived as letters exchanged between Airy and this firm, no attention has yet been paid to these documents. By exploring the history of the mechanical parts of the Transit Circle, this dissertation also adds to the history of telescopes by paying equal attention to the mounting, the body, and the optical parts of the instrument. Such a history of telescopes and astronomical instruments is yet to be written, though initial research has been carried out and published in articles, books, and chapters by Bennett, Chapman, Hingley, King, and Orchiston.[80] Following the path of these historians, the dissertation demonstrates that the materials out of which the Transit Circle was made and the design of its mechanical parts were exactly the unique features that were displayed and exhibited to the astronomical community as the technological advancements embodied within the instrument.

[80] Allan Chapman is also a leading name in exploring the history of the graduation of circles. The divided circle was a crucial part of the Transit Circle and its history will be explored in Chapter 2 of this dissertation. For histories of dividing circles Allan Chapman, *Dividing the Circle: The Development of Critical Angular Measurement in Astronomy 1500*-1800 (London: John Wiley & Sons, 1995); John Brooks, 'The Circular Dividing Engine: Development in England 1739-1843', *Annals of Science,* 49 (1992), 101-135; Jim Bennett, *The Divided Circle: A History of Instruments for Astronomy, Navigation, and Surveying* (Oxford: Phaidon Press, 1987). For discussion on the body, casting, and mounting of telescopes and astronomical instruments see King (2003); Allan Chapman, 'Out of the meridian: John Bird's equatorial sector and the new technology of astronomical measurement', *Annals of Science*, 52:5 (1995), 431-463; Peter D. Hingley, 'The Shuckburghs of Shuckburgh, Isaac Fletcher, and the history of the English mounting', *The Antiquarian Astronomer*, 7 (2013), 17-40; and Orchiston, *The English equatorial mounting*.

Fig. 7. Portrait of Airy holding a double-image micrometer eye-piece that he designed (1852, NPG, D7188)

7. Theoretical approaches

The theoretical influence of object biographies and assemblages on the approach of the dissertation has already been mentioned in this introduction. However, two other theoretical approaches also greatly influenced the research and analysis of this history of the Transit Circle. The impact of Actor-Network Theory (ANT) on the fields of Science and Technology Studies and History of Science cannot be underestimated. This dissertation borrows several of the key methods of analysis and investigation from all three. First, it borrows as its starting point the extension of symmetrical significance in the historical examination of both human and non-human objects.[81] Within the framework of ANT, the actions of non-human entities (i.e. actants) affect the network and its other members just as much as any participating human actant.[82] As a result, non-human entities have to be taken into account into any analysis to the same extent as human entities. The way in which it affects histories of science and scientific instruments is twofold. It shifts the attention away from a scientist, instrument maker, or any other human-centred understanding of an instrument, and instead examines how the instrument and its limitations also shaped the actions of the network. As Lorraine Daston stated, such an approach allows for incorporating the voice of the thing (and the things that surround the thing).[83] A recent example of this within the context of Airy scholarship is Jenny Bulstrode's article on glass springs, which entered into a 'material dialogue' with the objects through their technical

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[81] For an overview of the extension of the principle of symmetry to encompass non-human entities too, see John Law, 'Actor Network Theory and Material Semiotics', in Bryan S. Turner, (ed.), *The New Blackwell Companion to Social Theory* (Oxford: Blackwell, 2008), 141-158.

[82] Originally, ANT studies used this principle to include animals within their analysis. The most commonly cited example to this is Callon's study on the domestication of scallops. See Michael Callon, 'Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of Saint Brieuc Bay', in John Law (ed.) *Power, Action and Belief. A new Sociology of Knowledge?, Sociological Review Monograph,* 32 (1986), 196-233.

[83] Daston (2002), p. 11.

analysis.[84] This dissertation attempts to listen into the material dialogue between the Observatory staff and the Transit Circle through the internal notes that were preserved among the Airy papers. Furthermore, it views the instrument as a 'romantic machine' that is set free as the companion of astronomers.[85] In the case of the Transit Circle, this means a focus on how the materiality of the instrument reacted to the touch of the observers, and to the repair and maintenance work carried out by the instrument makers. By highlighting the active participation and "resistance" of the instrument in such interactions, the dissertation demonstrates the entanglement of human and non-human entities that co-produced the history of the Transit Circle.

The second important element of any ANT approach is its focus on following the actants around as they interact with other members of the network, and how they bring in new members to the existing network.[86] An actant in circulation shows the wide scale and scope of the networks with which it engages, and through the absence of the established environment and routines surrounding it, an object in circulation highlights the key aspects of its taken for granted interactions within its usual network.[87] This history of the Transit Circle showcases this network of interaction within which the instrument was embedded. However, the challenge posed by the Transit Circle to this approach is in its fixed nature along the meridian.[88] Yet, it is precisely its fixed nature that brings forth the "local circulation" of the instrument and its products within the

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[84] Bulstrode (2018). The concept of 'material dialogue' was derived from Blanca Callen and Tomas Sanchez Criado, 'Vulnerability Tests: Matters of "Care for Matter" in E-Waste Practices', *Technoscienza*, 6:2 (2015), 17-40.
[85] Tresch (2010), and John Tresch, *The Romantic Machine: Utopian Science and Technology after Napoleon* (Chicago and London: The University of Chicago Press, 2012)
[86] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (New York: Oxford University Press, 2005) pp. 61-62.
[87] In relation to the maintenance and repair of instruments, see Simon Schaffer, 'Easily cracked: Scientific instruments in states of disrepair', *Isis*, 102:4 (2011), 706-717. In relation to the circulation and transport of objects see John Mcaleer, '"Stargazers at the world's end": telescopes, observatories and "views" of empire in the nineteenth-century British Empire', *The British Journal for the History of Science*, 46:3 (2013), 389-413.
[88] In fact, the instrument was never removed from the meridian since its installation in 1850 (despite other instruments being moved out during the renovation of the Meridian Building).

Observatory. Rather than transporting it into the workshops of instrument makers, it required the members of the network to visit the instrument to make the necessary changes to it, or to simply use it. As a result, the wider network of the Transit Circle almost always emerges through examining the "local circulation".[89]

The analysis of the networks themselves provide another important aspect of ANT. Networks are not only the sum of their members. They are also composed of the connections and the relations between the entities. The maintenance of existing relations, and the creation of new connections supports or restricts the interactions between the actants.[90] Within Airy scholarship, several studies have brought forward the importance of the networks within which Airy and the Transit Circle interacted, though they did not follow the symmetrical focus on both human and non-human entities in their analyses. Smith's study of the Cambridge Network of men of science demonstrated how the lack of interaction between Airy and Adams led to the British delay in the discovery of Neptune.[91] Studies of early nineteenth-century mathematicians at Cambridge showed how the intellectual environment of the network of mathematicians at the University shaped what mathematical tools they applied to solve the problems they faced in their research areas.[92] Hutchins similarly showed the important role that universities and the Greenwich Observatory played in the training of astronomers, so that they could create further connections within the wider network of astronomers.[93] In relation to the Transit Circle, Satterthwaite demonstrated how the instrument was used and linked to positional astronomy, and therefore to

[89] The Transit Circle deviated from its fixed nature only in two cases: during its construction, and when parts of it were removed for repair.
[90] Law (2007), p. 8.
[91] Robert W. Smith, 'The Cambridge network in action: The discovery of Neptune', *Isis,* 80:3 (1989), 395-422.
[92] Alex D. D. Craik, *Mr Hopkins' Men: Cambridge Reform and British Mathematics in the 19th Century* (London: Springer-Verlag, 2008); Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (Chicago and London: The University of Chicago Press, 2003).
[93] Roger Hutchins, *British University Observatories 1772-1939* (Aldershot: Ashgate, 2008).

the network of astronomers and observatories that engaged in such research.[94] This dissertation reconstructs the network of instrument makers, Observatory staff, men of science, and politicians who interacted with and shaped the life of the instrument.

Besides Actor-Network Theory, the dissertation is also influenced by the recently renewed movement among scholars focusing on maintenance (and repair) practices. David Edgerton highlighted the need to analyse maintenance and repair issues in his 'ten eclectic theses on the historiography of technology'.[95] His argument focused on shifting the attention of analysis away from innovation to use, within which maintenance played a key role in stabilising the possibility of continued use. His approach was expanded in his later book *The Shock of the Old*, which included an examination of maintenance practices within the history of technology during the twentieth century.[96] Renewed organised attempts at opening up maintenance as a general line of enquiry began from 2015 onwards with conferences, special issues, and newspaper articles on the subject.[97] Promoters of the approach, Vinsel and Russell, highlighted that innovation-centred histories focused on change, while maintenance-centred histories focus on attempts at 'keeping things the same.'[98] Denis, Mongili and Pontille called attention to maintenance studies bringing forth the 'vulnerability' of both human and non-human entities, thereby linking the fragility of

[94] Gilbert Satterthwaite, 'Airy and positional astronomy', *Journal of Astronomical History and Heritage*, 4 (2001), 101-113.
[95] David Edgerton, 'From innovation to use: Ten eclectic theses on the historiography of technology', *History and Technology, an International Journal*, 16:2 (1999), 111-136.
[96] David Edgerton, *The Shock of the Old: Technology and global history since 1900* (London: Profile Books, 2006)
[97] The Maintainers Conference website offers a list of key resources (newspaper and research articles, as well as a selection of papers delivered at their conferences), which can be accessed at http://themaintainers.org. [Accessed 7 November 2018].
[98] Andrew L. Russell, and Lee Vinsel, 'After Innovation, Turn to Maintenance', *Technology and Culture*, 59:1 (2018), 1-25 (p. 13).

entities with attempts to keeping things the same.[99] Steven J. Jackson labelled this approach the 'broken world thinking', which allowed researchers to consider the world not as a stable entity, but rather as an ever-changing system, which requires constant repair and maintenance from people who engage with it.[100] Within the history of science and astronomy, such questions were translated into questions of expertise and into considerations of what constitutes a working instrument. Hoskin's articles on the South vs. Sheepshanks debate demonstrated the differences between astronomers about the definition of a working instrument.[101] His (and later McConnell's) studies were useful in demonstrating the social processes and interests (as well as legal proceedings) that determined the quality of an instrument.[102] Schaffer's study on the instruments of the Bombay observatory showed that knowledge about maintaining and repairing instrument was considered part of the expertise of an astronomer, and failing to put such expertise into practice resulted in disapproval from the astronomical community.[103] In another article, Schaffer argued that examining maintenance and repair practices demonstrate that 'social and material disorders are interdependent.'[104] This dissertation adds to the existing literature by expanding upon nineteenth-century practices of maintenance and repair and demonstrates the skills of instrument makers, Observatory staff, and astronomer upon which the maintenance of the instrument relied. At the same time, the dissertation goes beyond the physical maintenance by examining how the "ideal state" of the instrument was achieved through numerical

[99] Jerome Denis, Alessandro Mongili, David Pontille, 'Maintenance & Repair in Science and Technology Studies', *Technoscienza*, 6:2 (2015), 5-15.
[100] Steven J. Jackson, 'Rethinking Repair', in Tarleton Gillespie, Pablo J. Boczkowski, and Kirsten A. Foot (eds.), *Media Technologies: Essays on Communication, Materiality, and Society* (Cambridge, MA, and London, England: The MIT Press, 2014), 221-240 (p. 221).
[101] Hoskin (1989), and Michael Hoskin, 'More on "South v. Sheepshanks"', *Journal for the History of Astronomy*, 22:2 (1991), 174-179.
[102] Anita McConnell, 'Astronomers at war: The viewpoint of Troughton & Simms', *Journal for the History of Astronomy*, 25:3 (1994), 219-235.
[103] Simon Schaffer, 'The Bombay case: astronomers, instrument makers and the East India Company', *Journal for the History of Astronomy*, 43:2 (2012), 151-180.
[104] Schaffer (2011), p. 715.

calculations, and how the reputation of the instrument had to be managed in the eye of both the astronomical community and the general public.

8. The noise of blotting papers

The major novelty of the dissertation lies in its extensive use of the documents found among the Airy papers. As was mentioned previously, historians have been using these documents, but only very selectively, with studies focusing on either on a single or a small range of files. This is not surprising given that the entire collection of Airy papers is claimed to take up 12 cubic meters. It reflects Airy's attitude towards keeping records of everything, about which his friends jokingly stated that even blotting papers remain stored among the documents.[105] As a result, historians face a lot "noise" when researching very specific topics. This noise remains present due to the papers being preserved in the same system that Airy devised for cataloguing them. Within this system, papers are catalogued based on the type of "business" under which the general topic of the documents and letters fell. For instance, in the case of the Transit Circle, money requests for the purchase its parts can be found among the Naval Estimates (RGO 6/64-71), the opinion of the Board of Visitors about the instrument is placed within the Visitation Papers (RGO 6/9-10), the plans of the instrument among the Correspondence on Instruments (RGO 6/161-163), letters exchanged about the construction and subsequent repairs of it among the Correspondence with Tradesmen (RGO 6/720-758), while maintenance carried out by the local staff among the Papers on Moveable Property where the Reports on the State of the

[105] August De Morgan joked about Airy in a letter to Sir William Rowan Hamilton stating that 'if Airy wiped his pen on a piece of blotting-paper, he would endorse the blotting-paper with the date and particulars of its use and file it away amongst his papers.' Quoted in Robert Perceval Graves, *Life of Sir William Rowan Hamilton, vol. III.* (Dublin: Hidges and Figgis, & Co., 1889), p. 381.

Instruments are kept (RGO 6/56-63). Even this brief list of folders excludes important documents such as the papers related to exhibition of a model of the Transit Circle in Paris in 1855 (RGO 6/442) or the occasional orders to assistants regarding the operation of the instrument (RGO 6/33-41). This dissertation attempts to turn the scattered distribution of the documents into a strength of the resources by arguing that it reflected how Airy viewed the instrument itself within the larger operations of the Observatory. Within this framing, the scattered documents demonstrate how the Transit Circle was part of multiple networks of instrument makers, men of science, and local staff who all attached different meanings to the instrument.

The dissertation also revisits the official documents of the Observatory such as the *Greenwich Observations* and its multiple appendices.[106] Two descriptions of the Transit Circle were published as such appendices: the first a few years after its installation, and the second almost twenty years later in order to include the changes made to the instrument. Besides these descriptions, the *Greenwich Observations* and the *Annual Reports of the Astronomer Royal to the Board of Visitors* served as publications through which the state of the Transit Circle and modifications made to it were annually published.[107] While these official documents are useful in providing the historian with initial guidance, they almost exclusively recorded the final changes implemented into the instrument, as opposed to describing or justifying how such decisions were reached. By complementing these sources with the Airy papers, the dissertation provides a more complete picture of the history of the Transit Circle that encompasses the complex set of decisions leading to the modifications made to the instrument and brings to light what was excluded from the official reports.

[106] The *Greenwich Observations* is the term used in reference to the published observations of the Observatory.
[107] The Annual Reports of the Astronomer Royal will simply be referred to as the *Annual Reports* in the rest of this dissertation.

Another starting point for the dissertation was Airy's 'autobiography'. It is difficult to classify it as an autobiography, since the book was edited by his son, Wilfrid Airy.[108] The entire book is interwoven with Wilfrid's reflections on Airy, or on his findings about the life of his father. Furthermore, he exercised control over what was important or not for the book, for instance, by excluding Airy's reflections on family matters.[109] As a result, the 'autobiography' reflects Wilfrid's idea of what an autobiography written by George Airy would have looked like. Where George Airy's autobiography is directly taken up, the writing style is very dry and reads almost as a list of events. It provides a very abundant list of actions as opposed to personal reflections on why he made certain decisions. Considering this, the autobiography serves the same purpose as the official documents: it provides a guide for researchers on what places Airy visited, who he was in contact with, and what scientific and technological issues he was concerned at the time. The Transit Circle is mentioned several times in the autobiography within such a context, by providing information on the major changes made to the instrument over the years, the interaction with instrument makers during its construction, and one remark about Airy's intention for new meridian instruments dating 6 years before the approval for the construction of the Transit Circle.

The second half of the nineteenth century produced a relatively large number of descriptions of the Observatory, as well as articles related to its operations. Around 40 of these publications mention the Transit Circle, with around 15 more among them reflecting on the instrument in

[108] As a result of this, the dissertation will consider Wilfrid Airy as the editor of the 'Autobiography'. Wilfrid Airy (ed.), *Autobiography of Sir George Biddell Airy* (Cambridge: University Press, 1896).
[109] Ibid. p. ix.

detail. The critical analysis of these descriptions will form part of Chapter 6, which will discuss how they contributed to the maintenance of the instrument's reputation and status. A handful of these works have been used by previous historians to evaluate Airy's directorship. Walter Maunder's history of the Observatory is frequently used as the source for the image of Airy as a despotic factory manager.[110] However, it is important to note that Maunder worked at the Observatory during Airy's last years as Astronomer Royal, as opposed to knowing Airy throughout his entire life. This also has to be taken into account during his description of the Transit Circle. Several pages in his book are devoted to the Transit Circle, and its functions were connected to the operations at the various departments of the Observatory. However, the Transit Circle described was very different from the one installed in 1850, with its connection to the Chronograph having become a standard practice, and several parts of the assemblage of the instrument (lifting machinery, collimators etc.) having been replaced. While lesser known, Edwin Dunkin's autobiography is a more contemporary account.[111] Dunkin was both a long-time member of the Observatory staff, and someone who oversaw the instrument for many years. Therefore, his account of the instrument incorporates reflections on how the instrument changed and what remained of its original state at the time of his resignation. Alongside Dunkin's accounts are the various articles in magazines published by other members of the Observatory staff during the second half of the nineteenth century. Since the focus of these was the Observatory itself, the descriptions of the Transit Circle always included thoughts on how the instrument fit within the larger aims of the Observatory.

[110] E. Walter Maunder, *The Royal Observatory*.
[111] Edwin Dunkin, *A far off vision: a Cornishman at Greenwich Observatory: auto-biographical notes* (Cornwall: Royal Institution of Cornwall, 1999).

Finally, the dissertation also draws on first-hand experience gained in the annual maintenance of the Transit Circle at the Royal Museums Greenwich. My personal involvement in the task allowed me to receive a hands-on experience of maintaining the instrument. I was also able to witness how expertise and knowledge in relation to its maintenance was passed down over years and put into practice every year. The conservators still rely on the "checklist" supplied by Gilbert Satterthwaite, which was put together in the 1950s.[112] The safety concerns of nineteenth-century astronomers focusing on the instrument being exposed to heat or the bending of the telescope tube due to its weight have been replaced with safety concerns focusing on the individuals carrying out the maintenance. Finally, the internship at Royal Museums Greenwich provided me with access to the curatorial documents related to Transit Circle. As it will be shown in the last chapter, the question of whether the instrument could still be used as a relevant educational tool or not played an important role in determining whether it should be restored to an operational order or not. By examining this issue, the chapter will ask whether the Transit Circle was transformed into a 'dead object' or remained 'living' instrument but with different purposes for its use.

[112] There are two similar checklists that are among the records of the Curatorial Department of the Royal Museums Greenwich. The first one is labelled 'Procedure for raising the instrument for routine maintenance' (AST 0991 – Refracting Transit Circle (Airy's) OM/TC.1 [3 October 1997]). The second one is labelled 'Maintenance of the Airy Transit Circle' and similarly described the maintenance procedures step by step (AST 0991, unnamed folder, 10 May 1954).

9. Outline of the dissertation

The title of this dissertation highlights the two main themes that will be discussed in the chapters. The terms oversee and oversight were chosen to highlight the organisational aspects that surrounded the Transit Circle. It brings forth the significance of Airy's management of the Observatory based on a factory mentality and division of labour. Through these measures, he exercised control over every aspect of the Observatory business and placed under surveillance both the astronomical labourers and the astronomical instruments. This overseeing of the Observatory allowed for the large-scale production of astronomical data that was characteristic of positional astronomy and for ensuring a high level of reliability of the data produced. The second meaning of oversight refers to the omissions and unintentional errors made by individuals. As the chapters will demonstrate, errors and omissions were considered to be present at every stage of astronomical labour and within every entity that contributed to it. Therefore, Airy's organisation (overseeing) of astronomical labour was set up in order to minimise the possibility of such omissions and errors (oversight) during the production of astronomical data. The interplay between these two meanings of the word highlights the active dynamics that were embodied in the tools of astronomical labour. For example, skeleton forms simplified astronomical calculations to avoid the possibility of miscalculations, but at the same time they were also double checked by the superintendents of the computer, highlighting the expectation of errors from the computers. A similar interplay was embodied within the materiality of the Transit Circle too. Even though its construction incorporated the most precise techniques of the age, it was designed with the possibility to measure its instrumental errors with ease. In this sense, it was both a tool for exercising oversight (i.e. control) and an entity that was expected to suffer from oversight (i.e. omissions).

The second part of the title highlights the importance of focusing on production processes in science and technology. The first two chapters of this dissertation discuss how the final forms of scientific instruments are never achieved through a linear and single path. Instead, each step of its production embodies in the materiality the decision of the individuals involved in the project. This way, a focus on production processes highlights that there are always alternative paths that the final form of the instrument can take. Comparing these alternatives to the decisions embodied in the final material forms demonstrate why certain suppliers, materials, arrangements, or techniques are chosen instead of others. In the case of the Transit Circle, it demonstrates why Airy decided to use Simms as the supplier of the object glass instead of opticians from continental Europe. Focusing on production processes also opens up the black box of scientific work. Such an approach demonstrates the various decisions that are made at every step of producing scientific data. In the case of the Transit Circle, the approach illuminates its important role in the production of astronomical tables as well as in the processes that calculated time and spatial positions. As the final chapter shows, with the retirement of the Transit Circle from scientific work, the processes that produced Greenwich Time and the Greenwich Meridian remained black-boxed in publications produced by the National Maritime Museum as well as in the work of historians. This helped in maintaining the role of Greenwich Time and the Greenwich Meridian as linked to scientific standards, even though the processes that produced them have changed over time. Rather than considering time and space as already given entities, this dissertation discusses how they were produced, and how questions about power and politics were embodied within their production processes.

The first and second chapters of the dissertation focus on the origins, design, and construction process of the Transit Circle. The first examines the history of its object glass. By following the object glass from its origins, the chapter demonstrates who were the instrument makers considered for its making, and the extent to which they competed against each other. It demonstrates the international competition between manufacturers of object glasses, as well as Airy's personal preferences towards the instrument maker William Simms.[113] It also shows how the Astronomer Royal used 'economy and efficiency' as key points in evaluating the possibilities offered by the instrument makers. However, Airy did not act alone in making the final decision. He asked the opinion of the Board of Visitors and foreign astronomers. He also exchanged letters with his close friends (especially Richard Sheepshanks and John Herschel) to ask for their advice. From the findings of the chapter, the story of the object glass becomes more complex than the simple purchase of the glass from William Simms, as it was and has been stated in official documents and has been taken up by other scholars.[114]

The second chapter begins by investigating the history of the divided circle, which served as the other most significant part of the instrument. It adds to the existing research on graduated circles by focusing on the materials out of which they were made, and the contribution of engineering firms to their production, as opposed to being an expertise of specialist instrument makers and opticians. Since the divided circle was partly made by Ransome & May and partly by William Simms, its history serves as a useful example for demonstrating the collaboration between instrument makers. Similarly to the history of the object glass, the history of the divided circle also demonstrates that the production process of the Transit Circle 'could have also been

[113] Eleanor Mennim, *Transit Circle*.

[114] Satterthwaite, *Airy's transit circle*.

otherwise'.[115] As the chapter shows, Joseph Whitworth (the Manchester based engineer and industrialist, previously absent from histories of the divided circle) was considered by Airy to carry out the graduation of the divisions. The surviving letters in which Airy sought information about Whitworth's dividing engine foreshadowed the future clashes about standards and precision. Similarly, the communications between Airy, Simms, and May show that the construction process was not straightforward, and that they relied on each other in order to be able to complete the various stages of the production. Through the letters exchanged between these three individuals, the chapter highlights how Airy still relied on the expertise of engineers and instrument makers, despite the scholarship considering him an engineer manquée. The comparative analysis of Airy's interactions with artisans also brings forth the 'hidden engineers and workmen' working for the firms.[116] Finally, Airy's evaluation of the products of the workmen shows us the extent to which he trusted workmen that he did not have direct control over.

Chapters three, four, and five discuss the years during which the Transit Circle was operational (1851-1954), but with a major focus on the years under Airy's directorship (1851-1881) due to the large number of primary sources available about that time period. All three of the chapters are framed under the larger themes of maintenance and repair of the instrument. Such an approach matches the original aim of the dissertation with the introduction of the concept of assemblage by calling attention to the continuous alteration of the materiality and the larger

[115] The statement emphasising the human decisions incorporated throughout the design of artefacts is from Everett Hughes quoted in Susan Leigh Star, 'Introduction: The Sociology of Science and Technology', *Social Problems,* 35:3 (1988), 197-205 (p. 198).
[116] Steven Shapin, 'The Invisible Technician', *American Scientist*, 77:6 (1989), 554-563.

organisational context of the instrument.[117] Furthermore, it continues to demonstrate the role of the 'hidden technicians' within the everyday use of the instrument, such as the carpenters, chief or works, computers, and lower ranked assistants at the Observatory.

Chapter three looks at maintenance and repair work related to the Transit Circle in its traditional sense: alterations and modifications made to the physical materiality of the instrument. It demonstrates that the assemblage of the Transit Circle continued to be expanded with the addition of new parts, and its existing parts were replaced, substituted for new ones, or modified. By doing so, the role of the instrument makers and engineers are shown to remain important within the later life of the instrument too.[118] Within such a framing, the instrument is shown to be a long-term investment by the instrument makers as opposed to being a simple one-off investment of time, resources, and energy.

Chapter four shifts the classical definition of maintenance away from the materiality of instruments and towards their immateriality. It focuses on the measurements of the errors of the Transit Circle and the reductions of the observations (calculations accounting for errors of the instrument and other factors). The chapter contrasts the precision and accuracy attained by instrument makers through their tools, with those attained by astronomers and the observatory staff through their calculations. It not only serves as a way to demonstrate the perceived hierarchy between astronomers and instrument makers during the nineteenth century, but also brings forth the philosophy of instruments and errors upon which astronomers based their

[117] David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (London: Profile Books Ltd, 2008).; Andrew L. Russell and Lee Vinsel, *After Innovation*; Steven J. Jackson, *Rethinking Repair*.

[118] C. M. Lowne, *The Object Glass of the Airy Transit Circle at Greenwich*.

practices. Furthermore, what I call calculative maintenance highlights both the material and immaterial state of the Transit Circle. While physical maintenance engaged only with the instrument's materiality, calculative maintenance constructs an immaterial presence for it that can be altered and modified with tools of mathematics via calculations. This shift from material to immaterial allows the dissertation to break down the direct physical boundaries of the instrument, and to consider it outside the confines of the Transit Circle Room too. In such an immaterial state, the Transit Circle (and its products in the form of recorded measurements) was theoretically removed from its fixed position and circulated among Observatory assistants and astronomers beyond the boundaries of Observatory. This circulation of the Transit Circle in an immaterial state highlights the network of individuals engaged in its calculative maintenance and demonstrates the variety of shapes that its immaterial form took.

Chapter five takes upon the task of locating the immateriality of Transit Circle outside the confines of the Observatory. This is examined through how it was communicated to the astronomical community and to the general public. The various mediums used for the (re-)presentation of the instrument are explored in both a comparative and a chronological manner, interlinked with the breakdowns and the triumphs of the instrument described in the preceding chapters. The definitions of maintenance and repair continue to be expanded within this chapter by arguing that the management of the image of the instrument consisted of practices that maintained the status and the reputation of the Transit Circle within the eyes of the audiences. To demonstrate this, the chapter uses examples of how Airy responded to the criticisms that the instrument faced, and how he attempted to carry out damage control using his network of friends within the astronomical community.

Chapter six focuses on two key stages in the life of the Transit Circle. First, it demonstrates how errors of the instrument during the nineteenth-century were reconsidered as signs of major systematic faults by the beginning of the twentieth century. Second, the chapter shows how the Transit Circle was transformed into a museum object, and then exhibited to the visitors of the Observatory as part of the National Maritime Museum (and later the Royal Museums Greenwich). It demonstrates how the histories of the Prime Meridian and the Transit Circle became almost completely detached from each other in the public imagination. Returning to the question of a biographical approach to scientific instruments, the end of the chapter questions whether ceasing operations with the Transit Circle meant the death of the instrument, or simply a transformation of its function into a different life-stage.

Chapter 1 Trust in glass: The history of the object glass of the Airy Transit Circle

1. Why does the construction process of the Airy Transit Circle matter?

Transit circles and other astronomical instruments are products of construction processes. As artefacts, they do not appear out of nowhere. Instead, they are constructed (and later re-constructed) by individuals, tools, and machines. An analysis of the construction process of an artefact reveals the constituent parts of its materiality and the network of relations upon which its functioning relies. During the construction of an artefact, negotiations between individuals take place in order to decide on the "final form" of the intended product. In addition, producers enter into 'material dialogues' with the items used through the manufacturing practices.[1] The difference between the intended plans for an artefact and its final form demonstrates the divergent paths that the artefact's construction can take. Through these means, the artefact at the beginning of its life appears in a state of flux, or as a set of possible alternative paths that the construction process can take.[2] In the words Susan Leigh Star, a history of an artefact demonstrates that its life 'could have been otherwise'.[3] To put it differently, the artefact appears to exist in multiple immaterial forms at the same time. An analysis of the construction process

[1] Material dialogue does not refer to the "one-directional" act of listening to what the artefact reveals about its history, but rather on the reciprocal interaction between the individual and the artefact. As such, the chapter examines the interactions between the artefact being produced and the individuals interacting with it. For a contemporary example of this "material dialogue" approach see Callen and Criado (2015), p. 25.

[2] For examples of scholarly works within the history of astronomical instruments that demonstrate the debates about the various paths that a construction process can take, see Robert W. Smith, *The Space Telescope: A Study of NASA Science, Technology and Politics* (Cambridge, UK: Cambridge University Press, 1989); and Lee T. Macdonald, '"A large chunk of glass": the 98-inch mirror of the Isaac Newton Telescope, 1945-1959', *The Antiquarian Astronomer*, 6, 2012, 4-18.

[3] Star, *Introduction*, p. 198.

reveals these multiple coexisting paths that the artefact can take throughout its construction and the individuals who supported these different paths.[4] Furthermore, it reveals the interaction between the artefact's multiple forms, and supplies additional information on why one form was taken over another. Finally, the construction process highlights the malleability of an artefact: modifications are made to it by removing its components, turning them into waste, implementing it into new instrumental arrangements, or through the attachment of additional parts.

The analysis of the construction process of the Airy Transit Circle similarly demonstrates the multiple forms that the final instrument could have taken. It calls attention to the frequent negotiations between Airy, the instrument makers, and the members of the Board of Visitors during the production process.[5] By doing so, this chapter shows that while Airy made the final decisions about which ideas to implement into the design of the instrument, his decisions were shaped by discussions he held with the various individuals involved in the process. Within this framing, the instrument is shown to be the result of a collaborative enterprise as opposed to the work of a single individual. In addition, such a collaborative framing of the instrument shifts the focus of the attention away from final design features towards the interactions and the negotiations between the various members involved in the construction process. Through these interactions, the chapter demonstrates how the instrument makers, the astronomical community, and Airy himself shaped the "final form" of the Transit Circle as it was found upon becoming operational in 1851.

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[4] In constructionist approaches towards the history of science and technology, such an analysis demonstrates the different technological frames employed by different social groups (or individuals). See Trevor J. Pinch, and Wiebe E. Bijker, 'The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other', in Wiebe E Bijker., Thomas P. Hughes, and Trevor J. Pinch (eds.), *The Social Construction of Technological Systems* (Cambridge, Massachusetts: The MIT Press, 1993), pp. 40-44.

[5] For a discussion on Airy's interactions with instrument makers see Bennett, *George Biddell Airy and Horology*; Chaldecott, *Platinum and the Greenwich System of Time-Signals in Britain*; Ginn, William Thomas, *Philosophers and Artisans*, pp. 207-269; Gillin, *The Victorian Palace of Science*, pp. 214-264.

The analysis of the construction process is divided into three conceptual stages: planning, construction, and installation.[6] The planning stage included the gathering of information on the best design for the Transit Circle, the selection of the instrument makers, and persuading the Board of Visitors about the need for a new instrument. This stage highlights the competition between instrument makers, the personal preferences of astronomers in relation to a new instrument at the Observatory, and the influence of the instrument makers on the final design of the instrument. The construction stage involved the actual making of the instrument. During this stage the smaller design elements were negotiated with the instrument makers and new ideas were implemented into the product. The last stage of installation involved setting up the instrument inside the Observatory. As a result of the change in location, new individuals such as the Observatory assistants became involved with the project. This change in the individuals contributing to the construction highlights the active role of the Observatory staff, who have been 'hidden' under the currently established history of the instrument.[7] In brief, each stage brought forth a different set of challenges that needed to be tackled by the individuals working on the Transit Circle, and as a result defined different aspects of the final instrument.

[6] This is a further division of what Staudenmaier labelled as the construction and design stage of the history of an artefact. See John M. Staudenmaier, *Technology's storytellers* (Cambridge, MA: MIT Press, 1989), pp. 196-197.
[7] For instance, Satterthwaite's histories of the Transit Circle (1995; 2001) make no mention of the Observatory staff being involved in the construction of the instrument.

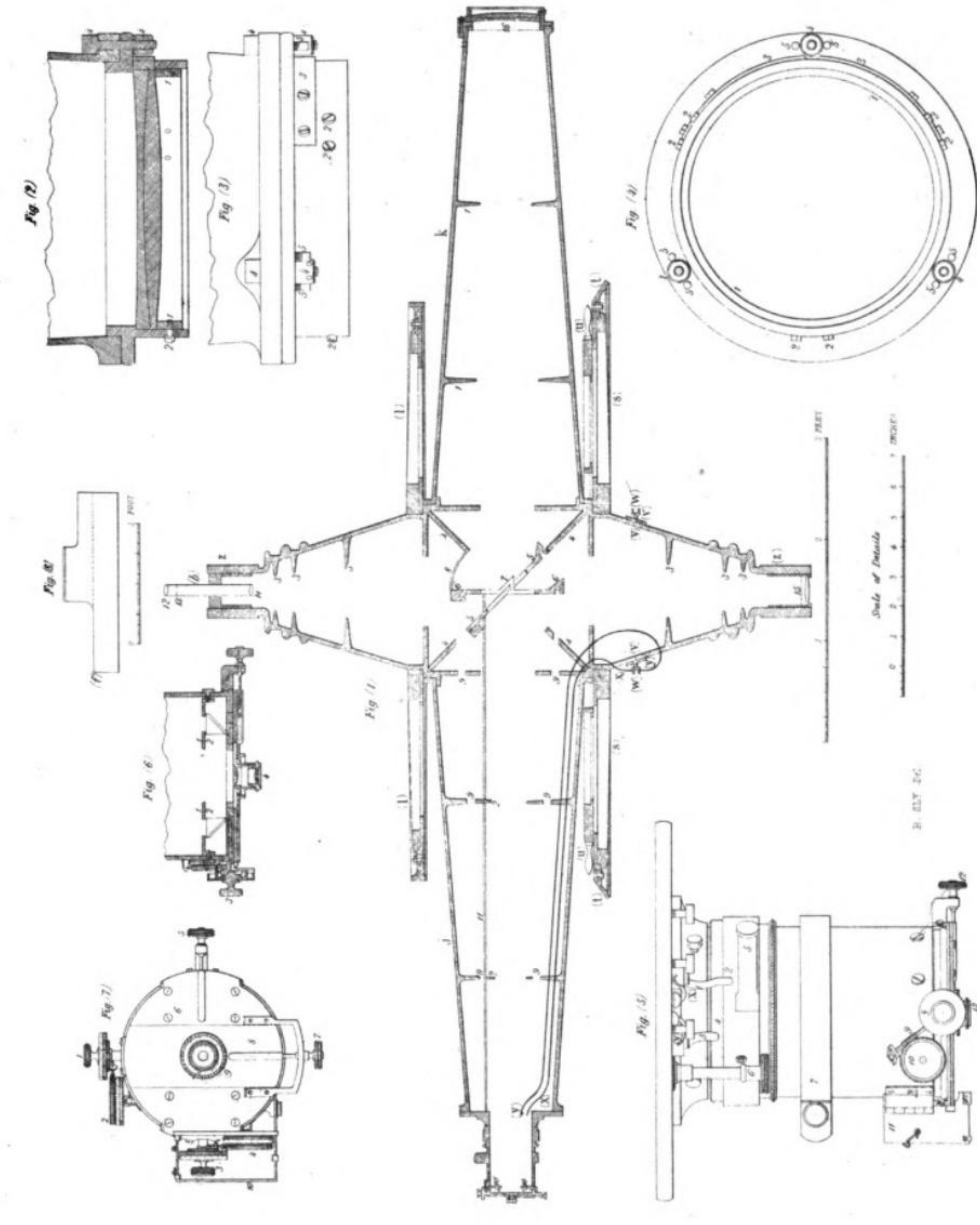

Fig. 8. Illustration from the official description of the Transit Circle showing the telescope tube, the eye-piece (bottom left and bottom right), and the frame of the object glass (top left and top right)

Dividing the construction process to three stages should be considered as a theoretically guiding demarcation as opposed to easily distinguishable phases. The stages often overlapped or had to be revisited in order to modify the initial plans. For instance, even though the object glass was not yet procured, it was anticipated that work on other mechanical parts of the instrument could begin, which decision demonstrated the overlap of the planning and construction stages. Another type of overlap occurred through the involvement of the same individuals throughout various stages of the process. Besides providing advice on the design of the Transit Circle and on possible suppliers for the different parts, both Charles May and William Simms (figure 9) participated in the making of the instrument through the supervision of the work. Finally, the Transit Circle continued to be modified after its installation, which signals that the construction process was only finished on paper, as opposed to in practice. These limitations highlight why the division into three stages should only be considered as tools for theoretical guidance as opposed to being reflective of three isolated stages.

Despite these limitations, the theoretical approach also has its advantages. It demonstrates how each one of the stages framed the Transit Circle in different ways. While the planning stage required it to be positioned within the aim and mission of the Observatory in order to convince both the Board of Visitors and the Admiralty of the necessity of a new instrument, such questions during the construction stage became negligible. By focusing on the construction stage only, the way in which such considerations shaped and became embodied within the instrument would have been omitted. The construction stage brought with it questions about how to implement the proposed designs of the Transit Circle, which led to the negotiations about the differences between the imagined forms of the instrument. By analysing this stage, we are able to highlight individuals who were more actively involved in the construction project than others.

For instance, it shows the active contribution of Charles May (the partner engineer of Ransomes & May) and John Green (the carpenter of the Observatory) - two individuals who are almost completely excluded in the current scholarship on Airy and the Observatory. The final stage of installing the instrument on site highlighted that the Transit Circle had to be implemented into both the material and the organisational context of the Observatory. It demonstrated that the instrument was not thought of as an isolated entity within the institution. Instead, it was considered to be part of a wider material, organisational, and practical assemblage. In summary, the three stages depict three different images of the Transit Circle.

Fig. 9. Portrait of William Simms

The two main instrument-making firms involved in the production of the Transit Circle were Troughton & Simms and Ransome & May. They focused their efforts on two different aspects of the instrument. While Troughton & Simms made the optical parts of the instrument (object glass, collimators, and micrometers) and carried out the dividing of the graduated circle, Ransome & May were employed in manufacturing the large parts of the Transit Circle such as the casting of the body of the telescope, the mercury trough with its counterpoises, and the lifting apparatus. This and the following chapter also analyse Airy's relationship with these two instrument maker firms. This chapter begins with the story of the object glass, since the Board of Visitors considered its procurement the first step in the making of the instrument. It tells the story of how Airy interacted with the Admiralty, the astronomical community, and instrument makers in order to have the most suitable object glass made for the instrument. The second chapter counters the prime significance of the object glass by demonstrating Airy's preoccupation with the mechanical parts of the instrument. By drawing upon the correspondence between the Astronomer Royal and Charles May, it highlights the possible alternative paths that the mechanical designs could have taken, and the extent to which May shaped the design and development of those parts. These two chapters demonstrate how Airy's re-instrumentation of the Observatory, which introduced instruments in the likeness of 'heavy machinery',[8] also embodied in the materiality of the instruments new networks of engineers to the already existing network of instrument makers. Thereby, Airy's transformation of the Observatory not only manifested itself in the 'factory mentality',[9] but also through forming important new connections within networks of engineers.[10]

[8] Newcomb, *Reminiscences*, p. 183.
[9] Chapman , *Sir George Airy and the Concept of International Standards*.
[10] This is an expansion on the previous studies of Airy's transformation of the Observatory, which did not consider the impact of the connections to emerging industrial networks that Airy introduced during his directorship.

2. Planning the Transit Circle

The first surviving reference to the introduction of a transit circle into the instrumentation of the Observatory can be traced back to 1843, when Airy began contemplating the substitution of the meridian instruments (the transit instrument and the mural circle) with one(s) that had greater optical power.[11] Between 1843 and the official proposal of the Transit Circle (in 1847), Airy was involved in the supervision and the making of the equatorial and transit instruments for the Liverpool Observatory.[12] During the same time period, Airy also supervised the construction of a new astronomical instrument (the Altazimuth) for the Observatory.[13] In light of this, Airy's involvement in these projects can be considered as testing grounds for both the quality of the products and the working relationship with instrument makers. As we will later see, Airy made references to the Liverpool project in his correspondence with other astronomers. In these, he argued that his (temporary) distrust in the Munich based instrument maker, Georg Merz, originated from the Liverpool project.[14] Similarly, the proposal of an Altazimuth instrument in 1843, and the subsequent employment of Ransome & May and Troughton & Simms foreshadowed the team of instrument makers that produced three of the major instruments installed during Airy's directorship.[15]

[11] Airy, *Autobiography*, pp. 157-158.
[12] Yuto Ishibashi, *In Pursuit of Accurate Timekeeping*, p. 478.
[13] Gilbert Satterthwaite, 'Airy's Altazimuth', *The Antiquarian Astronomer*, 3 (2006), 83-94.
[14] Airy to Herschel, 27 February 1848, RGO 6/9 197.
[15] The three major instruments being the Altazimuth (currently in the collection of the Science Museum; object number: 1929-948), the Transit Circle (currently in the collection of Royal Museums Greenwich; object ID: AST0991), and the Great Equatorial (currently being used as the guiding telescope for the Thompson 26-inch Photographic Refractor at the Royal Greenwich Observatory, Herstmonceux) – all of which were made by the same team of instrument makers. Airy's Reflex Zenith Tube (currently at the collection of the Science Museum; object number: 1937-692) also formed part of the "re-instrumentation" of the Observatory, but its use and immediate impact on the work of the Observatory was not as significant as those of the other three instruments.

The official documents and publications of the Observatory tell a slightly different story about the origin of the instrument. This story highlighted the importance of following the historical aim of the Observatory with a focus on positional astronomy and contributing to the ever more precise determination of longitude.[16] The initial idea of a new instrument replacing Troughton's transit instrument (figure 10) was mentioned in the *Annual Report* of 1846.[17] It identified the small optical power of other meridian instruments at the Observatory as a general problem. With the addition of this note, Airy suggested the possibility of also replacing the mural circles, which were used in conjunction with the Troughton transit instrument.[18] The problem of a small object glass was repeated in the *Annual Report* of 1847, but it was contextualised differently. Airy reported that the French instrument maker, Noel Paymal Lerebours offered to make the Observatory 'the largest refracting telescope in existence', but the Astronomer Royal felt obliged to decline this offer. He argued that such an instrument would have distracted the attention of the Observatory from the main 'plan of operations' in meridian astronomy, which was historically defined as its main mission. Instead, it was proposed to the Board of Visitors to contemplate whether 'meridional instruments carrying larger telescopes should not be substituted for those which [the Observatory] possess.'[19] From these two reports we can already see that the object glass emerged as a crucial point of departure for the construction of the Transit Circle. Its importance was further emphasised by the Visitors' response to Airy's suggestion in the report:

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[16] For a summary on Airy's insistence on positional astronomy being the main mission of the Observatory, see Meadows, *Recent History*, pp. 29-57.
[17] The Troughton Transit Instrument has been on display at the Observatory since its opening as a museum in 1967 (object ID: AST0982). After the installation of the Transit Circle, it was hung on the wall of the Transit Circle Room.
[18] *Astronomical Observations made at the Royal Observatory, Greenwich in the year 1845* (London: Palmer and Clayton, 1847) pp. 254-265. The two mural circles were the 6-foot Troughton Mural Circle installed in 1812 (in the collection of Royal Museums Greenwich; object ID: AST0973) and a Jones 6-foot Mural Circle (its current location unknown)
[19] *Ibid.*, pp. 266-278.

[the] Astronomer Royal to be requested to make further inquiries with respect to the size and character of new instruments fitted for such purposes [i.e. observation of small objects], and to report thereon to a future meeting of this Board.[20]

Fig. 10. The Troughton Transit Instrument (RMG, Object ID AST0982)

Airy was very inspired by such a response from the Board of Visitors. Towards the end of the year he started working on the preliminary designs of the Transit Circle at his countryside

[20] *Minutes of the Annual Meetings of the Board of Visitors*, *1847*, RGO 55/1/1 101

residence in Playford.[21] There are references to these designs in Airy's letters to Charles May, but it is difficult to determine whether any of the surviving plans of the instrument are these. The majority of the surviving plans seem to have been drawn up by the draughtsman of Ransome & May (and by Charles May himself according to Airy's autobiography).[22] However, a few of the plans were drawn upon a different type of paper, and with less accuracy, which might be Airy's.[23] All of these plans played a crucial role as they became the basis for the small models that were used for demonstrating the instrument for the Board of Visitors in order to convince its members about the need for the project and the viability of the instrument's design.[24] The plans served two other purposes. First, like annotations found in books, they were used to communicate and exchange ideas between individuals - in this case, between the Airy and the instrument makers. These were not only done through letters attached to the plans, but also through comments written over the designs themselves. Second, the plans demonstrate how the instrument changed and transformed even before it gained its material existence. In this light, it highlighted the instrument not as an object of consensus but rather as an artefact of contestation which constantly changed its immaterial form.

[21] Airy, *Autobiography*, p. 194. See also *Astronomer Royal's Journal*, RGO 6/25, entry for 1 January 1848: "I sent Circulars to the Visitors regarding the proposed Transit Circle. Drew plans and had consultations with Charles May respecting it."
[22] Ibid.
[23] These plans can be found in the file Correspondence on Instruments, RGO 6/160.
[24] Reference to this model can be found in Airy to Herschel, 5 April 1848, RGO 6/9 203.

3. The role of the Board of Visitors in the purchase of the object glass

Before venturing further into the story, it is important to clarify the role of the Board of Visitors under Airy's directorship. The Board of Visitors oversaw the operations of the Observatory in order to provide the Admiralty (the institution funding the Observatory) with expert advice.[25] Through the Annual Visitations they supervised the work of the Astronomer Royal, and in major projects (such as the construction of the Transit Circle) they provided him with advice. At the time of the Transit Circle's proposal, it consisted of the President of the Royal Society (the Marquess of Northampton), the President of the Royal Astronomical Society (John Herschel), selected Fellows of the Royal Society (John Lubbock, Captain William Smyth, Reverend George Peacock, Dr William Whewell, Reverend Richard Sheepshanks), selected Fellows of the Royal Astronomical Society (Charles Babbage, Samuel Hunter Christie, Sir Francis Beaufort, Manuel J. Johnson), former presidents of the two societies (Sir James South and Lord John Wrottesley), the Savilian Professor of Astronomy (William Donkin), and the Plumian Professor of Astronomy (Professor James Challis).

As can be seen, the Visitors included various established members of the scientific community, who were not in an agreement on every issue. In fact, personal grievances against each other often affected their meetings. For example, James South and Richard Sheepshanks engaged in one of the most dramatic disagreements on the quality of British craftsmanship, which in turn divided many members of astronomical community, including Charles Babbage and Airy.[26] Babbage also had more reason to nurture his disapproval of Airy. While Airy was still in Cambridge, he was appointed instead of Babbage as the Lucasian Professor of Mathematics in

[25] For a history of the Board of Visitors under Airy's directorship see Philip S. Laurie, 'The Board of Visitors of the Royal Observatory – II', *Quarterly Journal of the Royal Astronomical Society*, 8:4 (1967), 334-353.
[26] Michael Hoskin, *Astronomers at war*.

1826.[27] Furthermore, after becoming Astronomer Royal, Airy acted as a scientific advisor to the government, through which he did not support the renewal of funding for Babbage's differential engine.[28] In brief, while the Board of Visitors existed to provide expert advice to both the Admiralty and the Observatory, their members were not in unanimous agreement on every matter. However, one of Airy's major critics, James South rarely attended the Visitations, which helped to alleviate the major disagreements between the members.[29] With Airy's appointment as Astronomer Royal, the Board's function slightly changed. The Commissioners of the Admiralty were given the ability to issue instructions without the need to consult the Board of Visitors first.[30] With this change, Airy had the opportunity to bypass the Board of Visitors in certain matters. This was rarely exercised, and the members of the Board were generally consulted before making major decisions. However, as we will see, in the case of the object glass of the Transit Circle, Airy did not consult the Board when justifying the choice for its supplier. Instead, he applied directly to the Admiralty for funding with a justification offered in the form of a price comparison.[31]

The Annual Visitations with the meeting of the Visitors were held on the first Saturday of June. However, Airy called for an extraordinary meeting of the Board in January to discuss his proposal for a new meridian instrument. Prior to this meeting, Airy circulated a report that was going to be discussed by the Visitors. In this report, he highlighted his general plans for a transit circle. Before the meeting, he received responses from various members of the Board that

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[27] Simon Schaffer, 'The Lucasian professorship 1820-1839', in Kevin C. Knox and Richard Noakes (eds.), *From Newton to Hawking: A History of Cambridge University's Lucasian Professors of Mathematics* (Cambridge: Cambridge University Press, 2003), 241-94.
[28] Doron David Swade, *Calculation and Tabulation*.
[29] Laurie, *Board of Visitors*, p. 339. When South attended the Visitation again in 1853, Airy noted in his journal with surprise that "Sir James South came (not having been at the Observatory for 20 years)." (*Astronomer Royal's Journal*, RGO 6/25, entry for 4 June 1853).
[30] Laurie, *Board of Visitors*, p. 336.
[31] Airy to H. G. Ward (Secretary of the Admiralty), 17 April 1848, RGO 6/73: 65-66.

included both support and constructive criticism on the shortcomings of his plans.[32] Lord Wrottesley pointed out that the approximate cost of constructing the new instrument was not mentioned in the circular.[33] James Challis reported back on how he used the Northumberland Equatorial to make meridional observations, thus attempting to direct the conversation towards the procurement of a non-meridian instruments.[34] Richard Sheepshanks (figure 11) responded in most detail. He was the son of a wealthy textile manufacturer, a Cambridge graduate, and a lawyer by original profession. However, his background allowed him to devote his time to scientific research and to take active part in the scientific community and to build up close relationships with instrument makers.[35] Airy and Sheepshanks shared the same close circle of friends that Agnes Mary Clarke referred to as the 'Northern Lights', and through them they became close friends during Airy's student years in Cambridge.[36] Their proximity allowed Sheepshanks to share his personal thoughts with Airy on the Transit Circle. His response to Airy's letter stated that the larger size of the object glass did not always increase the ability of an instrument to observe fainter celestial objects, noting that other variables also had to be considered during the construction of the Transit Circle. On the other hand, he also pointed out that if the telescope was well built, then the larger object glass could increase the optical power of the telescope and extended the observing range with about two magnitudes. Finally, he added that in order not to waste the potential of a larger object glass, he preferred to use it as part of a transit instrument as opposed to as part of a transit circle. By doing so, he was arguing that

[32] The letters and the circulated report related to the meeting can be found among the Visitation Papers 1845-1848 folder RGO 6/9.
[33] Lord Wrottesley to Airy, 11 January 1848, RGO 6/9 158.
[34] Challis to Airy, 10 January 1848, RGO 6/9 157.
[35] Illustrative of Sheepshanks' proximity to instrument makers, was his portrayal in the biographical narrative of Ormsby Macknight Mitchel, in which he is introduced as the character sitting in the corner of the workshop of Troughton & Simms. See F. A. Mitchel, *Ormsby Macknight Mitchel: Astronomer and General*. (Boston and New York: Houghton, Mifflin and Company, 1887), pp. 93-97.
[36] Agnes Mary Clarke, 'Richard Sheepshanks', in *Dictionary of National Biography.*

constructing a transit circle instead of a transit instrument was too much of a risk with respect to the quality and size of the proposed object glass.[37] Three years later, an article written about the Observatory by one of Airy's friends, James David Forbes (Professor of Natural Philosophy at the University of Edinburgh), similarly highlighted the risk that Airy took with constructing a transit circle instead of a transit instrument, by labelling the project as a 'great experiment'.[38] In addition to the Visitors, Airy asked the opinion of established members of the astronomical community. An example of this was the response from Professor Schumacher, founder and editor of the international astronomical journal *Astronomische Nachrichten*. He called Airy's attention to the need to test the errors of the proposed collimating telescopes measuring the deviations of the telescope tube, since the temperature changes were going to affect several parts of the Transit Circle, such as the east-west axis and the piers.[39]

The responses Airy received allow us to reflect upon several aspects of the history of the Transit Circle. First, they show the role of the Board of Visitors in the construction process. Its members both supported Airy's proposal by suggesting further improvements to the transit circle, and offered alternative directions. Second, these suggestions demonstrate that the final design of the Transit Circle was the outcome of a collaborative discussion taking place among several members of the astronomical community, as opposed to being the product of a single individual. Third, as a result of the multiplicity of suggestions, the responses depict what issues were significant for the members, and how each individual framed the issue of the object glass differently. For example, while Lord Wrottesley was interested in the financial side of the purchase, Sheepshanks emphasised the need for reliability with regard to deriving the

[37] Sheepshanks to Airy, 9 January 1848, RGO 6/9 149-150; and Sheepshanks to Airy, 11 January 1848, RGO 6/9 160.
[38] [James David Forbes], 'National Observatories', *Edinburgh Review,* April 1850, 299-356 (p. 355).
[39] Schumacher to Airy, 4 February 1848, RGO 6/9 166.

performance of the object glass. Similarly, while Schumacher highlighted the importance of measuring the errors of the telescope, Challis described alternative instruments and methods in which Airy's aim could be achieved. In brief, the Transit Circle was not an artefact that embodied unanimous consensus; instead, it brought forth the various technological frames within which the artefact (even at its immaterial form) was interpreted.

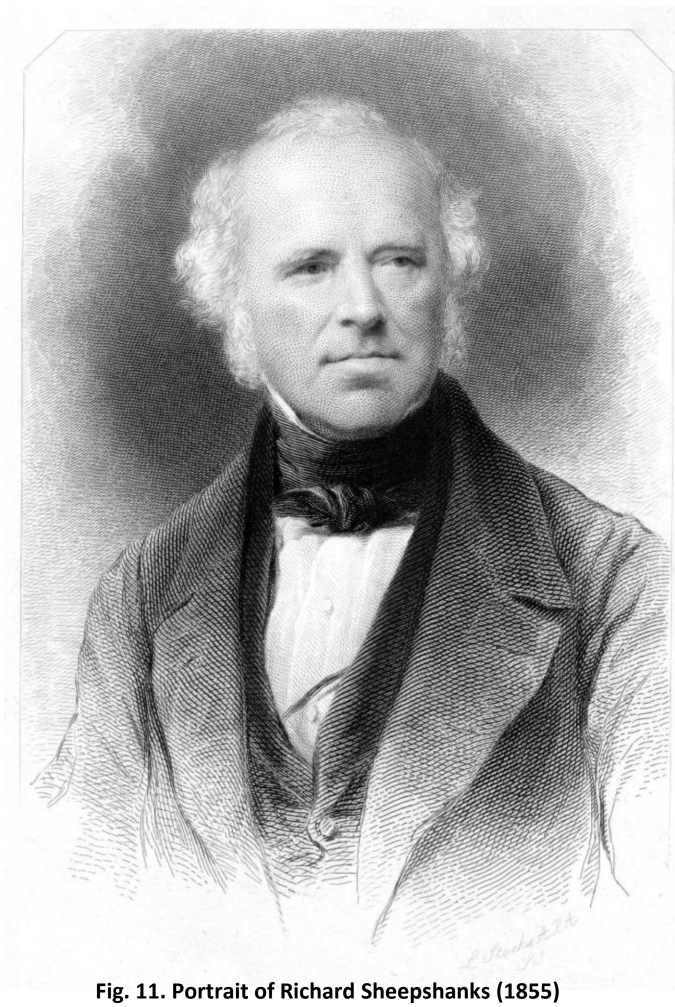

Fig. 11. Portrait of Richard Sheepshanks (1855)

While Airy received mixed responses in terms of the direction which he should take with construction of the Transit Circle, the minutes of the January 1848 meeting reveal that there was an agreement among the members about the need for a new instrument that allowed for the observation of fainter celestial objects. In fact, the meeting finished with emphasis on procuring the object glass for the instrument as the first step to begin the project, and in turn the Astronomer Royal was assigned the task of finding out and deciding who to purchase the object glass from.[40]

4. Trust and distrust in glass

The making of high quality object glasses was a secretive task during the first half of the nineteenth century. Those universally acclaimed to be of the highest quality were made by Louis M. Guinand.[41] However, Guinand was not alone in attempting to create higher quality object glasses. In 1805, he joined the craftsmen and opticians at Benediktbeuern. This establishment later included individuals who during the nineteenth century rose to prominence as opticians and instrument makers: Joseph Fraunhofer, Joseph Utzschneider, Georg von Reichenbach, and Georg Merz.[42] The making of optical glass in Europe was monopolised by this establishment until the 1850s. Astronomers sought to order object glasses from Benediktbeuern in order to ensure the reliability of the final product.[43] However, this also resulted in higher prices and long production times. Guinand did not spend his entire life at Benediktbeuern. He left the workshop in 1814 and returned to his home in Switzerland. Although he gave up object glass manufacturing for a few years, his appetite for the craft returned and supplied various instrument makers and opticians

[40] *Minutes of the Annual Meeting of the Board of Visitors*, 15 January 1848, RGO 55/1/1 103.
[41] The summary of Guinand's life is based on 'Some Account of the late M. Guinand, Optician of Brenets, in the canton of Neufchatel, in Switzerland, read at the Society of Physics and Natural History of Geneva, on the 19th of February, 1823', *The Quarterly Journal*, 19, 1825, 244-258.
[42] For a history of Fraunhofer's activities in Benediktbeuern, see Jackson, *Spectrum of Belief*. On the impact and the history of Merz telescopes, see Ileana Chinnici (ed.), *Merz Telescopes: A Global Heritage Worth Preserving* (Cham, Switzerland: Springer, 2017).
[43] Jackson, *Spectrum of Belief*, pp. 6, 95-97, 101-108, and 120.

with his glasses (Jean Lerebours, Robert-Aglae Cauchoix, Charles Tulley, Georges Bontemps, Noel Paymal Lerebours) which resulted in the dissemination of his work into the hands of a new generation of opticians.

While the secrets of Guinand and the opticians at Benediktbeuern were not revealed, other nations were keen to learn the secret manufacturing processes.[44] In Britain, astronomers considered the products and skills of the optician Peter Dollond to be superior to his continental competitors during the late 18th century. However, with the emergence of the Guinand-Benediktbeuern axis, the British scientific community gradually concluded that the British opticians produced glasses of inferior quality. One way in which the scientific community attempted to tackle this problem was through government-funded research into the improvement of object glass production techniques.[45] While the project was considered a success, the developed process was still unable to achieve the quality of Guinand and Benediktbeuern glasses. In light of this, British men of science made several offers to the Benediktbeuern workshop for the secrets of their manufacturing process, but all were rejected.[46] By the middle of the nineteenth century, the gradual dissemination of the technique to England was helped by the employment of the French optician Georges Bontemps by the Chance Brothers in Smethwick, Birmingham.[47]

Given the historical context for object glass manufacturing, it was no surprise that Airy quoted only the price of a Merz object glass (an instrument maker and optician from the Benediktbeuern dynasty) as a guiding estimate in his 20 December 1847 circular to the Board of Visitors.[48]

[44] Ibid. pp. 99-170.
[45] Melvyn C. Usselman, *Michael Faraday's Use of Platinum*.
[46] Jackson, *Spectrum of Belief*, pp. 99-170.
[47] Isobel Armstrong, *Victorian Glassworlds*, p. 54.
[48] RGO 6/2.

Reflective of this, on 18 January, just three days after the Board's meeting, Sheepshanks sent a letter to Airy urging the Astronomer Royal to purchase the object glass from Merz. Sheepshanks was well aware of other opticians, and listed three alternatives (William Simms, "Guinand of Paris", and Noel Paymal Lerebours).[49] Despite these alternatives, Sheepshanks firmly supported ordering an object glass from Merz, due to the quality of the alternative sources being unreliable.[50]

Opposing Sheepshanks's advice, Airy declared his determination to order the object glass from William Simms: '[i]f Simms can make a good 8 or 8 ½ inch object glass, in good time, I would prefer it to the one of Merz.'[51] He further provided three points for justifying his selection of Simms: 'first, on the principle of ostracism, secondly because Merz is confoundedly dear, thirdly because I do not think the he [Merz] is certain.'[52] The first reason ('the principle of ostracism') was not explained by Airy further. It seems to refer to his attempt to exclude Merz from the competition for the object glass. If that was the case, then the statement appears as a direct reaction against the monopoly of Merz, and a conscious support for aiding his competitors (especially British ones such as Simms). Airy's second reason, Merz being 'confoundedly dear', referred to the high price which the Bavarian optician requested for the object glass.[53] This reflected Airy's management style, whereby the cost of a project was given just as much importance as the final reliability of the instrument. Lastly, Merz's uncertainty can be interpreted in various ways. It was either used to counter Sheepshanks's emphasis on the

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[49] This was possibly a reference to Henri Guinand, son of Pierre Guinand, who worked at rue Mouffetard in Paris from 1842. No letters are found among the Airy Papers between Airy and Henri Guinand during the 1846-1849 period.
[50] Sheepshanks to Airy, 18 January 1848, RGO 6/9 169.
[51] The underlines are Airy's original emphases. See Airy to Sheepshanks, 23 January 1848, RGO 6/9 176.
[52] Ibid.
[53] Airy repeatedly emphasised the high price quoted by Merz in later correspondence with opticians, astronomers, and members of the Admiralty.

reliability on the quality of the optician's products, or referred to uncertainty whether Merz was going to agree to the making of the object glass (a point, which later will play a crucial role in Airy's decision). Despite all of these points raised by the Astronomer Royal, Sheepshanks stood his ground. He continued trying to convince Airy about the benefits of ordering the object glass from Merz, and about a rivalry between Merz and Simms fostering healthy competition and elevating the status of Simms as a supplier of object glasses.[54] However, Airy was set on his decision, and to close the discussion he repeated that he was planning to order the object glass from Simms if he 'will make a right good glass of the proper size and in the proper time…'[55]

5. William Simms and the 8-inch object glasses

Sheepshanks's insistence on Merz was somewhat surprising since he maintained a very close contact with Simms.[56] It was exemplified by the South vs. Troughton & Simms debate, in which Sheepshanks offered to defend the instrument makers in the lawsuit brought against them by James South.[57] With this close relation in mind, one would have assumed that it would have been Sheepshanks as opposed to Airy insisting on procuring an object glass from Simms. In order to shed more light on this matter, it will help us to reflect upon Airy's correspondence with Simms regarding the object glass.

[54] Sheepshanks to Airy, 24 January 1848, RGO 6/9 177, 178.
[55] Airy to Sheepshanks, 25 January 1848, RGO 6/9 179.
[56] Besides the close ties to instrument makers, Sheepshanks was also an expert in the technical aspects of telescopes. As an example of this, he wrote the entry on transit instruments in the *Penny Cyclopaedia*.
[57] For discussion on the debate see Hoskin, *Astronomers at War*; Hoskin, *More on "South v. Sheepshanks"*, pp. 174-179; and McConnell, *Astronomers at War: The Viewpoint of Troughton & Simms*, pp. 219-235.

After Sheepshanks's first letter, Airy wrote to William Simms about his availability and willingness to make an object glass for the Transit Circle. In this letter he emphasised that Simms's advantage at this stage lay not in his quality of craftsmanship, but rather in his ability to prepare the object glass within a short period of time. As Airy stated, 'time is a very important element in our arrangements' to such an extent that if there was the 'chance of long delay in one quarter [of the arrangements], we must of necessity look to another [supplier].'[58] This emphasis on time pressure is surprising, since the urgency for procuring the object glass was not mentioned in the conclusion that the Board of Visitors reached in relation to the Transit Circle project. Therefore, time pressure was either used here as a response to Sheepshanks's suggestions, or as Airy's personal preference in terms of beginning the construction process as soon as possible. It is worth keeping in mind that Airy at this point still maintained the view that the construction of the instrument could not continue any further until the object glass was finished.[59] As a result, in Airy's understanding of the project, securing an object glass quickly also had the practical advantage of construction work on other parts of the instrument beginning sooner.

Simms accepted Airy's conditions for the order and provided further information about when a new shipment of glass discs was going to arrive at his workshop.[60] It is important to note here that while Merz made the object glasses himself, Simms imported the semi-finished discs from France and then modified and polished them according to the needs of his clients. Simms's reliance on other sources for object glass could have been considered as another issue of reliability from Airy's part, since with an external supplier, Simms could not assure the quality

[58] Airy to Simms, 22 January 1848, RGO 6/721 827.
[59] However, Charles May later clarified that the work on various mechanical parts of the instrument could begin even without possessing the object glass. See Airy to Charles May, 28 February 1848, RGO 6/721 526.
[60] Simms to Airy, 24 January 1848, RGO 6/721 829.

of the object glasses. Despite this, Airy was adamant that Simms had to be given a chance, which insistence demonstrated the trust and the close connection that existed between the instrument maker and his client. In the same letter, Simms reassured Airy about the quality and the rapidity of the process by describing the high quality of discs received through previous orders. In addition, he promised to work on the object glass personally, so that it could be finished by the end of May at the latest.[61] Since this answer from Simms was received on 24 January, it explained why Airy decided to close further discussions with Sheepshanks (on 25 January) about alternative suppliers to the object glass.

In light of Airy's insistence on giving Simms the opportunity to provide the object glass, it is important to discuss where such reliance on the instrument maker originated. The proximity between Airy and Simms began when Edward Troughton took the latter as a partner in his business. As a result of the partnership, Simms frequently worked for orders made by Airy, dating as far back as the astronomer's directorship of the Cambridge Observatory (for the Cambridge Mural Circle (1832) and the Northumberland Equatorial Telescope (1840)). Prior to the proposal of the Transit Circle, Simms collaborated with Ransomes & May on another one of Airy's commissions, the Altazimuth.[62] Since Airy was pleased with the Altazimuth instrument, that project can be considered as an important testing ground for Simms's skills as well as his ability to cooperate with other instrument makers. Yet, Airy's emphasis on his preference for Simms's craftsmanship (as found in his letter to Sheepshanks) depicted the Astronomer Royal's reasoning in a different light. Rather than focusing on their previous projects, he highlighted the quick production process, good quality, and low price offered by Simms. These factors resemble the major points that Airy also emphasised in the construction of the Northumberland Equatorial

[61] Ibid.
[62] Satterthwaite, *Airy's Altazimuth*, pp. 83-94.

for the Cambridge Observatory, where he summarised them with the concepts of economy and efficiency.[63] Such factors demonstrate Airy's mindset in running the Observatory according to the principles of industrial standards (as a "factory") where economy and efficiency were the defining principles.[64]

William Simms began working on the object glass as soon as he received the first shipment of lenses from France in late February or early March. When Airy wrote to the optician to ask about the progress made on the object glass, Simms replied with both bad and good news.[65] The bad news made it clear that the glasses received were so imperfect for the task that the instrument maker had to return them to France. Therefore, Simms's initial promise to Airy failed. However, he explained his alternative plan, which was to perfect an object glass that was currently in his possession - a solution that according to the optician promised well.[66] While Airy's response to this letter did not survive, Simms's next letter exclaimed the good progress that he had made: 'as soon as the weather clears up, I shall submit an 8 inch object glass to your examination.' The letter also provided additional information about the history of the new object glass: 'The flint [glass] is one of those formerly in your hands but it has been reworked and I have obtained it a piece of English crown [glass] by which the performance is greatly improved… [The object glass was] intended for a college in America.'[67] The college in America referred to in the letter was almost certainly the University of Alabama, which did not receive its 8-inch equatorial telescope from the instrument maker until 1849 (the only other instrument being prepared by Simms at the

[63] 'If I may interpret your Grace's wishes, it is your desire that efficiency should be secured and that economy should be attended to.' Airy to Duke of Northumberland, 4 September 1834, RGO 6/157.
[64] Simon Schaffer, *Astronomers Mark Time,* pp. 118-119.
[65] Airy to Simms, 8 March 1848, RGO 6/721 832.
[66] Simms to Airy, 9 March 1848, RGO 6/721 833.
[67] Simms to Airy, 28 March 1848, RGO 6/721 839.

time that carried an 8-inch object glass).[68] The way in which Simms decided to solve the problem surrounding the object glass demonstrated both his ability to identify the factors significant to Airy correctly, and his level of commitment to maintaining a good relationship with the Observatory by giving it preference over the purchase and use of products made for other clients. The failure with the original shipment of glasses also shows that the initial promises and work of Simms were not fully reliable. Despite this, Airy maintained his trust in the instrument maker, which ultimately led to Simms prioritising one client over another.

Before testing the object glass, Airy asked Simms to specify the price, which signalled the Astronomer Royal's equal emphasis on the cost and quality when making the final decision for the purchase.[69] Simms's asking price was £300, which according him was lower than the actual time and resources put into its making.[70] After the successful trial of the lenses, Airy offered £275, which Simms accepted. However, the basis for negotiating it further provides us information about a third optician, who was also mentioned by Airy to be in competition for the Transit Circle project, Noel Paymal Lerebours: 'I may remark that the price of £300 is higher than that held at by Lerebours and lower than that of Merz (who, for saying that he has a monopoly, is very unreasonable).'[71] Once again we see that for Airy the price of the object glass was significant factor in its purchase, and he acted upon the basis of his principles of economy and efficiency.

[68] This is assumption is based on two sources. Mennim's biography of Simms mentions only this instrument with an 8-inch object glass being made in the workshops of Troughton & Simms at the time. See Mennim, *Transit Circle*. Reference to an 8-inch refractor supplied by Troughton & Simms to the University of Alabama was made in Gene Byrd, and Robert Mellown, 'An Antebellum Observatory in Alabama', *Sky and Telescope*, 65 (1983), 113-115 (p. 113).
[69] Airy to Simms, 3 April 1848, RGO 6/721 843.
[70] Simms to Airy, 3 April 1848, RGO 6/721 844.
[71] Airy to Simms, 22 April 1848, RGO 6/721 851-852.

6. Lerebours and the historical aim of the Observatory

As Sheepshanks pointed out in one of his early letters on the project, having instrument makers competing for the object glass gave Airy a strategic advantage during the negotiations. Airy pressed this advantage by repeatedly comparing the prices offered by the different opticians. With this in mind, it is important to look at how the interactions and negotiations with both Lerebours and Merz (Simms's competitors for the object glass) took place. By analysing the "failed" negotiations, we get a glimpse into how Airy's preferences were highlighted in his interactions with other instrument makers, and what factors led to the "failure" of these negotiations.

Noel Paymal Lerebours (figure 12) was a French instrument maker who is best remembered today for his daguerreotypes.[72] He was also one of the opticians who was able to procure object glasses made by Guinand. As a result, he also engaged in making telescopes.[73] The first contact between Airy and Lerebours can be traced back even before the proposal for the Transit Circle. In 1846 Lerebours offered to make the largest equatorial telescope in existence for the Observatory, but Airy declined the offer.[74] In the Report to the Board of Visitors of 1847 he stated the reason for rejecting the offer as preventing distraction from the meridional work of the Observatory, which Airy considered to be the historical aim of the institution. Despite this, Airy and Lerebours continued to keep in touch through the latter's London agents. On 4 August 1847 Airy wrote to Lerebours asking whether he had 'an object glass of 6 to 8 inches aperture?'[75] Lerebours's agents responded positively in two consecutive letters, the first one stating the

[72] This speciality of his was remarked by even Sheepshanks when Airy mentioned that the French optician reached out to him. Sheepshanks to Airy, 22 March 1848, RGO 6/9 199-200.
[73] King, *The History of the Telescope*, p. 179.
[74] *Greenwich Observations of 1845*, pp. 254-265.
[75] Airy to Claudet, 4 August 1847, RGO 6/719 665.

instrument maker was in possession an 8 ¼ inch and a 9 ½ inch object glass, as well as several 6 inch object glasses.[76] However, the responses coincided with Airy's visit to the Pulkovo Observatory, which caused significant delays in his response.[77] When Airy finally responded on 21 September, there was no more enquiry about the 8-inch object glass, but he asked for more information about the 6 inch object glasses.[78]

Fig. 12. Image showing Lerebours (far left)

In these negotiations, it is important to keep in mind the sizes of the different object glasses. The object glass of the Airy Transit Circle was 8 inches, while the one being negotiated by Airy with

[76] Claudet to Airy, 6 August 1847, RGO 6/719 666; Claudet to Airy, 14 August 1847, RGO 6/719 669.
[77] Main to Claudet, 16 August 1847, RGO 6/719 670; Pellen to Airy, 21 August 1847, RGO 6/719 672.
[78] Airy to Pellen, 21 September 1847, RGO 6/719 672.

Lerebours was a 6 inch glass. There are three possibilities that could explain the differences in sizes. First, perhaps Airy wanted to employ different makers for the mechanical parts of the instrument and for its optical parts. This idea was supported by Airy's letter in which he asked for the price of the object glass in a simple tube with an eyepiece. It highlighted Airy's intention to construct an astronomical instrument around the object glass, as opposed to ordering an entire instrument from the French instrument maker. As we will see in Airy's negotiations with Merz, the same question (an 8-inch object glass without the instrument) was asked from him too. If this was the case, then it highlighted that the Astronomer Royal had already in mind the employment of another firm (possibly Ransome & May) for the manufacturing of the mechanical parts of the Transit Circle. The second possibility was that Airy considered purchasing an astronomical instrument different from a transit circle. This possibility was brought up by both Challis and Sheepshanks and, at this point, Airy had not yet specifically proposed the construction of a transit circle. The third possibility was the purchase of a smaller telescope that required a smaller object glass. This would explain why Herschel discouraged Airy from beginning work on the construction of the mechanical parts of the instrument, since they argued that the focal length of the lenses was going to determine the size of other parts of the instruments (e.g. the telescope tube or the size of the lifting apparatus).

The negotiations about the 6-inch object glasses progressed as far as discussions about their trial. Airy asked whether they could be tested prior to purchase at the Paris Observatory or in London, by either Airy himself or a person appointed/sent by him. While Lerebours agreed to these conditions, there remains no surviving evidence about whether the trial had taken place or not. The last reference to it was made in a letter dated 6 December, where Lerebours's agent stated that the foggy weather had limited their ability to send out the object glass for testing at the Paris Observatory.[79]

The next time the object glass resurfaced in Airy's correspondence with Lerebours was in a letter written on 22 February 1848. This was a few days after Airy had declared to Herschel that 'all negotiations must be stopped [with Merz]',[80] but before Simms received the first shipment of object glasses from his French supplier. This shows us that Airy was constantly looking for possible alternatives, even when he clearly declared his preference for Simms's object glass to both Herschel and Sheepshanks. In the letter Airy provided an official rejection of any further negotiation regarding the 6-inch object glass due to 'conference with the proper authorities'. Instead, the 'altered' direction of the letters focused on questions about an 8-inch object glass.[81] Airy's next letter to Lerebours was written on 27 March, which was just a bit more than a week before Airy purchased the object glass from Simms. The questions asked of Lerebours reflected Airy's concerns that had already been highlighted in his letters to both Herschel and Sheepshanks: (1) the price of the object glass, (2) the condition for it to be purchased only after trial, (3) the conditions of trial, and (4) the time it would take to finish.[82] Despite these questions, Airy's next letter stated that he had found another supplier in London and, as a result, he was not going to proceed any further with the negotiations.[83] The halting of the negotiations was not taken kindly by Lerebours. The French instrument maker ended up accusing Airy of backing out from an actual order. However, to counter Lerebours' arguments, Airy provided four pages of evidence referencing their correspondence demonstrating that he never placed an order, and

[79] See correspondence between Airy and Lerebours' agent, RGO 6/719 675-683.
[80] Airy to Herschel, 17 February 1848, RGO 6/9 192
[81] Airy to Pellen, 22 February 1848, RGO 6/721 424.
[82] Airy to Pellen, 27 March 1848, RGO 6/721 426r.
[83] Airy to Pellen, 7 April 1848, RGO 6/721 428.

repeatedly specified that he had only made enquiries as opposed placing orders.[84] After this exchange, no further letters seem to have survived coming from or going to Lerebours or to his agents.

The negotiations with Lerebours highlighted several significant aspects of the history of the object glass. First, it demonstrated that Airy had been in contact with the French instrument maker about an 8-inch object glass even before he proposed the Transit Circle to the Board of Visitors, thereby showing Airy's interest in constructing the instrument as far back as August 1847. Second, the story demonstrated Airy's quest for an alternative supplier. This further showed Airy's distrust in the work of Merz, as well as the impact of Richard Sheepshanks in encouraging Airy to always have alternative options open for the supplier of the object glass. In addition, since Airy had written to Lerebours only a few days before he finalised his offer to Simms, it questions the extent to which the Astronomer Royal really trusted Simms throughout the entire negotiations. In this light, while at the beginning of the project Airy was a strong supporter of Simms, due to the poor quality of the first shipment, and the use of an alternative object glass, Airy's late contact with Lerebours showed the Astronomer Royal's diminishing trust in Simms.

Airy's attempt to look for alternatives serves as a ground for reconceptualising the object glass during this stage of its history. It first demonstrates that the object glass could have materialised in a different form, and that between January and April 1848, the object glass of the Airy Transit Circle existed in three alternative forms simultaneously: one repolished in Simms's workshop, one in stock at Lerebours' workshop, and one on paper waiting to be ordered by Merz. Secondly, the correspondence with Lerebours further repeated the factors that Airy considered important in

[84] Airy to Lerebours, 13 April 1848, RGO 6/721 430.

relation to purchasing the object glass. The four themes of price, conditions of trials, trial before purchase, and time necessary for preparing the object glass were the recurring factors emphasised in Airy's letters about the object glass. The emphasis on these factors highlighted Airy's managerial mentality towards the construction of astronomical instruments, as opposed to being involved only in the quality testing of the object glass. Finally, the Lerebours correspondence demonstrated Airy's preference to test the object glass himself or by a trusted appointee, which highlighted Airy's attempts to personally overlook every step of the production process to assure the quality of each part of the Transit Circle.

7. Negotiations with Merz

Besides Lerebours and Simms, Airy also corresponded directly with Georg Merz (figure 13). While extracts from their correspondence were used in Airy's letters to other individuals, it is necessary to take a look at what aspects of the original correspondence were omitted from these second-hand accounts. Furthermore, the analysis of the original letters to Merz allows us to see the differences and the similarities between how Airy approached negotiations with various instrument makers.

The Astronomer Royal first wrote to Merz on 31 January 1848, thereby making it the second letter to directly refer to the object glass of the Transit Circle as approved by 'the authorities of the Royal Observatory of Greenwich.'[85] In this letter, Airy asked three of the four recurring questions relating to aspects of the object glass: 1) how much time it would take to finish an 8-inch object glass 2) whether Airy or one of his deputies could test the object glass either at

[85] Airy to Merz & Son, 31 January 1848, RGO 6/721 438.

Munich or at Bogenhausen 3) how much would the object glass cost (without the tube or any other mounting). The lack of a questions relating to the conditions of the trial of the object glass shows that Airy did not think that it was going to be an issue.

Fig. 13 Portrait of Georg Merz (undated)

It was Merz's response that caused the turmoil around the conditions of the trial, which later was discussed between Airy, Herschel, and Sheepshanks. In this letter Merz stated that he only allowed trial on his own mounts (all of which were equatorial mountings) and on terrestrial objects. Merz argued that this was because they could only guarantee the quality of their own tools during the tests.[86] Airy was discontent with this response, since the conditions of the trial set by Merz did not take into consideration that the object glass was intended for a transit circle, which required a non-equatorial mounting. Furthermore, Airy wanted to try the object glass on celestial objects as opposed to on terrestrial objects only.

[86] Merz & Son to Airy, 7 February 1848, RGO 6/721 439.

Airy's response was dated 21 February. It is important to keep in mind that between Merz's initial answer and this letter, Airy wrote to both Herschel and Sheepshanks, asking them about their opinions on the conditions of the trial set by Merz. Both of them continued attempting to reassure the Astronomer Royal about the quality of the object glasses made by Merz. Furthermore, Sheepshanks suggested that Airy clarify to Merz the intended use of the object glass in order to avoid future miscommunications. Taking up this suggestion, Airy's letter clarified that 'the object glass [was] not required for a parallactic instrument [but] for an instrument of a different class [i.e. transit circle] not usually made by you.'[87] By doing so, Airy was attempting to renegotiate the conditions of the trial.

Merz replied confirming that Airy understood clearly the original conditions of the trial set by the instrument makers and, while understanding Airy's concerns, Merz insisted on a trial only being possible on terrestrial objects as they did not have a proper mounting for trial on celestial objects. Instead, Merz asked for Airy's trust based on the previous instruments that he received.[88] Following a month-long hiatus in the correspondence, Airy notified Merz about finding another supplier. However, unlike in the case of Lerebours, the letter left the possibility of future purchases from Merz open.[89]

The letters exchanged between Airy and Merz highlight several new aspects of the history of the object glass of the Transit Circle. Most importantly, it shows that Airy seriously considered purchasing the object glass from Merz, thereby illuminating the competition that Airy induced between instrument makers for the Transit Circle. However, this strategy of making instrument

[87] Parallactic mountings were used to support an equatorial telescopes, while the Transit Circle required a different configuration for its mounting. Airy to Merz & Son, 21 February 1848, RGO 6/721 440.
[88] Merz & Son to Airy, 28 February 1848, RGO 6/721 441.
[89] This ending also raises the possibility that if Lerebours had not misinterpreted Airy's question, then the French instrument maker would have had a good chance of supplying the Observatory with object glasses in the future. Airy to Merz & Son, 7 April 1848, RGO 6/721 442.

makers compete against each other was not Airy's idea, but rather that of Sheepshanks. Therefore, the competition and Airy following the suggestions of Sheepshanks in his negotiations with Merz, further bring into light the influence that Sheepshanks had on Airy.[90] The Airy-Merz correspondence also demonstrates what Jackson identified as the diminishing power of Merz by the middle of the nineteenth century. The high price of his object glasses, the inflexibility regarding trials, and what Airy considered to be poor services, were all factors contributing to the eventual diminishing of his monopoly. Furthermore, Airy's decision to ostracise Merz showed that at least one member of the astronomical community actively and consciously made attempts to do this. Finally, the letters showed the importance that trust played in the purchase of instruments and object glasses. While Airy trusted Simms (even after the bad first shipment of object glasses), he was less patient in his negotiations with Merz. When Merz eventually appealed to Airy's trust, it showed that the instrument maker was unaware of the distrust that Airy held against him. We can gain a better understanding of the sources of Airy's distrust by looking at the letters exchanged between Airy and another one of his friends, John Herschel.

[90] Despite his influence on the Astronomer Royal, besides Hoskin's *Astronomers at war* articles, Sheepshanks's role within nineteenth-century scientific communities has very rarely been considered.

8. Herschel's advice and his support of Merz

Besides Richard Sheepshanks, Airy wrote to John Herschel too on several occasions to seek advice on the purchase of the object glass. Being the son of William Herschel, the famous pioneer in astronomy, John Herschel was brought up in a family and circle of friends closely connected to both men of science and instrument makers of the nineteenth century.[91] By 1848 he had published his results of the observations made more than a decade earlier at the Cape of Good Hope in South Africa, which increased his already high standing in the British astronomical community.[92] Educated at Cambridge University, he became a core member and role model of the 'Cambridge Network' of men of science.[93] By the time Airy started his undergraduate studies at Cambridge, Herschel had already left the university, but George Peacock (one of Airy's close friends) introduced the young Airy to Herschel.[94] After their first meeting, a friendship developed, which formalised into even more frequent interactions after Airy was appointed Astronomer Royal.

During 1848 Herschel was a member of the Board of Visitors by being the President of the Royal Astronomical Society. However, in the purchase of the object glass for the Transit Circle, his role went beyond that of an ordinary Visitor. Rather than only asking for his initial and overall thoughts on the project, Airy repeatedly contacted him for advice, or to simply share his own thoughts with someone. Besides their friendship, and Herschel's expertise within the field of astronomy, Herschel also had prior experience in dealing with both continental and English instrument makers, which allowed Airy to rely on more than just Sheepshanks's opinion on the

[91] For a discussion on John Herschel's upbringing see Emily Jane Winterburn, 'The Herschels a scientific family in training' (unpublished PhD dissertation, *Imperial College London*, 2011).
[92] Stephen Case, ''Land-marks of the universe': John Herschel against the background of positional astronomy', *Annals of Science*, 72:4 (2015), 417-434.
[93] For a case study on how the "Cambridge Network" operated see, Smith, *The Cambridge Network in Action*, pp. 395-422.
[94] Airy, *Autobiography*, p. 38.

quality of Merz's products. Airy's desire for a second opinion of Merz and his work was not a straightforward distrust in Sheepshanks's advice, but rather, a precaution by Airy based on his previous experience with Merz. The British Government asked for Airy's help in setting up an observatory at Liverpool. His role was to order the new instruments for the observatory. To do so, Airy ordered one of the instruments from Merz. As we will see, Airy thought the quality of the instruments received to be worse than expected, but still good enough for use. Furthermore, there were minor complications regarding the payment, as Merz and his English clients calculated with different exchange rates when it came to deriving the final price of the instruments. As a result, Merz contacted Airy demanding the rest of the money. However, Airy was only able to settle this with the involvement of Herschel, who was also in the process of paying for his own purchase at the time.[95] In brief, the Airy-Herschel-Merz triad had interacted with each other in the past, which memory Airy seemed to have preserved clearly in his mind.

Airy's first letter to Herschel concerning the object glass was sent on 17 February 1848. In this, Airy copied a long extract from Merz's letter regarding the conditions of the trial of the object glass. The extract described how Merz only carried out trials on terrestrial objects, and with mountings different from those used for transit circles. Therefore, Merz was only allowing the sale of the object glass without the condition of trial. This condition was not in accordance with the terms set by the Board of Visitors who made it clear that the object glass had to be tested before purchase. This was a preference shared by Airy too. Based on these complications, and the unusual conditions set by Merz, Airy directly declared: '... I do not trust Merz. Therefore it seems - I think that all proceedings with him must be stopped for the present.'[96]

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[95] For the letters exchanged between Airy, Herschel, and Merz see RGO 6/155.
[96] Airy to Herschel, 17 February 1848, RGO 6/9 192.

Herschel's response was very calm and diplomatic. He began by pointing out that if he were to purchase a telescope for private use with an 8-inch object glass he would order one from Merz without hesitation since others also had dealt with Merz and were well treated. To ease Airy's worries further, Herschel proposed to wait until a recent purchase from Merz by the Royal Observatory at the Cape of Good Hope arrived and Thomas Maclear, the director of that observatory, had tested the object glass. Herschel promised that if Maclear found the object glass to be of poor quality, then he would never say another word in favour of Merz. However, if Maclear found the object glass of good quality, then the word of another director perhaps could change Airy's opinion. Finally, Herschel finished the letter by emphasising the importance of procuring an object glass before the construction of the Transit Circle started, since he presumed that the tube could not be 'exactly constructed so long as any small uncertainty exists as of the focal length [of the object glass].'[97] In brief, through Herschel's first response about the object glass we see that neither Herschel nor Sheepshanks shared Airy's concerns regarding Merz. Perhaps most surprisingly, Herschel did not mention whether the testing procedure for the object glass quoted by Airy was an unusual way or carrying out the trial or not. Therefore, Herschel seemed to have found Airy's main concern unfounded. Furthermore, mentioning Thomas Maclear and opportunity to test another Merz instrument highlighted a hierarchy of credibility within the astronomical community, and Herschel's attempt to increase Airy's trust in Merz by involving views of another astronomer of high repute.

Airy responded to Herschel's letter the next day. He began by summarising the state of the negotiations and outlined his analysis of distrust in Merz: 'Merz will allow trials of object

[97] Herschel to Airy, 26 February 1848, RGO 6/9 195-196.

glasses sold as mounted on his equatoreal stand. Merz's object glasses so sold with the equatoreal mounting are always trustworthy.' On the other hand, 'Merz will not allow trial of object glasses which are sold without an equatoreal stand. Merz's object glasses sold without equatoreal mounting are not always trustworthy.' Based on these four underlying statements, Airy continued by refuting the former side of the argument. Referencing the order for the equatorial telescope for the Liverpool Observatory, he found that the object glass supplied with the telescope was 'not so perfect as we expected'. In consequence, for Airy, neither side of the argument (whether the object glass was going to be supplied (a) with or (b) without the telescope) guaranteed the high quality of the object glass, making Merz 'untrustworthy'. In light of this, we see the important role that the quality of previous products and services played in long-term interactions between astronomers and instrument makers. The rest of the letter refuted Herschel's doubts about not having the object glass at hand halting the production process, by highlighting that a 'large portion of the work (building, piers, Y's, transit-axis, clamp circle, graduated circle, microscopes and collimating telescopes)' could begin even without an object glass.[98]

Airy's next letter to Herschel about the object glass was written about a month later, just a couple of days before confirming the purchase of the object glass from Simms. In this letter, Airy provided a detailed account of the trial to which he subjected the object glass. However, the letter's main aim was already clarified in the first lines:

[98] Airy to Herschel, 27 February 1848, RGO 6/9 197.

> I would be glad to have your friendly advice, not for the purpose of relieving me from any responsibility or for of excusing me from the necessity of judging myself, but for my own clarification.[99]

In these first lines, Airy attempted to change Herschel's frame of reference so that Herschel could consider the letter as an exchange between two friends as opposed to being an official correspondence. The letter continued to describe Airy's source of distrust in Merz's work, which was based not on his own observations, but on the ones made by William Simms who carried out the first trial of the object glass of the Liverpool Equatorial. The letter described how the initial method of the trial was not adequate for Airy, and asked Simms to carry out a trial on celestial objects too. After the second trial, Simms 'was very well satisfied with it'. From Airy's description we now see a third source for his distrust in Merz emerging. However, unlike previous ones, this was based entirely on the method with which they did not test the object glasses on celestial bodies, as opposed to on the unreliable quality of their previous final products.

The rest of the letter provided the results of the trial in great detail by describing the extent of the visibilities of several celestial bodies. At the end of this description, signaling the good quality of the object glass, Airy proceeded to ask Herschel the following two questions: 'Now do you not think it would be well to purchase this object glass at once? Or do you suggest any other examination as necessary or desirable?'[100]

[99] Airy to Herschel, 5 April 1848, RGO 6/9 201.
[100] Airy to Herschel, 5 April 1848, RGO 6/9 202.

In brief, Airy seemed to be very keen on purchasing the object glass as soon as possible, but wanted a second confirmation from Herschel, in order to ensure that he did not overlook anything during the trials. The letter then finished with two practical solutions that Airy wanted to implement into the Transit Circle: one correcting the chromatic dispersion of the light, the other focusing on a design for the eyepiece that allows it to be tilted so that the chromatic effect caused by the imperfection of its centring could be corrected. This addendum demonstrated that Herschel was not only involved in advising on the supply of the object glass, but also on the optical arrangements of the telescope.

9. Conclusion

The story of the object glass provides us with new insights into the history of the Transit Circle. It demonstrates that several instrument makers were considered as possible suppliers of the object glass. In light of this, the procurement of the object glass was not as straightforward as it was described in the *Annual Reports* and the official descriptions of the instrument, upon which later scholarship based the history of the Transit Circle.[101] Furthermore, the inclusion of instrument makers from continental Europe showed that the Observatory was not only embedded within the British network of instrument makers, but also within the wider European one. Each one of the possible suppliers excelled in different aspects of their offers: Lerebours offered the cheapest glasses, Merz had a global reputation, while Simms offered to make it in the shortest amount of time. With Simms failing on his initial promise (by not receiving good shipment of lenses from France), Airy's decision to employ him was no longer a straightforward decision.

[101] Satterthwaite, *Airy's transit circle*, *p.* 120; Lowne, *The object glass of the Airy transit circle at Greenwich*, pp. 44-45.

The fact that Airy wrote to Lerebours just a few days before Simms finally prepared the object glass for testing, demonstrated the Astronomer Royal's gradually decreasing confidence in the work of the English instrument maker. However, Simms understood Airy's emphasis on time and quality, and the re-use of an object glass from another work in progress signalled the priority that the Observatory (and the Astronomer Royal) enjoyed in the workshop of the instrument maker. This act demonstrated Simms's knowledge based on previous experience on how to interact with the Astronomer Royal in order to secure the production.[102] In relation to the work of Merz, Airy's distrust based on prior work led him to be hesitant over reaching out to the instrument maker, which once again demonstrated the important role that the previous contacts with the Astronomer Royal played. Furthermore, Merz's reluctance to alter the conditions of the trial of his object glass according the wishes of a prospective client, as well as Airy's distrust in the quality of his work exhibited the first signs of the loss of the credibility in the products of the instrument maker, which eventually led to his diminishing monopoly over the making of object glasses.[103]

Airy's preferences for the order brought forward the principles of 'economy' and 'efficiency', which factors were also prominent in the running of the Observatory as a factory. He emphasised the inseparability of time, money, and quality when deciding upon the supplier. By doing so, the principles and standards of business were not only implemented into the rules and division of labour set up at the Observatory but were also embodied within Airy's approach to negotiating the construction of instruments and their parts. The analysis of the early correspondence relating to the object glass further showed that it was not only Airy and the instrument makers who were involved in its procurement, but the members of the Board of Visitors too. By receiving advice

[102] Ginn, *Philosophers and Artisans*, pp. 207-269.
[103] Jackson, *Spectrum of Belief, p. 174.*

from them, two of its members were able to shape the direction that Airy took with the negotiations. In light of this, the procurement of the object glass was a collaborative enterprise between Airy, the instrument makers, and selected members of the Board of Visitors.

The interaction between the Airy, the instrument makers, and the members of the Board of Visitors also highlights how and why Airy oversaw the business of the Observatory. Most importantly, close oversight of the production process was important because of the unreliability of the instrument makers. By being closely involved in every stage of production, Airy maintained the option to delegate the task to another supplier. In addition, since Simms was already engaged in the general maintenance and repair of the instruments at the Observatory, he was in frequent contact with Airy, which allowed the Astronomer Royal to receive regular and quick news on the progress of the order. This chapter argued that it was precisely because Simms failed to regularly provide information to Airy that Lerebours and Merz were contacted at the later stages of the negotiations. By doing so, Airy's close oversight gave him more control over the selection of suppliers, but it was also a source of heightened anxiety.

Chapter 2 : Engineering Airy's Oversight and the Transit Circle

1. Introduction

The object glass was considered by the Board of Visitors as the starting point for the construction of the Airy Transit Circle. While the procurement of the lenses was a significant step in the process, it did not mean that production of other parts of the instrument could not proceed.[1] This was possible because their sizes were not dependent on the final dimensions of the object glass. The aim of this chapter is to examine the history of those subsidiary and non-optical parts. In addition, it continues to reimagine the Transit Circle not as a single instrument, but as an assemblage of multiple smaller instruments and mechanical parts. Finally, the focus on the divided circle and the pivots of the instrument will bring forth the significance and the contribution of the firm Ransome & May (and especially the role of Charles May), which has been largely simplified in past studies of the Transit Circle and Airy's interactions with instrument makers.

In the official description of the Transit Circle, Airy distinguished between three categories of components that made up the instruments: massive, optical, and graduated parts.[2] The distinction between these three categories highlighted the differences in the specialisation of the two firms (Ransomes & May, and Troughton & Simms) contributing to the construction process. Troughton & Simms focused most of their attention on the optical parts: the object glass, the

[1] Airy to Charles May, 28 February 1848, RGO 6/721 526

[2] George Biddell Airy, 'Description of the Transit Circle of the Royal Observatory, Greenwich', Appendix to the *Greenwich Observations 1866* (1868), p.2.

illuminating system, the collimating telescopes, the microscopes of the Western pier. By contrast, the massive parts were made by Ransome & May who were specialists in the manufacturing of agricultural equipment. These parts of the instrument included the telescope tube, the pivots, the mercury trough, the counterpoises, and the lifting apparatus. The third category of graduated parts highlighted the collaboration between the two firms. For instance, the circular support for the divided circle was cast by Ransome & May, but it was Simms who inserted the silver band of the circle and graduated its divisions. Similarly, the pivots of the Transit Circle were made at the factory of Ransome & May, but the examination of their accuracy was carried out by Simms, who also advised May on how to achieve even better accuracy. This chapter will use these categories to examine the interactions between Airy, Ransome & May, and Troughton & Simms.

The attention in this chapter will mainly be turned towards the firm Ransome & May and other engineers. As a result of this, the chapter will begin with an overview of the history of the firm and how they developed relations with Airy over the years, which led to their employment on the construction of the Transit Circle. In addition, the chapter will highlight the competing definitions of accuracy that were employed by engineers, opticians, and astronomers, through the considerations of different instrument makers and engineers for the task of dividing the circle.

The chapter then investigates the construction of the pivots of the Transit Circle. While often taken for granted, making them as cylindrical as possible posed great challenges to instrument makers. Its history highlights the significance of the pivots in transit instruments and transit circles, and illustrates the competing definition of a "finished product" between instrument makers and astronomers. The chapter then directs its attention to what Airy labelled in his letters with May as the subsidiary machinery. The discussion about the mercury trough and the lifting apparatus shows how Airy and the instrument makers considered the Transit Circle as an assemblage of multiple instruments and parts, which thinking was later showcased at exhibitions too. By complementing the history of the divided circle and the object glass with the briefer histories of the smaller parts of the Transit Circle, the chapter demonstrates the multiple stories that the different parts of the instrument can tell. Furthermore, by focusing on how these parts were constructed, it demonstrates that the Transit Circle was more than just the sum of its parts. Instead, it also referred to the relations between the multitude of parts. These relations will be highlighted through the discussion on the errors made during construction of smaller parts, which inevitably led to delays in installing the Transit Circle.

Finally, the chapter will close with a brief analysis of the piers and the walls of the Transit Circle Room. The piers themselves had supported the two mural circles that the Transit Circle replaced, and they serve as an example to how the materiality of the instrument embodied the historical lineage of the meridian instruments at the Observatory. Meanwhile, the walls demonstrate the significance of including the room itself as part of the assemblage of the instrument. By considering the history of the various parts of the Transit Circle, the chapter will challenge the underlying assumption that object glasses should be taken as the starting points for the analysis of a history of a telescope. Instead, in the case of complex astronomical precision instruments such as the Transit Circle, the multiple parts of the instruments were given equal significance throughout the construction process. In this light, astronomical precision instruments appear as assemblages of equally important parts, all of which contribute to both the perfection and imperfection of the installed instrument.

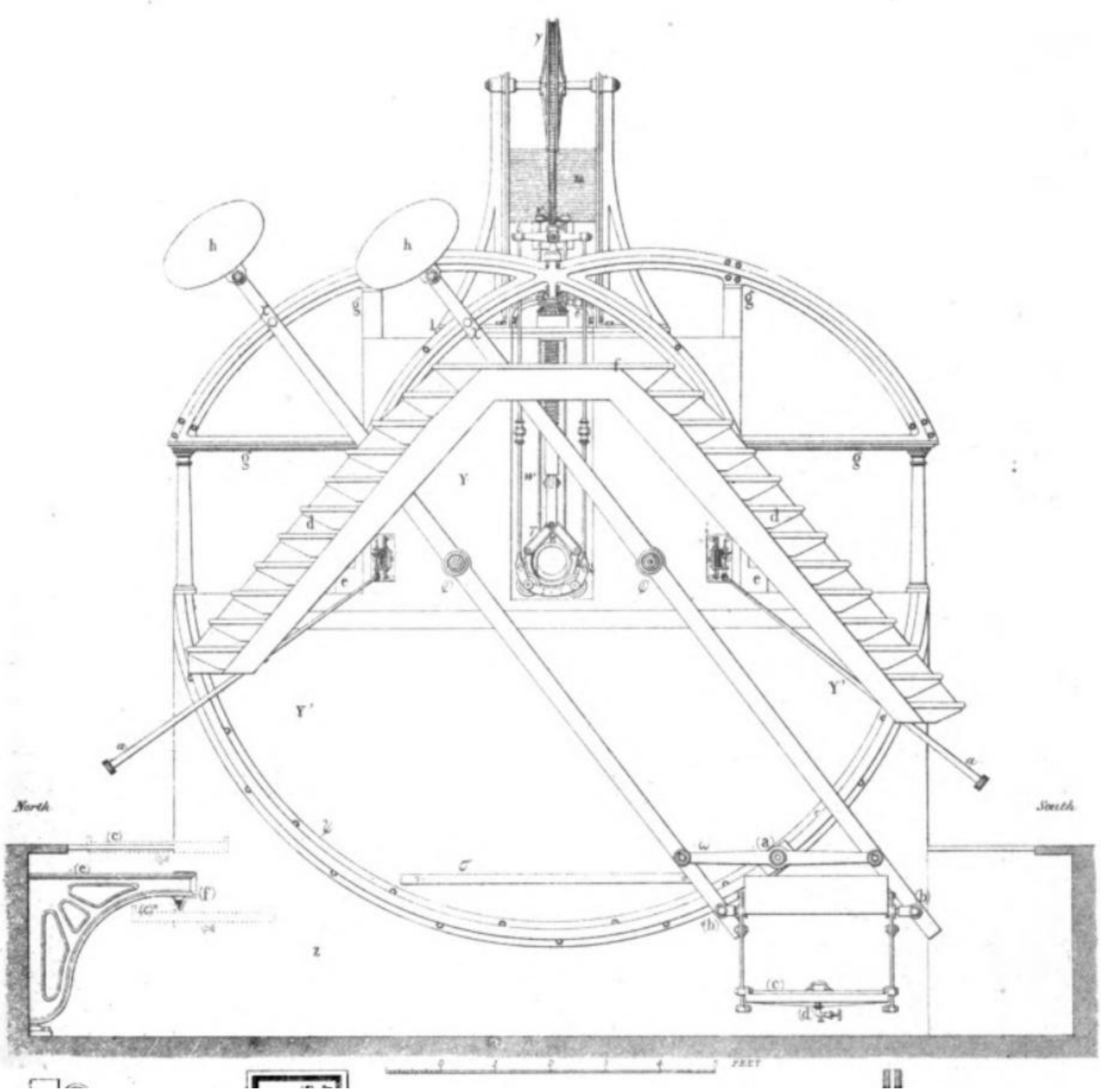

Fig. 14. Illustration from the official description of the Transit Circle showing the large parts of the Transit Circle: the mercury trough (bottom right) with the two counterpoises attached to it, and the lifting machinery on the top of the pier (top middle)

2. Airy and engineering

Before venturing any further into the history of the mechanical parts of the Transit Circle, we need to consider Airy's position within the context of engineering and the mechanical arts in the nineteenth century. The current scholarship on Airy tends to downplay Airy's engagement with instruments after they were purchased. Most commonly it is based on the *Greenwich Observations* listing him as an observer for only a few observations. Despite this, there have been several articles on Airy's engagement with issues related to engineering and mechanics. Arthur Jack Meadows in his history of Airy's directorship argued that the Astronomer Royal should be considered an engineer manquée, who enjoyed coming up with mechanical designs for problems.[3] This becomes visible through the entries of the Astronomer Royal's Journal too, in which Airy recorded engaging in the constant adjustment and maintenance of instruments around the Observatory.[4] Another example came from Allan Chapman, who similarly highlighted Airy's 'technical genius' as a key foundation for the good relationship he maintained with engineers and instrument makers.[5] Following Chapman's framing of the role of the Astronomer Royal as a public servant, we reach further connections to engineering. As a scientific adviser to the Government, Airy was part of the Royal Commission on the Railway gauge,[6] he was consulted for the construction of the Tay Bridge,[7] he criticised the structural design of the Crystal Palace

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[3] Meadows, *Recent History (1836-1975)*, p. 6.
[4] For Airy adjusting Pond's 25-foot Great Zenith Tube, see RGO 6/24 12: entry for 8 November 1836; for Airy inspecting and trying out St Helena instruments see 7: 28 June 1836 and 10: 14 September 1836; and for Airy adjusting a clock by Dent, see 13: entry for 20 Jan 1837
[5] Allan Chapman, 'Science and the Public Good: George Biddell Airy (1801-92) and the Concept of a Scientific Civil Servant', in *Science, Politics and the Public Good: Essays in Honour of Margaret Gowing*, ed. by Nicolaas A. Rupke (Basingstoke and London: The Macmillan Press, 1988), 36-62 (p. 40).
[6] Adam Perkins, *Extraneous government business*, pp. 143-154.
[7] Roy MacLeod, *Government and Expertise: Specialists, Administrators and Professionals, 1860-1919* (Cambridge University Press, 2003), pp. 53-54

built for the Great Exhibition of 1851,[8] he was involved in the correction of compasses on iron-ships,[9] and provided advice on the usefulness of Charles Babbage's difference engine.[10] If the definition of engineering can be extended to instrument making and the mechanical arts, then Airy's engagement with the field becomes even more apparent. He was in regular contact with clock makers,[11] played a significant role in the re-building of the Palace of Westminster,[12] designed the original plans for many of the instrument of the Observatory,[13] was consulted for supervising the purchase of instruments for other observatories,[14] participated in South vs Troughton & Simms debate,[15] and contributed for the technical development of telegraphic time-signal distribution through his interactions with railway engineers.[16] The esteem in which he was held as an expert on issues of engineering was highlighted by the appraisal of his skill by Isambard Kingdom Brunel. He stated that Airy was both 'a first rate mechanic as well as a mathematician.'[17] In a similar appraisal remarking the inventiveness of Airy's mind, James Stuart recalled how the Observatory was filled with the Astronomer Royal's inventions:

> There was nothing with which he came in contact that he did not improve and illuminate. For instance, the whole of the Observatory was full of his inventions – doors which shut by contrivances of his own, arrangements for holding papers, for making clocks go

[8] Malcolm Millais, *Building Structures: From Concepts to Design* (Taylor & Francis, 2005), p. 295.
[9] C. H. Cotter, 'George Biddell Airy and his mechanical correction of the magnetic compass', *Annals of Science*, 33:3 (1976), 263-274; C. H. Cotter, 'The early history of ship magnetism: The Airy-Scoresby controversy', *Annals of Science*, 34:6 (1977), 589-599.
[10] Swade, *Calculation and Tabulation in the Nineteenth Century*.
[11] Bennett, 'George Biddell Airy and horology'.
[12] Gillin. T*he Victorian Palace of Science.*
[13] Satterthwaite, 'Airy and positional astronomy'.
[14] Ishibashi, 'In pursuit of accurate timekeeping'.
[15] Hoskin,.'Astronomers at war'.
[16] Chaldecott, 'Platinum and the Greenwich System of Time-Signals in Britain'.
[17] Reference to Brunel's statement can be found in Alfred Pugsley, *The Works of Isambard Kingdom Brunel: An Engineering Appreciation* (Cambridge University Press, 1980), pp. 21 & 205

> simultaneously, for regulating pendulums, for arranging garden beds, for keeping planks from twisting, for every conceivable thing from the greatest to the smallest.[18]

Airy's contribution to engineering, instrument making, and the mechanical arts were also communicated to the engineering and scientific community through various papers. A quick glance at the printed papers of Airy reveals enthusiasm about the subject from his early career. Two of his earlier papers were related to the construction and uses of telescopes, and one related to the form of the teeth of wheels/gears.[19]

By demonstrating Airy's engagement with issues related to engineering we can position him better in his interactions with instrument makers. Approaches to Airy's directorship that depict him as a manager, public servant, or a high-ranking clerk create the illusion that he was a simple client removed from the construction project and oversaw only the non-technical details of the operations. By contrast, by understanding Airy as an engineer manquée, his close involvement highlights him as a collaborator in the construction process who not only fostered a keen understanding of the field, but also managed to improve upon it. Such an approach transforms the correspondence between the instrument makers and the Astronomer Royal from mere business correspondence to in-depth discussions on mechanics, engineering and instrument making. Illustrative of this shift is the location of the working plans in the RGO archives (that still largely preserve Airy's system of categorising his own manuscripts). The working plans form part of the 'Correspondence on instruments' section, which also includes discussions on new designs and instrumental errors. By contrast, the written correspondence forms part of the 'Correspondence with tradesmen section', alongside the bills and receipts received.

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[18] James Stuart, *Reminiscences* (London: Chiswick Press, 1911), p. 159
[19] These papers are listed at the end of Airy's Autobiography.

3. Airy, Ipswich, and the history of Ransome & May

While the negotiations over the object glass involved the network of opticians, the making of the mechanical parts involved a new network of engineers. In light of this, the main protagonist of the history of the large parts becomes the firm Ransome & May. It was originally established by Robert Ransome (figure 15) in 1789 as an iron-foundry - at the time known as Ransome and Co. From the early years of the 1800s, the firm started using chilled iron in the manufacturing of their products, especially for the manufacturing of agricultural equipment.[20] Chilled iron was made through the quicker cooling of one side of molten iron than its other side. The resulting material allowed for the more uniform wear of instruments. For instance, in its application to ploughshares, due to the underside and the top side wearing at different rates, allowed for maintaining the sharpness of edges. In relation to the Transit Circle, the use of chilled iron helped in the uniform wear of the parts of the instrument that were undergoing constant wear. Furthermore, the technique also created a material lighter than usual, which compensated for the large size of the Transit Circle. Being a unique technique at the time, it led the firm to gain an advantage on the market over their competitors and created a solid grounding upon which the firm could expand its portfolio into different areas such as railways or astronomical instruments.

[20] J. Allen Ransome, *The Implements of Agriculture* (London: J. Ridgway, 1843), pp. 17-19.

Fig. 15. Drawing of Robert Ransome (1849, NPG, D39210)

Fig. 16. Drawing of James Allen Ransome (1849, NPG, D39206)

Throughout its history, the firm employed several famous engineers such as William Cubitt, Charles May, and William Dillwyn Sims. However, the main connection of the firm to the history of the Transit Circle appears through Airy's uncle, Arthur Biddell, who was a close friend of Robert Ransome and the firm too. While growing up, Airy spent long periods of time at his uncle's house, where he was introduced to Arthur Biddell's circle of friends, including Robert Ransome. Airy remembered the old Ransome fondly as the first person to show Airy the planet Saturn through a telescope.[21] This relationship with the Ransome family established at an early age never faded throughout Airy's life. The firm was consulted during Airy's early career for the construction of the Northumberland Equatorial at the Cambridge Observatory, and towards the mid-1840s culminated in their contribution to the construction of the Altazimuth instrument. Through the Altazimuth project, Airy also brought Ransome & May in contact with

[21] George Biddell Airy, *Popular Astronomy* (London: Macmillan and Co, 1868), p. 2.

Troughton & Simms. The close relationship through relatives between Airy and the Ransomes becomes even more relevant in the current scholarship on Airy, which emphasises the Astronomer Royal's preference for controlling all aspects of his projects, as well as the running of the Observatory.[22] The close relationship allowed Airy to exercise close oversight, characterised by being informed on every matter relating to projects and being involved in even the smallest details.[23]

Ransome and Co. was renamed Ransome & May in 1836 upon the chemist/engineer Charles May becoming a partner in the firm. May, similarly to the old Robert Ransome who had died in 1830, was interested in astronomy. Partly due to this, he became Airy's first point of contact with the firm during the making of the Altazimuth and Transit Circle instruments. Despite May's leading role in these projects, historical scholarship has devoted relatively little attention to him. The most extensive accounts of his life were the obituaries that appeared in the Minutes of proceedings of Civil Engineers and the *Monthly Notices of the Royal Astronomical Society*. From these we learn that astronomy caught his imagination at an early age, and he constructed several reflecting telescopes himself.[24] Through his passion for mechanics and astronomy, he befriended William Henry Smyth, who later asked for May's aid in the construction of the equatorial tower for the Hartwell Observatory of Dr John Lee.[25] In addition, May was employed on the construction of a large dome an observatory at Bury Hill.[26] This work proved to be crucial in his contact with Airy. In the 1830s, Airy oversaw the construction of the Northumberland Equatorial of the Cambridge Observatory at the request of the Duke of Northumberland. With the new

[22] Smith, *National Observatory Transformed*
[23] Ginn, *Philosophers and Artisans*
[24] [Obituary of Charles May], *Minutes of the Proceedings of the Institution of Civil Engineers*, 20, (1861), pp. 148-149; [Obituary of Charles May], *Monthly Notices of the Royal Astronomical Society*, 21:4, pp, 101-102.
[25] William Henry Smyth, *Aedes Hartwellianae* (London: John Bowyer Nichols and Son, 1851), p. 239.
[26] [Obituary of Charles May], *Monthly Notices of the Royal Astronomical Society*, 21:4, p. 102.

instrument, a new building for the Observatory was also proposed. Since Airy at this time still lacked the expertise and insight into the construction of domes, he reached out to various individuals who might be able to advise him on this matter. In one of the responses Airy received from his uncle Arthur Biddell, he refers to May having worked on the Hartwell Observatory's dome.[27]

In 1836, May became a partner of the Ransomes firm, where he turned his attention towards industrial mechanics by focusing on iron chilling techniques, agricultural machinery, and the design of railway seats.[28] While a partner at Ransomes, he carried out work on the Altazimuth Telescope and the Transit Circle. As a result of his time spent with the Ransomes, most of the sources related to relationship between Airy and May survive as correspondence between the Airy and the firm from the mid-1840s until 1851 (in which year the partnership between the Ransomes and May was broken up). After the work on the Transit Circle was completed, May left the Ransomes and moved to London to become a consulting engineer. He remained in London until the end of his life in 1860.

4. The correspondence between Airy and May

One of the interesting features of the correspondence between Airy and May is the Astronomer Royal's friendliness towards the engineer. The letters themselves are embellished with the friendly and informal remarks that are unusual of Airy's correspondence with other tradesmen (such as William Simms). One of the letters began with Airy's praise of May, after the

[27] RGO 6/157.
[28] Charles May, 'On a new form of railway chairs and improved fastenings', *The Civil Engineers and Architect's Journal*, July 1841, 236.

engineer complied with the Astronomer Royal's request to reorganise the order of work: 'Long live the Engineer, for they have more go in them than any body else.'[29] Similarly, in another exchange of letters, Airy adapts a quote from Shakespeare: 'Thou are neither fish nor flesh, a man knows not where to have thee.'[30] As Airy explains later, he is referring to Charles May's constant travels around England, and the difficulties which arise as a result when it comes to corresponding on the construction. In another letter, Airy resorts to the expression 'a bird in the hand is always more than four in the bushes' as advice for a paper which Charles May wanted to present at the Royal Astronomical Society.[31] This playful language also suggests a relationship between the two individuals that went beyond the formalities of firm-client relations, which is uncharacteristic of his dealings with other instrument makers and engineers. To some extent, the contrasting personalities also appeared in the distinct writing styles. The calmness of William Simms is in direct contrast with Charles May's more active lifestyle.[32] The two different sets of correspondences also demonstrate two different conversational styles. The friendship of Airy and May is stated explicitly both through references to their personal lives and by including playful quotes and praise as demonstrated above. By contrast, the closeness of Airy and Simms was expressed implicitly through Airy's special requests from the instrument maker and through playing with the formalities of the business correspondence. The latter was highlighted by Ginn, when Airy stated an extremely high price as a penalty for Simms in case if he did not follow Airy's orders. Similarly, Airy's proximity to Simms was demonstrated through his request that he gather information for the Greenwich Observatory during his visit to Merz's workshop. In brief, the Airy-May and the Airy-Simms correspondences depict two very different approaches

[29] Airy to May, 28 February 1848, RGO 6/721 526
[30] Airy to May, 5 June 1848, RGO 6/721
[31] Airy to May, 30 November 1848, RGO 6/721
[32] Mennim, *Transit Circle*; Ginn, *Philosophers and Artisans*.

to maintaining relationship between astronomers and artisans. While the Airy-Simms correspondence shows us Airy as the king of 'methodists',[33] who likes to play around with the formalities of the relationship, the Airy-May correspondence depicts Airy as someone who is less bound by limits of formalities, and willing to engage in informal discussions even on paper. In this light, Airy's striving for oversight did not emerge from his methodical personality but, rather, it was an extension of the oversight employed within the Observatory to other people involved in the business of the Observatory. This brief detour to discuss Airy's relations with engineers and Charles May, helps us gain a better understanding about the context within which the large parts of the Transit Circle were discussed.

5. The Divided Circle and the Engineer

Besides the large size of the object glass, it was also the accuracy and size of the divided circle that made the Transit Circle significant as a technological novelty. Divided circles were used for measuring the vertical angle at which the transit of the celestial body occurred. The circular support for the divided circle of the Transit Circle was cast by Ransomes & May, while the insertion of the silver band as well as its graduation were carried out by Troughton & Simms. This way, the divided circle was one of the co-constructed parts that were created by both instrument makers.

William Simms at the time was a leading name in the division of circles. His reputation was partly based on being a partner of Edward Troughton, and partly on his own improvements made

[33] In reference to Airy's love for method, Augustus De Morgan (a close friend of Airy), jokingly noted in his letter to William Rowan Hamilton about libraries that Airy and his organisation system made him the 'prince of *method*ists.' (Original emphasis) See Robert Perceval Graves, *Life of Sir William Rowan Hamilton, Vol. III.* (Dublin and London: Hodges, Figges & Co. and Longmans, Green & Co., 1889), p. 381.

to dividing engines. Graduating circles by machines was traced back to its horological origins by Allan Chapman.[34] The introduction of machinery for the task raised the possibility of creating original graduations within a short amount of time, as opposed to having to rely on the copying of master circles by hand. John Brooks provided further elaboration on the history of dividing machines by taking Jesse Ramsden's second dividing engine as his starting point – an invention for which in Ramsden was awarded £615 in 1777.[35] His new design demonstrated that a higher accuracy of division was achievable through the use of machines than through division by hand. A few years later Edward Troughton turned away from Ramsden's design principles, and began developing his own method of graduation. Troughton's description of the new method was awarded the Copley Medal in 1809, and was quickly taken up by other instrument makers.[36] His contribution shifted the focus of future improvements from the skills of the operators of the dividing engine to the ever more precise construction of the machine.[37] Simms continued Troughton's approach by introducing the self-acting mechanism to the dividing engine, which made the 'whole graduation process mechanical'.[38] The divided circle of the Transit Circle was graduated on such an engine, and by doing so it became 'one of the first important research instruments to be engine-graduated.'[39]

While Brooks and Chapman did not expand on why Airy decided to use Simms's dividing engine for the graduated circle of the Transit Circle, the way in which they characterised Simms's improvements helps us understand their interpretation of the matter. Chapman described it as a distinctly industrial engine, since it reduced the time and the labour from the

[34] Chapman, *Dividing the Circle*, pp.123-124.
[35] Brooks, *The Circular Dividing Engine*, p. 102.
[36] Ibid. p. 123.
[37] Chapman, *Dividing the Circle*, p. 136.
[38] Ibid.
[39] Ibid. p. 137.

side of the instrument maker. In this light, the graduated circle embodied Airy's preference for implementing methods that brought together both industrial and scientific solutions. While Brooks and Chapman provided a detailed technical analysis of the development of dividing engines, they focus exclusively on the role of opticians and specialist instrument makers. This chapter attempts to expand on their analysis by focusing on Airy's justification (as a client) to employ an optician over an engineer. Such an approach not only provides new insight into the perception of dividing engines, but also contributes to an understanding of the concept of accuracy in the middle of the nineteenth century, which concept was not explored further in neither Chapman's nor Brooks' account.

Fig. 17. John Troughton's Dividing Engine (Science Museum, Object number: 1932-22)

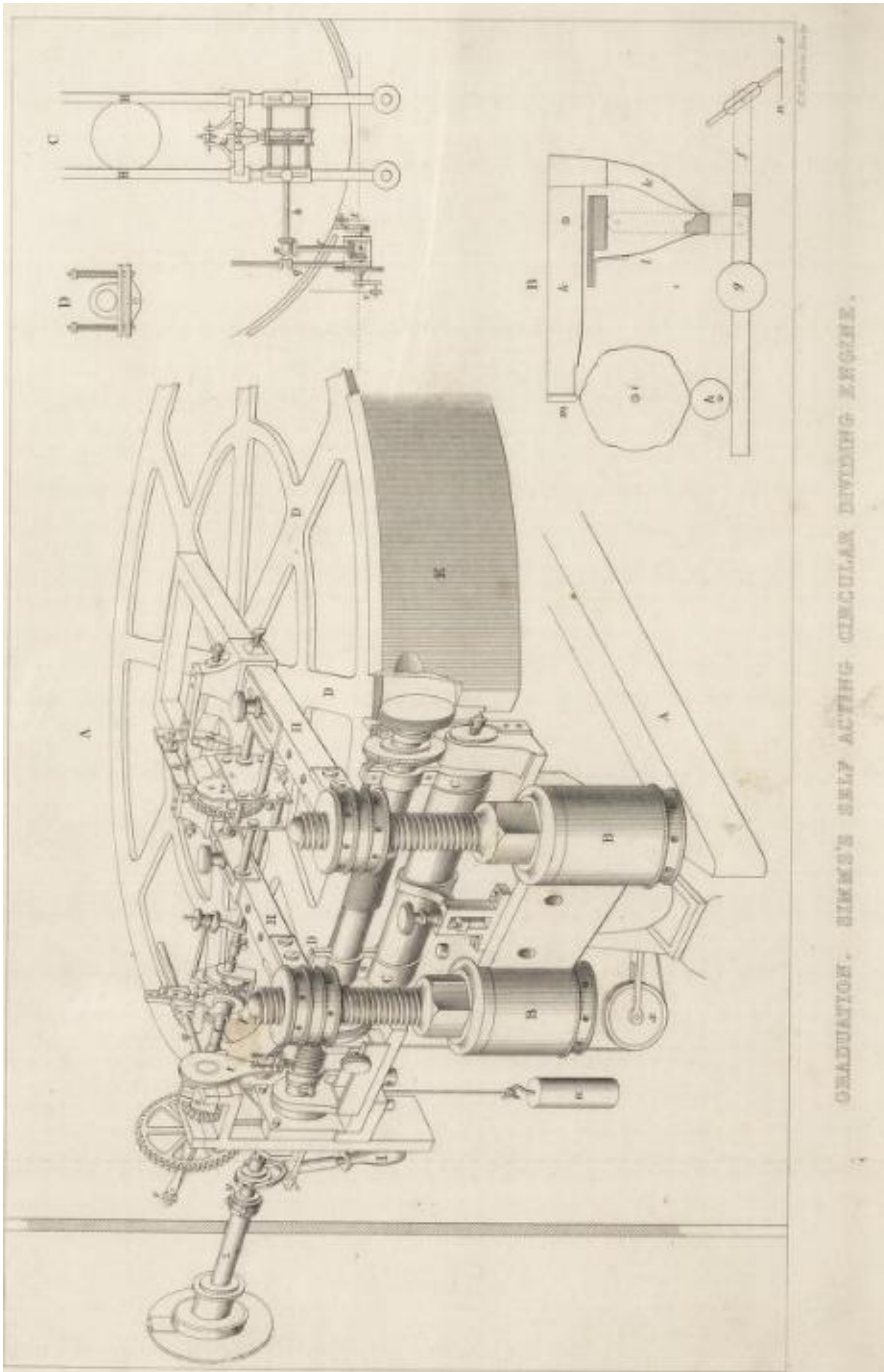

Fig. 18. Illustration of Simms's self-acting dividing engine (Cyclopaedia of useful arts, mechanical and chemical, manufactures, mining, and engineering,1854)

Discussion about the graduated circle began on 2 January 1848. At this stage, Airy and May were still discussing the final designs for the Transit Circle. As a result, the possibility of placing the graduated circle at another part of the instrument was raised. Similar discussions resurfaced at the end of February when May declared his dissatisfaction with the accuracy of Simms's dividing method.[40] While he did not expand on his reasons for it, the statement demonstrated that, contrary to Brooks and Chapman, Simms's methods were still facing criticisms from at least one major engineering firm. Instead of Simms, May recommended Joseph Whitworth (figure 19) for carrying out the task of dividing the circle.

Whitworth was a leading engineer at the time, who was trained at the workshop of Henry Maudslay alongside other famous engineers such as James Nasmyth, and while working for Joseph Clement, he was involved in the manufacturing of Babbage's Difference Engine. In the 1830s he set up his own manufacturing firm in Manchester, where he specialised in the production of machine tools. During the 1840s he developed further manufacturing techniques that increased the accuracy of the final products and began implementing new measuring techniques that aided the implementation of a new unified standard for screw threads, which later became known as the British Standard Whitworth.[41]

Charles May's suggestion to include Whitworth in the graduation of the circle implied the shifting of the work away from optical instrument makers into the realm of engineering and industry. Furthermore, it showed that the problem of division was not one being tackled by mathematical instrument makers only, but by engineers too. Airy was supportive of May's ideas. His response began with the joyful exclamation of '[l]ong live the Engineer, for they have more

[40] May to Airy, 26 February 1848, RGO 6/721
[41] For a detailed biography of Whitworth, see Norman Atkinson, *Sir Joseph Whitworth: 'the world's best mechanician'* (Stroud: Sutton Pub Ltd., 1996).

go in them than any body else.'[42] Airy then specified that he considered the best divided engines to be those first 'divided by eye-division, then finished up by screw-cutting, and then used with screw.' This method served as the basis for Airy's concept of accuracy, and incorporated both manual and mechanical dexterity. In light of this, it becomes understandable that Airy asked for further information on how Whitworth's engine was made, and declared that '[w]hat is accurate for him may not be accurate for us.'[43] Despite this, Airy's letter demonstrated his curiosity and openness towards the option of employing Whitworth, even proposing the possibility of travelling to Manchester to see him and his engine in action. As an alternative to a trip to Manchester, Airy wanted to have the engine tested on an iron circle.

Fig. 19. Joseph Whitworth (c. 1860, NPG, Ax30401)

[42] Airy to May, 28 February 1848, RGO 6/721 526
[43] Ibid.

Airy's letter finished with the statement that he did not know who Whitworth was. This seems somewhat surprising given that since the late 1830s Whitworth and Airy were engaging in debates (though not with each other) on the question of standards. This was due Airy being appointed as the head of the Commission for the restoration of standards and weights that were lost in the burning of the Palace of Westminster. The aim of this Commission was to carry out preliminary research on standards, and to provide possible solutions to their restoration.[44] Even though Whitworth was not part of the Commission, its members engaged in gathering information about the existing standards. As we will see later, his method of creating and using standard measures faced severe criticism from members of the Commission, thereby bringing him in contact with the question of standards.[45] Despite this, the first report of the Commission published in 1841 made no mention of Whitworth.[46]

May seemed enthusiastic in his response. Besides providing a brief sketch of Whitworth's career, he praised the flat surfaces attained by the engineer, and he also declared that the 200 workmen working for Whitworth were 'keen on accuracy'.[47] While no information was provided on how his dividing engine was made, May described the mechanism with which it worked. We also learn from the letter that Whitworth had recently worked on a measuring instrument (attaining the precision of 1/20,000 of an inch), and that he was delighted to offer his services to the Observatory. This was probably reference to an early version of what became known as the Whitworth Measuring Machine. It was eventually exhibited at the Great Exhibition of 1851, and

[44] Ronald Edward Zupko, *Revolution in Measurement* (Philadelphia: The American Philosophical Society, 1990), pp. 191-192.
[45] Atkinson, *Sir Joseph Whitworth*, pp. 102-103.
[46] Atkinson describes the Commission as a 'curious coalition, [composed] mostly of lawyers and other non-engineering people' Ibid. p. 96. For the report produced by the Commission, see *Report of the Commissioners Appointed to Consider the Steps to be taken for Restoration of the Standards of Weight & Measure*. (1841)
[47] May to Airy, 6 March 1848, RGO 6/721

became known for being able to measure to a millionth of an inch.[48] However, there remains very little information about any dividing engine that Whitworth constructed at the time. For example, Atkinson only mentions one dividing engine made by Whitworth, which was constructed at the request of a locomotive manufacturing company.[49] Airy was so impressed with May's description that he immediately declared his plans for arranging a journey to Manchester. However, the dealings with Whitworth came to an abrupt end. He was no longer mentioned in later letters with the exception of one from 1850, in which May promised to introduce him to Airy the next day. From this exchange it can be inferred that Airy's plan to visit Whitworth in Manchester and to see his engine in action did not materialise.[50]

6. Foreshadowing debates on standards

The discussion between Airy and May about the meanings of accuracy foreshadowed the more intense clashes between Whitworth and the Astronomer Royal that were to follow from the 1850s onward as part of the Standards Commission. The conflict arose on the topic of the most accurate way of measuring the standard yard and deriving divisions from it. The issue centred around two methods of measurements: end- and line-measurement. End-measurement related to the use of the actual physical length of bars/pins/units to represent the desired measure: the end of the bar being the limits of the standard unit. Whitworth himself saw (and possibly used) a bench micrometer that embodied such principles during his formative years at Maudslay's iron

[48] T. M. Goodeve and C. P. B. Shelley, *The Whitworth Measuring Machine* (London: Longmans, Green and Co., 1877).

[49] Atkinson, p. 148. An online trade catalogue also lists a small dividing engine built by Whitworth in 1851. However, its small size would have made it impossible to be used for graduating the divided circle of the Transit Circle. See: https://www.earlytech.com/earlytech/item?id=653 [accessed 1 March 2019].

[50] Within the RGO archives, there is no record of letters between Airy and Whitworth around this time period.

foundry, and later developed his own length gauges and measuring machine that relied on the principles of end measurement.[51]

Against the 'end method' stood 'line measurement', which referred to the use of lines engraved onto bars to represent the standard units. This way, it was the distance between the engraved lines that represented the standard unit, as opposed to the physical length of the bar upon which they were engraved. While end measurement was supported by Whitworth, engineers and industrialists, line measurement was supported by the scientific community. Those in favour of the line measurement argued that the distance between the centres of two lines could be established accurately once accounted for the personal differences between the measurements of the length by sight. This position relied on the theoretical idea that a perfect standard unit was impossible to create. Furthermore, it was also impossible to establish perfect accuracy through only one person's measurement. The only solution to material imperfections was to numerically establish a value based on the known errors of the material and after the comparison of measurements of several people. Such thinking was expanded upon by John Herschel in his *Outlines of Astronomy*, where he argued that products of artisans are close to perfection, but never perfect. In relation to this, the role of the astronomer (and any person using the products of instrument makers) was to detect and to measure all the errors of the instrument, and to fix such errors through the use of calculations.[52] Airy implemented practices at the Observatory based on a similar approach. Once the errors of instruments and the human biases were identified as predictable, compensating for these errors through calculations allowed the observations to be more accurate.[53] By contrast, end measurement was based on the idea that accuracy could be

[51] Atkinson, *Sir Joseph Whitworth*, p. 94
[52] Herschel, *Outlines of Astronomy*, p. 78.
[53] This issue will be expanded in the chapter on 'Calculative Maintenance'.

achieved to such a degree in the production of artefacts that the small errors still affecting their materiality were negligible. Whitworth and other engineers were keen on this idea, since many of them had already based their practices on this method. In addition, basing standards on such grounds would have allowed for the quicker and wider dissemination of the tools and methods connected to end measurement practices. Even though this approach was most widely supported among the engineers, a few major astronomers also showed preference towards it. For example, Friedrich Bessel used the end measurement technique when he created a new Prussian Standard of length in 1838.[54] He chose this method to avoid any possible interference caused by the bending of the material (i.e. by flexure), since any line measurement on the surface of the standard would have been affected by it. However, when the Standards Commission was set up to replace the destroyed British Standards, Bessell acknowledges the possibility of line measurement solutions. He agreed to the Commission's suggestions that the effects of flexure could be avoided 'if the lines were engraved on surfaces depressed to the middle of the thickness of the bar.'[55]

The question of this standard involved questions of politics and power. The imperial standard served as a symbol for the power of the Empire to disseminate its central authority (and standards) over its territory. The proposal of Whitworth and his supporters would have shifted this balance of power into the hands of the industry. If the standard was to be established by industrialists, the centralised authority of the Empire was threatened with the establishment of a new power within one of its segments. While both Schaffer and Atkinson depicted Airy's

[54] Atkinson, *Sir Joseph Whitworth,* p. 105.
[55] 'Conferences at the Exhibition of Scientific Apparatus: Linear Measurement', *The English Mechanic and World of Science*, 26 May 1876, no. 583, p. 272.

position as a supporter of the standard yard, his status in the debate was much more complex.[56] As it was highlighted at the beginning of this chapter, Airy had a keen interest in engineering since his childhood. The engineering community as well as the instrument makers accepted him as an expert on many issues relating to their fields. Furthermore, as it was highlighted in his correspondence with May, he did not look down on engineers. Finally, upon learning about Whitworth's dividing engine, even though he stressed the differences in the approaches to accuracy, he still exhibited enthusiasm towards employing and learning more about the new technique. In summary, Airy's preference for the line measurement method was not based on a complete rejection of the end measurement approach. Instead, it reflected Airy's and Herschel's belief in men of science being the overseers of the commercial products of artisans.[57] The other way in which the balance of power was redistributed concerned the relationship between men of science and artisans. Since line measurement was advocated for by the scientific community, while end measurement was based on the practices of artisans, a standard based on the end measurement would have shifted the power into the hands of artisans. As it was highlighted above, this threatened to transform the established roles of men of science and the artisans in relation to the instruments: men of science losing control through the numerical calculations over the material products of artisans.

[56] See Simon Schaffer, 'Metrology, Metrication, and Victorian Values', in Bernard Lightman (ed.), *Victorian Science in Context* (Chicago; London: The University of Chicago Press, 1997), 438-474.
[57] The distinction between the *commercial* and the *scientific* standards was a key motive in Airy's reports for justifying the use of line measurement. See George Biddell Airy, 'Account of the Construction of the New National Standard of Length, and of Its Principal Copies', *Philosophical Transactions of the Royal Society of London*, 147, (1857), 621-702 (pp. 646, 690 & 698).

7. Further work by May on the divided circle

The divided circle remained unmentioned in the correspondence with May until the autumn of 1848. This was due to the actual dimensions of the Transit Circle remaining unconfirmed. The lack of specifications allowed for further discussions about the position of the circle. While May initially thought that it was going to be attached to the horizontal axis (as it was the case with the Groombridge and Palermo Circles), Airy had to clarify that it was going to be independently placed on the inner side of the western pier. Airy also noted that the diameter of the circle could only be confirmed once the alteration of the piers was finished. The need for the various parts of the instrument to be decided upon once again highlighted the importance of the instrument as an assemblage of multiple instruments and parts, where their final forms were dependent upon their relations to the other parts of the assemblage.

The actual casting of the circle did not begin until May 1849. During the same casting process the clamping circle was also made, which was to be placed on the eastern side of the telescope tube. This circle had two main purposes. First, it was used for turning the telescope tube and securing it in place once it was set to the required angle. Second, it helped to balance out the weight distribution on the east-west axis of the instrument. While the body of the clamping circle was cast without any problem, the final cast of the divided circle was found to be too spongy. In fact, further attempts were found to be so bad that May decided to throw the entire circle out, begin the casting process once again, and to give it his 'anxious attention'.[58]

[58] May to Airy, 16 October 1849, RGO 6/722.

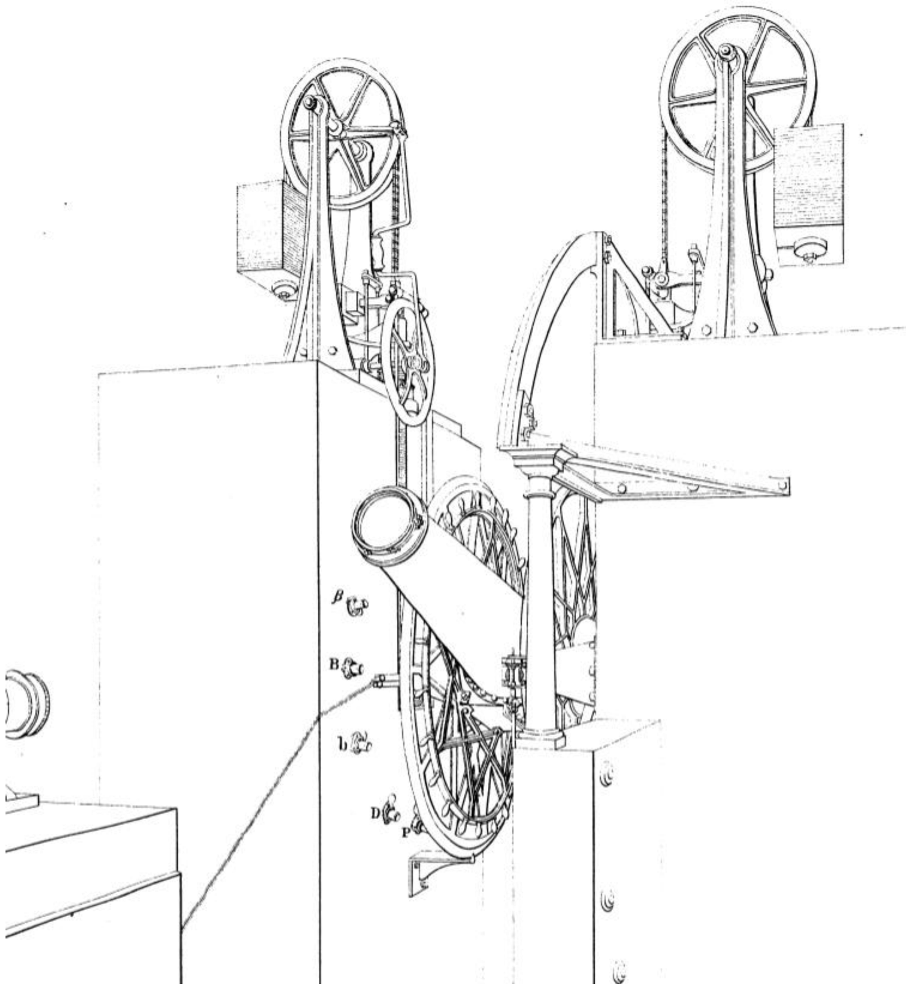

Fig. 20. Detail from Plate 2 of the official description of the Transit Circle showing the divided circle (to the left of the telescope tube) and the arrangement of the microscopes for viewing its graduations

The extra attention had a positive effect on the construction process, and the next letter to Airy described good progress. May also noted that plans were made for further consultations with Simms about the silver band that was to be attached to the cast of the divided circle.[59] Despite this, the Astronomer Royal had to wait until the beginning of the next year to receive news about any progress. At that point, May reported on the visit from one of Simms's workmen who helped in the fitting of the silver band into the cast of the divided circle.[60] In March, Airy had the opportunity to visit May's workshop. In a letter sent after the visit, Airy declared May's part of

[59] May to Airy, 26 October 1849, RGO 6/722.
[60] May to Airy, 7 January 1850, RGO 6/723.

the job on the dividing circle finished. The engineer only had three outstanding responsibilities. The first one was to accommodate the visit of Simms and his workmen in order to engrave the initial figures on the cast circles. Second, to set up the circles on the east-west axis of the instrument for examination by Simms. May's final responsibility was to secure the safe shipment of the divided circle to the workshop of Simms, where he was going to make the final divisions on the circle with his dividing engine.

The interaction between Airy and May demonstrated four important aspects of the history of the Transit Circle. First, expanding on the history of divided circles in general, it demonstrated the key role that engineering firms played in the casting of the circles. Their role was so important that May's initial failure led to delays to Simms beginning work on the instrument. May's suggestion to employ Joseph Whitworth for dividing the circle also expands on the history of circle division by demonstrating that it was not exclusively opticians and specialist instrument makers engaged in improving dividing engines, but instead, there was a considerable effort made by engineers too. However, their definition of accuracy was different from the one used by astronomers and scientific instrument makers, which led to astronomers like Airy raising doubts about the quality of the work that they could provide. Third, since the divided circle relied on the contribution from engineers like Ransome & May, the final form of the Transit Circle embodied the networks of both engineers and scientific instrument makers. By doing so, the instrument was a prime example of mechanisation of the Observatory and the transformation of astronomical labour and instrument under Airy's directorship. Finally, the story demonstrates that progress on the construction of the divided circle relied on the progress made to other parts of the instrument. As a result, it highlighted the Transit Circle as an assemblage of multiple instruments and parts that were interdependent on each other's proper working order.

8. Simms and his work on the divided circle

While Ransome & May were focusing on the issues related to the casting of the circular support of the divided circle, William Simms devoted his attention to the problem of dividing the scale. The major technical issues that the Simms faced originated from the large size of the circle. As Chapman pointed out, the instrument makers specialising in graduation of circles carried out most of their works on small instruments. By contrast, this was a 6-foot circle that superseded the size of the previous ones that Simms had divided in the past. In light of this, it was not surprising that Airy expressed his doubts to Simms about his dividing engine having the ability to carry out the task as required. Instead, based on May's recommendation, Airy suggested that Simms delegate the task to Whitworth, who was described to be in the possession of an instrument capable of dividing a large circle. However, since neither Airy nor Simms had interacted with Whitworth before, the Astronomer Royal asked Simms what method they should use in order to check the accuracy of Whitworth's dividing engine.[61] Simms accepted Airy's suggestions, and recommended testing Whitworth's engine on a sample circle. At the same time, Simms wrote about his willingness to divide the circle in case the sample from Whitworth turned out to be unacceptable.[62]

These letters exchanged between Airy and Simms highlighted a different role in which Simms contributed to the construction of the Transit Circle. He was not only the maker of an instrument, but also one of Airy's reliable consultants on the project. His advice on the test highlighted that he was willing to provide information on how Airy should approach other instrument makers (and possible competitors) related to the project. However, whether this was simply due to his

[61] Airy to Simms, 8 March 1848, RGO 6/721: 832
[62] Simms to Airy, 9 March 1848, RGO 6/721:833

good will or due to Simms not perceiving Whitworth as a competitor to this business remains unclear from the correspondence.

Discussions about Whitworth came to an abrupt end in the Airy-Simms correspondence too. Instead, the letters began focusing on reworking the design of the wheel carrying the divided circle. While the original plans included divisions only on the side of the wheel facing the pier, Airy expressed his interest in inserting a ‘setting circle’ with rough graduations on the other side of the wheel too.[63] This setting circle was used in conjunction with a pointer microscope and two setting pointers with which the divisions could be read off with more ease than those of the graduated circle. Such an arrangement allowed the observer to point the telescope at the required angle more quickly.

The design of the setting circle faced further modifications during the later stages of the construction process. Once Airy received tracings of the graduated and setting circles from May, he noticed that there were mistakes in the original design with respect to their positions.[64] As a result, he notified both instrument makers about what alterations were required for the setting circle. However, it was only May who received instructions and specifications on how to execute the design of the setting circle.[65] This demonstrated the prime significance that casting the circle played, and the important role of Ransome & May played in the making of the divided circle. After Airy’s instructions were sent to May, the designs and the plans of the graduated and setting circles were considered temporarily finished.

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[63] Airy to Simms, 9 October 1848, RGO 6/721: 897. This arrangement was modified for the Cape Transit Circle, where the setting circle was part of the circle on the other side of the telescope tube p. v. (Reports from 1866-1870 of the Cape Observatory)

[64] As mentioned previously, this was due to May believing that the frame of the divided circle was going to move together with the telescope tube, as in Ramsden’s Palermo Circle or with the Harvard Transit Circle.

[65] Airy to Simms, 4 November 1848, RGO 6/721:909; Airy to May, 30 October 1848, RGO 6/721.

Further production on the graduated and setting circles did not continue until more than a year later. The next technical issue that the project faced arose from the method employed in dividing the circle. Airy agreed with May's idea of engraving the figures on the setting circle by hand due to being less time consuming than mechanical engraving.[66] Even though Simms's response did not survive, from later correspondence we learn that he accepted Airy's and May's suggestion. In the same letters Airy showed further concern about how the divisions were going to be represented: either with dots or with dashes.[67] With these issues clarified, the engraving signalled the end for the discussion on the setting circles, and its position was finalised when added to the wheel in August 1850.

While the correspondence between Airy and Simms did not refer to the progress of the divided circle until May 1850, the updates received on the progress of the work from Charles May demonstrated the continuous engagement of Simms and his workmen on the project.[68] Once the cast of the divided circle was finished, it was sent to Simms for graduation.[69] Surprisingly, Simms only managed to start the actual engraving on his engine a month later.[70] Luckily, work was delayed in Ipswich too, which did not cause Simms any trouble.[71] However, by the middle of July, Airy hurried the division of the circle by telling Simms that he wanted to see it personally, once it was deemed to be close to completion.[72] Similarly to the setting circle, the question of how the divisions were going to be represented re-emerged in the letters. Airy confirmed that using numbers to show the degrees were essential and asked Simms to represent

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[66] Airy to May, 11 March 1850, RGO 6/723; Airy to Simms, 13 March 1850, RGO 6/723: 740.
[67] Simms to Airy, 9 April 1850, RGO 6/723: 745 & 3 August 1850 RGO 6/723: 775; Airy to Simms, 8 August 1850 RGO 6/723: 778.
[68] See for example, Airy to May, 7 July 1848, RGO 6/721; May to Airy, 18 October 1848, RGO 6/721; May to Airy, 26 October 1849, RGO 6/722.
[69] Airy to Simms, 17 [or 19?] May 1850, RGO 6/723: 756.
[70] Simms to Airy, 21 June 1850, RGO 6/723: 762.
[71] Airy to Simms, 1 July 1850, RGO 6/723: 763.
[72] Airy to Simms, 13 July 1850, RGO 6/723: 767.

the variations in degrees with a variations in symbols (single dots, double dots, and long 'shakes').[73] Unfortunately, William Simms at the same time fell ill, which prompted him to leave his workshop.[74] Despite assigning the work to his nephew, work on the divided circle was temporarily halted. It meant that Airy had to wait until September to see the finished product. By the middle of September, all parts of the Transit Circle were delivered to the Observatory except for the divided circle. Such a delay caused the halting of the installation of the Transit Circle and, for the first time throughout the construction process, Airy showed his anger by demanding its immediate transportation to the site.[75] Knowing to give in to the demands of the Astronomer Royal, Simms sent the divided circle to the Observatory the next day, with which its construction process was deemed finished.[76]

The Airy-Simms letters relating to the divided circle showcase important theoretical points relating to the history of the Transit Circle and its divided circle. First, it demonstrates once again that the Transit Circle was thought of as an assemblage of instruments and its parts, where a delay or mistake on one part of the assemblage could halt the entire construction process. Second, this was reflective of how Airy had to interact with the instrument makers. He had to make sure that the two instrument makers were aware of the progress of the work made by both instrument makers, since a misunderstanding by one instrument maker (as in the case of the position of the circles) affected the progress of the other instrument maker too. Third, thinking about the instrument (and the project) as an assemblage provides an understanding of why Airy was eager to be involved in every miniscule detail of the constructions. It was not only because he was one of the designers of the instrument, but also because the construction of a complex

[73] Airy to Simms, 8 August 1850, RGO 6/723: 778.
[74] Simms to Airy, 13 August 1850, RGO 6/723: 779.
[75] Airy to Simms, 21 September 1850, RGO 6/723: 786.
[76] Airy to Simms, 22 September 1850, RGO 6/723: 788.

precision instrument like the Transit Circle required that much attention in order to function according to the expectations of a national observatory like that at Greenwich. Fourth, with the involvement of both William Simms and Ransomes & May in the construction of the divided circle, it emerged as a hybrid part of the instrument that was produced with contribution by scientific instrument makers and engineers of agricultural machinery at the same time. Thereby, an analysis of its construction questions whether the categorisation of the parts of the instrument reflects the instrument makers involved in their production. Furthermore, it demonstrates how the Transit Circle embodied the work of both engineers and astronomical instrument makers, reflecting in the materiality of the instrument Airy's transformation of the Observatory into a site that brought together such new networks from nineteenth-century British science and technology. Finally, the presence of Whitworth as an alternative first choice to Simms demonstrated that similarly to the story of the object glass, while Airy maintained a preference towards employing Simms, he was not always the first candidate that Airy had in mind, nor the one that could provide the most reliable services.

9. 'Pivots, pivots, pivots'

The story of the Transit Circle's divided circle brought forth the work of engineers within the broader history of the divided circle, and described it as a hybrid graduated part of the Transit Circle. This next section begins from a reversed position. It examines whether there are also hybrid parts of the assemblage that have previously been considered mechanical. To do so, it will investigate the history of the pivots of the Transit Circle. Their history will serve as a useful example to bring forth how the specialist knowledge of astronomers and engineers were applied to their construction.

The pivots were crucial parts of transit instruments and transit circles, as they allowed for the smooth rotation of the telescope. Any small changes that occurred on the cylindrical form of the pivots resulted in errors in the measurements of distant objects. Most commonly this was the result of either the form of the pivots not being cylindrical, or the surface of the pivots not wearing over time in a uniform manner. Such problems could cause what were labelled as the level and azimuth error of the instrument. In the case of the Transit Circle, Airy implemented solutions into the design of the instrument in order to minimise the friction on the pivots.[77] This helped in reducing their gradual wear. The major challenge that Airy faced in its implementation arose from the large sizes and weight of the telescope tube, the setting circle, and the divided circle. Due to friction, they would have caused the pivots to wear away more quickly than the pivots of smaller transit circles. Airy's solution was to introduce counterweights that relieved the pivots from resting their entire weight on the bearings, thereby further reducing friction. Due to the constant wear of the surface of the pivots, another design consideration was the material out of which they were made. As discussed previously, various parts of the Transit Circle were made with chilled iron technique, since it granted lighter weight and more uniform wear to the material. Following these expectations, Airy decided to make the pivots of the Transit Circle using this technique.

It was not only the material that posed a challenge to making pivots. The skills and the techniques that their production relied upon also placed limitations on the final quality of the parts. This was due to the impossibility of creating a perfectly cylindrical surface. It was

[77] Airy, *Description of the Transit Circle*, (1854), p.8

precisely this obstacle that Herschel, called attention to in his *Outlines of Astronomy*, and labelled it as one of the main errors of workmanship from which scientific instruments would never be free. Highlighting how widespread and generally accepted this error was, he argued that this was one of the 'practical annoyances, which every observer [had to] contend with.'[78] Another astronomer, Elias Loomis, similarly highlighted this error as the basis for understanding the maintenance and use of astronomical instruments. In his *An Introduction to Practical Astronomy*, he described several methods with which errors of forms of the pivots could be detected with a spirit level.[79] In addition, he described how the measured errors could be fixed through calculations. Airy was very aware of the problem with pivots and transit instruments. His first published engagement with the issue can be traced back to his years as the director of the Cambridge Observatory. In the introduction to the first *Cambridge Observations* he reflected upon the difficulty with which circularity of the pivots could be examined. While he agreed with the statement that the perfect cylindrical form was impossible to achieve, he praised the accuracy attained by instrument makers. In fact, he stated that the 'process by which [the pivots] are shaped is probably the most perfect in the mechanical art.'[80] However, Airy was less lenient with the judging of the diameters of the pivots, which he examined with greater care.

[78] Herschel, *Outlines of Astronomy*, p. 79.
[79] Elias Loomis, *An Introduction to Practical Astronomy* (New York: Harper & Brothers Publishers, 1855), pp. 74-75.
[80] George Biddell Airy, *Cambridge Observations*, (Cambridge: J. Smith, 1829), p. 30.

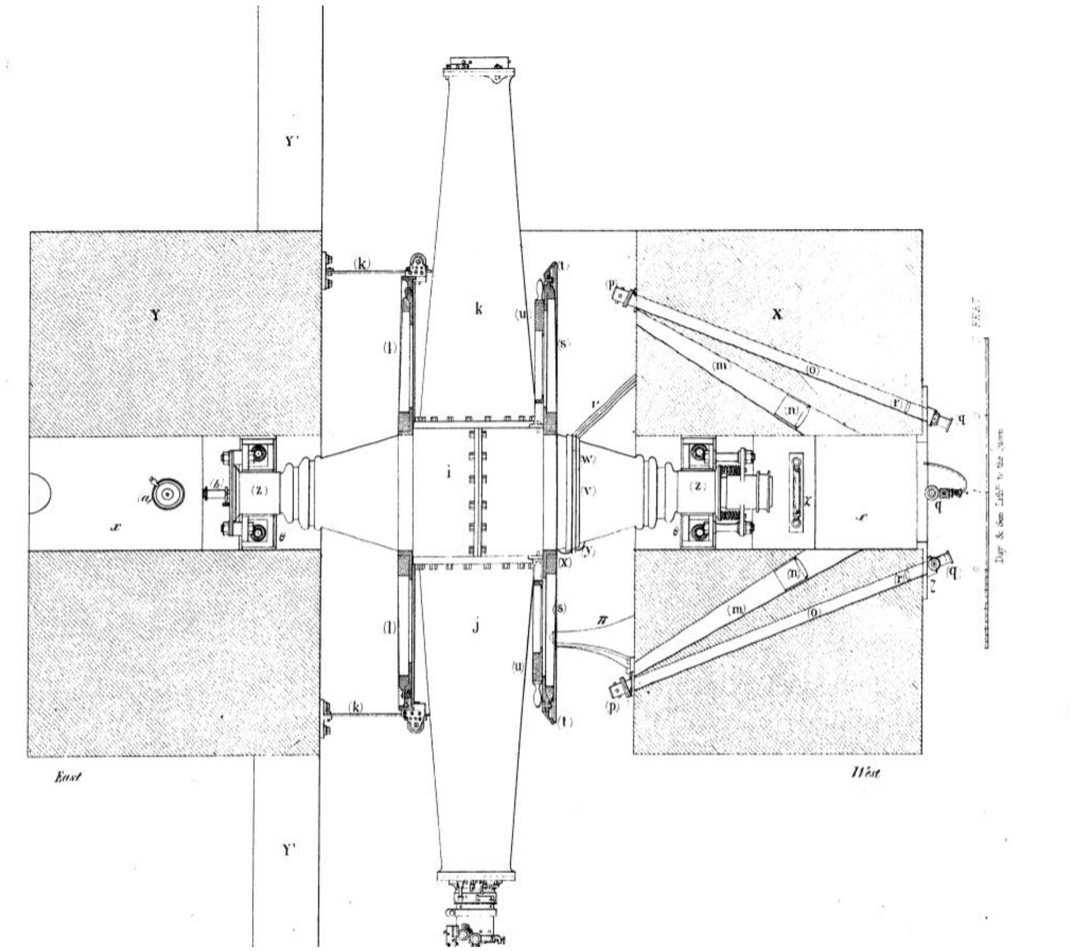

Fig. 21. Plate 11 from the official description of the Transit Circle showing the pivots and their bearings from the top

With such attention given to the possible errors of the pivots, Airy was keen to visit the Ransome & May workshop when the pivots were being made.[81] However, it was not until the pivots were deemed finished by May that more detailed discussions began on their forms. It began with a letter from May in which he asked for instructions from Airy on how to measure the roundness of the pivots.[82] Airy's detailed answer included a sketch of a contrivance that could measure the

[81] Airy to May, 18 October 1849, RGO 6/722.
[82] May to Airy, 3 December 1849, RGO 6/722.

variations of form and surface of pivots (figure 22).[83] Equipped with such a tool, May reported on the completion of the pivots, and for preparing them for a close examination of their cylindrical forms.

'Pivots, pivots, pivots' – began the next letter of Charles May highlighting the attention paid to them, as well as the annoyance that they have caused to the engineer. The letter described how the first examination of their forms was carried out by Simms, and that the spirit level indicated a degree of ellipticity 1/7000 of an inch in one and double that amount in the other pivot. This was to be reduced further through a method proposed by Simms to May.[84] Further improvements were made to the pivots, and two months later they underwent another examination by Simms and his nephew. May reported that the ellipticity was reduced by ¾, but one of the employees (George Arthur Biddell, the cousin of George Airy) was still working to reduce the error further. In addition, May remarked that attaining perfection was 'out of the question, but [it was going to take] a good observer to find the effect upon the observations of the error left in the pivots.'[85] The next summary of the work was sent to Airy by Arthur Biddell himself. He reported that the pivots underwent only minor structural changes since the last time, mostly due to the lathe being used for its production being in high demand by others.[86] The final modifications to the forms of the pivots were made in June 1850. May reported to Airy that the pivots were 'so close an approach to perfection as to render it right to consider them finished.'[87]

[83] As seen on Fig. 22. Airy to May, 4 December 1849, RGO 6/722.
[84] May to Airy, 12 March 1850
[85] May to Airy, 16 May 1850
[86] George Arthur Biddell to Airy, 30 May 1850
[87] May to Airy, 20 June 1850

Fig. 22. Sketch made by Airy showing the instrument to check the ellipticity of the pivots (Airy to May, 4 December 1849, RGO 6/722)

The correspondence between Airy and May about the pivots repeatedly emphasised the issue of perfection regarding the pivots. May first relied on the delicate measuring instruments of Simms to detect the errors, then argued that the errors were reduced so much that they were almost undetectable. Like the accuracy of the graduation of the divided circle, the pivot also raised the question of what could be considered accurate or perfect. May's remarks highlighted an approach that emphasised the practicality of precision (e.g. the difficulty to detect errors or and the pivots being 'close to perfection'), which was reflective of the concept of accuracy shared by Joseph Whitworth, engineers, and other supporters of the end measurement method. However, Airy's approach was different. While he was also aiming to achieve the perfectly cylindrical form of the pivots, he was more interested in knowing their degrees of ellipticity, so that they could be corrected through mathematical calculations once put into use. In this light, Airy's approach reflected that of John Herschel who argued that 'though we are entitled to look for *wonders* at the hands of scientific artists, we are not to expect *miracles*.'[88]

The installation of the Transit Circle at the Observatory brought up new issues related to the pivots. First, Airy asked Ransome & May to provide dust caps for the ends of the pivots. Now that we understand that significance of the precision expected from the pivots, the importance of

[88] Herschel, *Outlines of Astronomy*, p. 78.

such protective equipment is easier to imagine. As Airy found out to his surprise, the dust caps were not even included in the original plans. Similarly to Simms's delay with the divided circle, Airy expressed his anger and disappointment in the instrument makers for the first time. In addition, he scolded May in particular for not including them in the original plans: '[you knew] the want of these [protective caps] better than any body else…'[89] The other source of Airy's anger was revealed at the end of the letter where he noted that even if 'the caps [are] made, it is not possible to introduce them into their places without taking down more of the machinery than I dare to meddle with.'[90] This remark revealed that despite Airy possessing a good understanding of mechanical arts, he still relied on the expertise, skills, and tools of engineers and instrument makers. In fact, it highlighted the problem in the core of the hierarchy between instrument makers and astronomers that were advocated and acted out by individuals such as Airy and Herschel: no matter how much mathematics allowed for correcting the errors of the instruments, they were still reliant on the work of instrument makers in the first place. In this light, Airy's regulations in relation to the use of instruments at the Observatory ('never meddle with any galvanic apparatus except you most thoroughly understand it and have a definitive motive for meddling with it'[91]) are given another meaning. It is not only related to preserving the working order of instruments, but also to avoid bringing forth the reliance of the Observatory on the work of the instrument makers.

Once the installation of the Transit Circle was finished, Airy and the Observatory staff began the determinations of the errors of the instrument. This was in accordance with the belief that no perfect instrument exists and that by knowing and accounting for the errors of the instrument, the

[89] Airy to May, 10 October 1850
[90] Ibid.
[91] Notes to members of staff by Airy, RGO 6/38 29, 35.

staff will be able to eliminate them during the calculations (or 'reductions' of observations). They found discrepancy in the errors, whereby at one side of the pivots the errors were larger than on the other side.[92] This signalled to Airy that the pivots were either not straight, or that the Y bearings upon which they rested were faulty. When the graduations of the divided circle were about to undergo similar detection of errors, the staff found that the circles were not turning. On raising the instrument, they found that oil had run away from the bearing and that the pivot was only bearing in its middle. Airy's assumption was that such an issue caused the previously measured discrepancy, and asked May for suggestions. Similarly to the previous letter about the pivots, Airy expressed his dissatisfaction, by wishing that May had examined the same problem.[93]

May was somewhat surprised about the problem, and he emphasised that both bearings were fitted with equal accuracy as far as he could judge. He raised the possibility of bending occurring when they were screwed down into holes in the pier, or due to oxidation. However, upon replicating the described situation in his workshop, May found that the oil used allowed for the contact to be too tight between the bearing and the pivot, which resulted in the lubricant being squeezed out (or 'running away' as Airy observed). However, besides the description of this experiment, May decided not to derive any definite conclusions, and instead send Arthur George Biddell to examine the bearings.[94] After the visit, Airy reported that Biddell found the pivots and their bearings in perfectly good order. As a possible solution, and continuing on with May's identification of the oil as a cause of the issue, he suggested using sperm whale oil instead of olive oil. However, still maintaining the possibility of rust being present, Airy described his

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[92] Airy to May, 19 December 1850
[93] Ibid.
[94] May to Airy, 20 December 1850, RGO 6/723.

hypothesis about rust falling into the bearings before the arrival of the caps protecting the instrument from the dust.[95]

The history of the pivots highlights several key aspects of the construction of the Transit Circle. First, similarly to the divided and setting circles, it shows that the construction process relied on the other parts of the assemblage to be ready, thereby demonstrating the interdependent nature of the various parts of the Transit Circle. In addition, the question of the accuracy of the pivots showed that such an interdependence of parts continued after the construction had finished, and determined the working performance of the instrument. Second, the accuracy brought forth how the competing definitions of accuracy were resolved during construction process. Despite the fact that Ransome & May relied on a practical definition of accuracy to make the pivots as cylindrical as possible, Airy knew that his task was going to be to check the error of the pivots again and again once it was installed. This meant that while Airy expected the engineers to make the pivots as cylindrical as possible, he was not expecting 'miracles' from them. Third, the discussions on accuracy also demonstrated the close engagement between scientific instrument makers, engineers, and astronomers. Airy offered a description and a sketch of an easy-to-build contrivance with which the engineers could measure the ellipticity of the pivots. Furthermore, Simms offered his help in both examining the pivots and providing instructions on how to make them even more cylindrical. In this light, the pivots were just as much a hybrid part of the Transit Circle that embodied the contributions of scientific instrument makers, astronomers, and engineers, the same way as the divided circle did. Finally, the story of the pivots also highlighted the extent to which Airy relied on the skill, expertise, and tools of the engineers. When he

[95] Airy to May, 23 December 1850, and May to Airy, 25 December 1850, RGO 6/723.

realised that the dust caps were not made for the pivots, his worry that the instrument had to be taken apart again led him to express his anger and disappointment in Ransome & May.

10. The assemblage approach to astronomical instruments and their limitations

The focus in the previous two chapters on the history of the various parts of the Transit Circle demonstrated that the parts had their own individual histories that entangled with each other in the assemblage of the larger instrument. Writing a detailed history of every part of an instrument as complex as the Transit Circle is an undertaking that is beyond the scope and the limits of this dissertation. In addition, even in the case of less complex instruments that are made up of a few parts, the approach would still allow for its breakdown to a seemingly unlimited number of parts. To take a famous example, in the case of Galileo's telescope, the internal assemblage of the object incorporates into the first level of analysis the lenses, the tube, the leather used, and the separate housings at the two ends of the telescope.[96] At the second level, the analysis is expanded internally, which investigates the physical composition of the glass,[97] the origin the leather, and the design of the gold tooling used on the telescope – each revealing another member of the larger network that contributed to the materialisation of the final product. At the same level of analysis, the assemblage can be expanded externally too. It examines the history of the various accessories that Galileo devised to be used in conjunction with the instrument (e.g. micrometer and helioscope). Moving away from operation to presentation adds another dimension to the same level of analysis. It examines the ivory frame holding the

[96] Massimo Bucciantini, Michele Camerota,and Franco Giudice, *Galileo's Telescope* (Cambridge, MA & London, England: Harvard University Press, 2015)
[97] Giorgio Strano, 'Galileo's telescope: history, scientific analysis, and replicated observations', *Experimental Astronomy*, 25, (2009), 17-31.

Galileo's telescopes and lens.[98] The third level of analysis, building upon the expansion of the original "simple" assemblage, approaches the telescope as an instrument interacting with various other objects and entities. For instance, it incorporates the light conditions provided by the space where the telescope was used, or the effects of the movements of the observer during its operation.[99] By following the interactions between the various entities, the assemblage is expanded beyond what seems like a reasonable scope. However, as it was emphasised throughout this chapter, the importance of the approach is not on how extensive the final assemblage can be, but rather on demonstrating the interdependence of the various parts of the assemblage, which brings forth the importance of their connections to each other.

So what does this mean in relation to the history of the Transit Circle? The entanglement of the different parts of its assemblage means that the every part of its assemblage is reduced to an equal level of significance for analysis. At the same time, it questions the preference given in analysis to one part of the instrument over another. For instance, despite the object glass being the main concern of Airy and the Board of Visitors, the engineers argued that construction on other parts of the assemblage could begin prior to purchasing it. The delays on the construction on the divided circle or the dust caps meant that the Transit Circle's installation took longer. These delays once again showed the interdependence of the parts: the assemblage as a whole could not begin work until every part was at its place. By focusing on such themes, Chapters 1 and 2 approached scientific instruments not as objects made up of isolated entities, but as

[98] It is worth noting here that the ivory frame was a later addition to the telescope. Thereby, approaching instruments through assemblages also highlights the various historical relations between their multiple internal and external parts.
[99] For a discussion on the importance on the tacit knowledge involved in operating the telescope, see Mario Biagioli, *Galileo's instruments of credit: Telescopes, images, secrecy* (Chicago and London: The University of Chicago Press, 2006).

assemblages of objects where their operation relied on the harmony or the discord between the various parts.[100]

11. Conclusion

This chapter examined the construction of the non-optical parts of the Transit Circle. It extended the analysis of the object glass in Chapter 1 by demonstrating that the construction of other parts of the Transit Circle similarly underwent negotiations (as well as alternative possibilities). If Chapter 1 highlighted Airy's relation with opticians, Chapter 2 devoted itself to highlight Airy's relations with engineers. While previous studies have mostly focused on Airy's relation with clock makers, opticians, and scientific instrument makers, this chapter expanded the field by focusing on his interactions with engineers. Furthermore, it highlighted his knowledge of engineering through constantly advising both William Simms and Charles May throughout the construction of the Transit Circle. This chapter also examined the interactions of Airy with Charles May. Since May's life and career have not yet been examined in any historical work, this chapter made preliminary research for further studies on his life. In addition, it expanded the wide network of engineers within which Airy's observatory was connected to, and demonstrated how such networks were embodied within the materiality of the Transit Circle through decisions made during its construction. By comparing Airy's interactions with May and Simms, the chapter also demonstrated that Airy employed different ways of engaging with different instrument makers. While Airy's engagements with Simms and clock makers have previously served the purpose of highlighting his formal interactions with negotiations, his letters

[100] Although it is worth keeping in mind that as in the case of the accuracy of divisions, different people would perceive the operations differently.

exchanged with Charles May showed that he also engaged in informal discussions with them. As a result, his formal interactions do not reflect a complete picture of his personality, but rather, simply highlight how Airy carried out formal negotiations and even played around with such formalities.

The history of the divided circle, similarly to the object glass, demonstrated alternative engineers who were considered for the construction of the Transit Circle. May's suggestion to employ Joseph Whitworth also expands on the current scholarship of the history of the divided circles. While previously the focus has only been on astronomical instrument makers, the studies on the development of divided circles are now extended to works of engineers too. By doing so, the chapter also demonstrated the overlaps between the roles of engineers and astronomical instrument makers. The possible employment of Joseph Whitworth brought forth the different definitions employed by astronomers and engineers in attaining accuracy. Such discussions between Airy, May, and Simms foreshadowed the major debates regarding the production of standards and the competing measurement techniques (end measurement and line measurement) during the second half of the nineteenth century.

The history of the construction of the pivots continued its focus on the collaboration between astronomers, instrument makers, and engineers. However, rather than exploring the network once again, it focused on how the examination of the accuracy of the pivots highlighted the imposed hierarchy between the tasks of the astronomers and the instrument makers. Airy did not expect miracles from May and Simms. Instead, he accounted for the errors of the pivots sot that he could incorporate the figures into the reductions of the observations. However, this did not mean that Airy was no longer reliant on the work of the instrument makers. As it was demonstrated through the missing dust caps, he still relied on the skills, tools, and expertise of engineers and instrument makers for the production of new parts for the Transit Circle. Airy's anger and disappointment expressed in his letters, revealed this fundamental part of the astronomer-instrument maker relations that the imposed hierarchy and the mathematical calculations took for granted. In brief, this reliance on the engineers posed a threat to Airy's oversight of the Transit Circle, since only the engineers were able to modify its materiality.

Chapters 1 and 2 examined the construction process of what can be considered the internal parts of the assemblage of the Transit Circle. It did so with the aim of demonstrating how the histories of these different parts were both isolated and interdependent at the same time: the size of the object glass determined the size of the other parts of the instrument, but any delays from the construction of the divided circle or the pivot affected when the instrument was finally put into operation. The internal components of the Transit Circle were not the only parts of the larger assemblage. As we will see in Chapters 3 and 4, the assemblage was ultimately expanded to incorporate the subsidiary instruments, the walls of the Transit Circle Room, and even instruments from other buildings of the Observatory. By doing so, the following chapters will expand even further on the interdependent nature of the multiple parts of the Transit Circle. However, rather than demonstrating it through the construction project, the chapters will demonstrate it through how the good performance and the working order of the instrument was maintained and achieved

Chapter 3 : Maintenance and repair practices interacting with the materiality of the Transit Circle

1. Introduction

Simon Newcomb was one of the major American astronomers of the nineteenth century. Similarly to his other American colleagues, he made several trips to Europe in order to gain a better understanding of the European astronomical practices. During his first trip in 1870, he spent some time visiting the Royal Observatory at Greenwich when it was under Airy's directorship. His description of the Observatory in his *Reminiscences* included an interesting passage about the Airy Transit Circle:

> Before [Airy's] time the trained astronomer worked with instruments of very delicate construction, so that skill in handling them was one of the requisites of an observer. [By contrast,] Airy made them in the likeness of heavy machinery, which could suffer no injury from blow of the head of a careless observer. Strong and simple, they rarely got out of order. It is said that an assistant who showed a visiting astronomer the transit circle sometimes hit it a good slap to show how solid it was.[1]

Within this passage, Newcomb was able to capture the Transit Circle as part of Airy's factory-like Observatory: a 'heavy machinery' that stood in direct contrast to the 'delicate construction' of previous astronomical instruments; the 'machine' was almost immune to any damage by 'careless observers'; and it combined simplicity with reliability. The passage also captured the

[1] Newcomb, *Reminiscences*, pp. 288-289.

Transit Circle as a sturdy instrument that was inviting to the touch (or 'slap') of any individual. And most importantly, it hardly ever broke down. The beauty of Newcomb's writing rested in his ability to evoke the central character of the instrument, which was not only 'scientific' but also 'industrial'. As we have seen in previous chapters, the combination of these two aspects brought together the networks of industry and science of nineteenth-century England.

But did such a reflection also capture the day-to-day struggles of the Observatory staff and Airy in relation to the Transit Circle? An internal note from Airy to Hugh Breen (superintendent of the computers) provides us with a different image: 'Explain to every one of the Computers that no one is to touch the Transit Circle or other instrument except in the presence of the Observer who is charged with the observations.'[2] Similarly, Airy asked his First Assistant and later Chief Assistant (Robert Main from 1835 to 1860, Edward Stone from 1860 to 1870, and William Christie from 1870 to 1881) to provide a *Report on the State of the Instruments* every month. The need for small adjustments and repairs of the Transit Circle were constant features of these reports.

In these internal documents, Newcomb's image of the Transit Circle completely vanishes: the implied unrestricted touch of heavy machinery was replaced with restrictions imposed on people not associated with its direct use. The sturdiness that resisted the 'carelessness' of observers was substituted with regular surveillance driven by an anxiety that the instrument could easily get out of order. Within such a framework, Newcomb's original statement on the slap of the machine can be reinterpreted as an act symbolising not the heavy machinery, but rather the assistant's close connection with the instrument through acts of both care and surveillance.

[2] Airy to Breen, 28 April 1854 RGO 6/38 178.

The following chapter investigates such a discrepancy between the internal correspondences of the Observatory and the external (as well as official) accounts of the Transit Circle. By doing so, the chapter demonstrates a different side of the instrument's history: one that is characterised by regular breakdowns, improvisations, and strong reliance on the maintainers of the instrument.

2. What is maintenance?

With the turn towards processes within history, politics, and sociology of science and technology, maintenance appeared as a prominent feature of how science was practiced, and how the instruments were used. When Latour looked for a way to examine 'science in action', he recalled 'the maintenance man of Data General [who stopped] by every week to fix up some minor problems'.[3] Through the example of Kodak photo cameras he demonstrated how the push of a button can hide the networks of individuals (including the maintainers) that will later be required for developing the image.[4] As Steven Shapin wrote two years later, these people formed part of the 'hidden technicians' of science and technology.[5] Continuing with ethnography of scientific work, Sharon Traweek described how the 'full-time' maintainers of equipment for high-energy physics were destined to the peripheries of research groups, while at the same time the physicists themselves carried out occasional maintenance of the instruments.[6] Maintenance and repair work remained a key feature of analysis within studies of organisation.[7] Since the

[3] Bruno Latour, *Science in Action* (Cambridge, MA: Harvard University Press, 1987 (2003)) p. 2.
[4] Ibid. p. 137.
[5] Steven Shapin, *The Invisible Technician*.
[6] Sharon Traweek, *Beamtimes and lifetimes* (London, England and Cambridge, MA: Harvard University Press,, 1992), pp. 85, 92 & 138.
[7] See Christopher R. Henke, 'The Mechanics of Workplace Order: Toward a Sociology of Repair', *Berkeley Journal of Sociology*, 44 (1999), 55-81; and Stephen Graham and Nigel Thrift, 'Out of Order: Understanding Repair and Maintenance', *Theory, Culture & Society*, 24:3 (2007), 1-25.

early 2010s, with the emergence of the concept of obsolescence, with new interest in infrastructure studies, the support of repair by DIY and maker movements, and formations of research groups such as The Maintainers, the themes of maintenance and repair have been enjoying a rise in popularity.[8]

Despite such themes being present, a general history of maintenance is yet to be written.[9] The most comprehensive summary of a history of maintenance has been written by David Edgerton, but he focused more extensively in the 20th century aspects of the practice.[10] However, the case studies and articles that embraced the theme of maintenance have focused on maintenance and repair practices within history of science and technology at other time periods. Simon Schaffer approached the problem through analysing how the breakdown of instruments both altered and maintained the relationship between instrument makers and their clients. His article on the instruments for the observatory at Bombay examined the extent to which maintenance and repair of instruments were considered part of the skill-set of astronomers.[11] Other works emphasise most prominently the role of instruments in transition from one place to another, as opposed to the role of local observatory staff.[12] For instance, McAleer highlighted how the cases within which the instruments were transported had to be given special attention throughout shipping. When maintenance practices at local level are mentioned, then the focus tends to remain on the

[8] In recent years, *The Maintainers* research group was established which attempts to bring together researchers in the field, and popularise the concept as a criticism of approaching technology through "innovations". For an overview of the wide variety of research topics covered by the group see the conference papers published online at themaintainers.org, or Denis, Mongili, and Pontille, *Maintenance and & Repair in Science and Technology Studies*, pp. 5-15.

[9] For a history of maintenance and repair of scientific instruments in the nineteenth century, see Schaffer, *Easily Cracked*. Maintenance practices are also a focus of research within the fields of Sociology of Science. For an example see Cyrus C.M. Mody, 'A Little Dirt Never Hurt Anyone: Knowledge and Contamination in Materials Science', *Social Studies of Science*, 33:1 (2001), 7-36.

[10] Edgerton, *The Shock of the Old*.

[11] Simon Schaffer, *The Bombay Case*, pp. 172-173

[12] Ivano Dal Prete, 'Brokering Instruments in Napoleon's Europe: The Italian Journeys of Franz Xaver von Zach (1807-1814)', *Annals of Science*, 71:1 (2014), 82-101 (pp. 85-86); for discussion on the repair and maintenance of scientific instruments 'on the move' see: McAleer, *Stargazers at the world's end*; Baker, *Precision*, pp. 14-29.

astronomers as opposed to on the local staff. A notable exception to this was Joydeep Sen's study of *Astronomy in India*, which described in great detail the significant role of Mir Mohsin, the personal instrument maker and maintainer to the expedition of George Everest.[13]

When the practice of maintenance is discussed in the scholarship, the term tends not to be distinguished from repair.[14] While similarities do exist between the two concepts, conflating the two terms overlooks the crucial differences. Most importantly, maintenance takes place while an instrument is still in working order. By contrast, repair refers to the restoration to a working order, implying that the instrument is broken. Such breakdowns and repairs are often recorded as they disrupt the working order. As a result, they are easier to notice or identify. For example, the 'astronomers at war' episode within nineteenth-century astronomical community broke out because of an instrument was deemed faulty. By contrast, acts of maintenance remain almost invisible in historical records. Since maintenance takes place while the instrument is still working, it tends to generate less of a shock in the workflow. However, maintenance (and its absence) only becomes noticed, when its absence *leads* to a breakdown after the gradual accumulation of problems. According to David Gill, the first copy of the Transit Circle (made for the Royal Observatory at the Cape of Good Hope) fell into exactly this problem due to years of neglect.[15] This example illustrates the usefulness of investigating the Transit Circle at the Royal Observatory, Greenwich: it was not only under constant maintenance, but the practices themselves kept the instrument in an excellent state of repair that contributed to the survival of its working order for more than a hundred years.

[13] Joydeep Sen, *Astronomy in India, 1784-1876* (London: Pickering & Chatto, 2014), pp. 85-89.
[14] For an example of this, see Simon Werrett, 'Recycling in early modern science', *British Journal for the History of Science*, 46:4 (2013), 627-646 (pp. 637-640).
[15] David Gill, *A History and Description of the Royal Observatory, Cape of Good Hope* (London: His Majesty's Stationery Office, 1913), p. xl.

Records of acts of maintenance are difficult to find, as they are most often embedded in the 'ordinary business' of organisations.[16] As a result, they have to be derived from manuscripts related to the creations and alterations of such regulations, or when maintenance was not carried out properly. The advantage of studying maintenance in connection to the Transit Circle lies in Airy's meticulous record-keeping habit, which led to the survival of the internal notes exchanged between Airy and the Observatory staff at every level of the organisation. These notes provide us with a glimpse into the role that the members of staff played in the maintenance and repair of instruments at the local level. The notes also paint a picture of how the different members of the observatory staff practiced maintenance, how they perceived the instrument, and the relationship between Airy and the members of the Observatory staff. Maintenance often continues in modified form even after the "working life" of an instrument. In the case of the Transit Circle, there also survives a set of instructions (mainly for purposes of conservation) written by one of the last of its users upon the transformation of the Observatory into a museum.

Chapter 3 will apply a traditional analysis of maintenance, by examining how the Transit Circle was maintained through modifying parts of the instrument and altering its materiality. Chapters 4 and 5 will go beyond the limited use of the term maintenance as a set of practices that directly interact with the materiality of the instrument. Chapter 4 will introduce the term calculative maintenance, which refers to the maintenance of the instrument through mathematical calculations as opposed to through modification of the materiality of the instrument. This conceptualisation of maintenance enlists practices that are carried out in relation to the instrument, but without the physical modification of its materiality. Following David Aubin, it considers mathematics as a tool with which astronomers and observatory staff tinkered with the

[16] 'Ordinary business' was the term used by Airy to describe the days when no special events took place. See *Astronomer Royal's Journal* RGO 6/24-27.

Transit Circle.[17] Going beyond physical alteration not only illuminates the role of a new network of individuals (the computers), but also highlights the hierarchy of knowledge imposed on the astronomer-artisan-relations by astronomers. Within this hierarchy, an astronomer was a (re-)maker of instruments too. Since no instrument was ever perfect, their task was to calculate the errors of the instrument on paper. Within this light, the Transit Circle will take up an existence in both physical form (standing inside the Observatory), and an 'ideal' immaterial form presented through the large scale and long series of calculations. Chapter 5 will consider the Transit Circle not only as a scientific instrument, but also an instrument that symbolised the reputation of the Observatory. The chapter will argue that the 'image' of the instrument communicated to different audiences was another ideal and immaterial form of the instrument. The construction of its 'image' and Airy's attempts to control how and what 'images' were communicated were directed at maintaining the reputation of the instrument.

3. Airy's physical maintenance of instruments at the Observatory

Analysing maintenance practices provides us with new insights into the extent to which factory mentality was introduced under Airy's directorship of the Observatory.[18] The division of astronomical mental labour and the specialisation of the assistants into the use of different instruments reflected the management techniques applied to the running of factories in industrial Britain. An analysis of maintenance practices expands upon such a scholarship, by demonstrating

[17] 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* (Cham, Switzerland: Springer, 2017), 177-196.
[18] Chapman, *Sir George Airy and the Concept of International Standards*, pp. 321-328; Schaffer, *Astronomers Mark Time*; Smith, *A National Observatory Transformed*.

Airy's role not as a despotic manager of a factory of numbers, but rather as a director who strived to keep a continuous eye on the work carried out at the Observatory.[19] While previous studies by Schaffer and Hoffman on the personal equation linked the factory mentality with the surveillance of individuals, they did not analyse in detail the surveillance of inanimate instruments.[20] This chapter fill this gap in the scholarship by analysing the surveillance regime under which the instrument was placed. Within such a framework, the Transit Circle was no longer seen as passive and inanimate, but rather as an entity that required to be put under surveillance precisely because of its active and animated nature.

Maintenance practices also shed light on the 'hidden technicians' of instrument making by demonstrating the role that the workmen of established instrument makers as well as the assistants and carpenters of the Observatory played in maintaining the Transit Circle.[21] While articles in the past have focused on the individual assistants of the Observatory, through the lens of maintenance we are able to highlight how the assistants and other members of the Observatory collaborated with each other.[22]

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[19] Airy's image as a dictatorial director has been slightly challenged in Chapman's later writings in which he provided a more personal account of the astronomer. See: Allan Chapman, 'Porters, watchmen, and the crime of William Sayers: the non-scientific staff of the Royal Observatory, Greenwich, in Victorian times', *Journal of Astronomical History and Heritage*, 6:1 (2003), 27-36. David Gill, Astronomer Royal at the Cape of Good Hope Observatory, also painted a humane and joyful image of Airy in his memoirs. For this, see: George Forbes, *David Gill: Man and Astronomer* (London, Albemarle Street: John Murray, 1916), p. 85.

[20] Schaffer, *Astronomers Mark Time*; Christoph Hoffmann, 'Constant differences: Friedrich Wilhelm Bessel, the concept of the observer in early nineteenth-century practical astronomy and the history of the personal equation', *The British Journal for the History of Science*, 40:3 (2007), 333-365.

[21] Their role seemed to have been the same as the "invisible technicians" described in Steven Shapin: present and essential at the time when scientific work was carried out, but left out from the majority of historical accounts. Shapin , *The Invisible Technician*.

[22] For a historical summary on the assistants under George Airy's directorship see: Allan Chapman, 'Airy's Greenwich Staff', *The Antiquarian Astronomer*, 6 (2012), pp. 4-18. For an introduction to the life of Edwin Dunkin, see: Dunkin, *A Far Off Vision*. For a discussion on the life of Edward Walter Maunder see: Anthony J. Kinder, 'Edward Walter Maunder FRAS (1851-1928): his life and times', Journal of the British Astronomical Association, 118:1 (2008), pp. 21-42.

Since maintenance focuses mostly on practices that took place within the grounds of the Observatory, it also questions the extent to which the instrument making process was gradually removed from the observatory sites during the 18th century.[23] As opposed to the removal of all the practices related to instrument making, this chapter highlights how maintenance as a form of instrument making partially remained bound with the functions of the site where the instrument was used. Focusing on maintenance also asks the question whether the making of instruments is ever completed. Or to put it differently: is an instrument completed once the instrument maker hands it over to the client? As the chapter shows, an instrument is always made and re-made. Therefore, the Transit Circle needs to be considered as an instrument that is in an ever-changing state, constantly becoming an instrument as opposed to being the same one throughout its life. This shift in approach requires us to consider the instrument differently at different parts of its lifetime, since through maintenance and repair the materiality of the instrument (and the assemblage, which it forms part of) is constantly modified.

4. The physical maintenance of the Transit Circle

Frequently checking an instrument for its errors was a general practice within nineteenth-century science. Schickore highlighted how microscopes were checked by men of science after they were purchased because of the bad experiences that they had with other microscopes.[24] Frederick Kurzer showed how people holding professorships in chemistry at the laboratory of the

[23] Herrmann, *The history of astronomy*, p. 158.
[24] Jutta Schickore, 'Ever-Present Impediments: Exploring Instruments and Methods of Microscopy', *Perspectives on Science*, 9:2 (2002), 126-146.

London Institution were responsible for the maintenance of the equipment present at the site.[25] Fleetwood demonstrated through topographical surveys of the Himalayas that the users of the instruments had to rely on themselves for the maintenance of the instruments while they were away from the centres for networks of science.[26] Ratcliffe's analysis of the British Transit of Venus expeditions similarly described that while some instruments were more trusted than others, before and after use their errors had to be measured and re-measured.[27] This recurring and painstaking work was highlighted in one of the journals of the observers at the Sandiwch Islands too, where the monotony of work was broken by infrequent earthquakes that offset the previous adjustments of the instrument.[28]

The Transit Circle was classified as a precision instrument and as such it required constant maintenance in order to manage its precision.[29] Its errors and precision had to be checked on an hourly basis while being in use. As a result, the Transit Circle serves as an excellent example for an analysis of maintenance practices. Brief descriptions of the instrument's maintenance can be found in Satterthwaite's thesis and article about the Transit Circle.[30] However, he focused most on the major repair works, such as the modification of the central cube and re-division of the divided circle. At the same time, his works relied almost exclusively on the official publications of the Observatory (especially on the *Annual Reports*, and on the description of the Transit Circle attached to the Greenwich Observations published in 1854 and in 1869).

[25] Frederick Kurzer, 'Chemistry and Chemists at the London Institution 1807-1912', *Annals of Science*, 58:2 (2001), 163-201.
[26] Lachlan Fleetwood, '"No former travelers having attained such a height on the Earth's surface": Instruments, inscriptions, and bodies in the Himalaya, 1800-1830', *History of Science*, 56:1 (2018), 3-34.
[27] Ratcliffe, *The Transit of Venus Enterprise in Victorian Britain*, p. 101
[28] Honolulu Station Journal, RGO 59/70, p. 81.
[29] For more on the care and maintenance demanded within precision engineering see Evans, *Precision engineering*.
[30] Satterthwaite, *The History of the Airy Transit Circle*; Satterthwaite, *Airy's transit circle.*

Relying on the official publications of the Observatory has one major advantage. Since Airy meticulously recorded the major changes made to the instrument in them, such an approach is useful in providing a detailed outline of the instrument's history. However, since these reports were written by Airy himself, he was able to exercise great control over what was included and excluded from the accounts.[31] On the other hand, the aim of the Reports was to provide the Board of Visitors with an overview of what happened at (and to) the Observatory during the past year. In this light, Airy was not expected to include in them discussions about possible alternatives. Furthermore, the minutes of the meetings record very little of the discussions that took place. Therefore, reliance on the official accounts can give the illusion that Airy's actions were always met with approval, and that no negotiations had to take place. Instead of focusing on the official accounts, this chapter analyses the correspondence between Airy and the maintainers of the Transit Circle, and relies on the internal notes and reports written by the members of the Observatory staff. Therefore, the two sets of resources combined (official and internal) provide a more complete picture of both the "Airy era" and the instrumentation used during Airy's time.

Within the official documents, there is a general absence of descriptions of maintenance practices. Yet, the archives reveal that maintenance and repair featured prominently in the Observatory's everyday routine. Within the Airy Papers, notes related to the maintenance take up a large part of the Occasional Orders folders.[32] It includes notes exchanged between Airy and the observers about the distribution of the work related to the Transit Circle. Similarly, it includes direct orders to the observatory staff on maintenance and repair related to the instrument.

[31] Chapter 1 on the story of the object glass demonstrated how despite the Annual Reports and the official Description of the Transit Circle only mentioning William Simms as the supplier of the glass, Airy did not reveal that he contacted other opticians too. Another notable example is Airy's control over the official publication was regular inclusion of criticism about work related to chronometer ratings taking away both time and resources from the Observatory's astronomical projects.

[32] See *Occasional orders to Assistants,* RGO 6/33-41.

Another large source of material can be found within the Papers on moveable property. It includes the Reports on the States of the Instruments, which was a monthly report on the state of the instruments at the Observatory compiled by the First Assistant.[33] The document's significance was frequently highlighted when Airy asked for its correction and for its completion (when not sent to him in time).[34] The Reports on the State of the Instruments provide us with a different side of the history of the Transit Circle. It shows the Transit Circle in a more fragile light where parts of the instrument quite regularly broke down and required frequent repair or essential maintenance. To put it differently, they were in frequent state of disrepair,[35] or in a constant state of physical flux.[36] The table below illustrates the repair and maintenance work related to the Transit Circle mentioned in the Annual Reports in comparison to the Reports on the State of the Instruments during the year 1852.[37]

Annual Report of the Astronomer Royal	**Reports on the State of the Instruments**
New eye-piece added for measuring personal equation	March: "the instrument moves stiffly"
	May: "east band of the divided circle is getting very much tarnished"
	July: "the instrument moves rather heavily"
	September: "tin case of the exterior

[33] This position was renamed in 1870 to Chief Assistant. During Airy's directorship, this position was taken up by Robert Main from 1835 to 1860, Edward Stone from 1860 to 1870, and William Christie from 1870 to 1881.
[34] George Airy to Edward Stone, 1862, RGO 6/61; George Airy to Robert Main, 1858, RGO 6/60, 625
[35] Schaffer, *Easily Cracked*, pp. 706-717.
[36] Baker, *Precision*, pp. 14-29.
[37] For the Reports, see Robert Main, *Report on the State of Instruments*, RGO 6/58 240-261.

	thermometer needs repair"
	October: trough needs more mercury
	November: the third wire of the eye-piece is missing
	December: clock Hardy is broken

The Correspondence with Tradesmen section takes up another key part of the archives related to the maintenance of the instrument.[38] Within this group of folders, we find Airy's correspondence with the main instrument makers (Troughton & Simms, Ransomes & May, and Dent) about the construction, repair, and maintenance of the Transit Circle. The existence of these letters open up the need for future analysis to consider what role the maintenance of instruments played in managing the relations between instrument makers and the Observatory (or other clients). Furthermore, the large number of letters demonstrate the active and close involvement of the instrument makers with the Observatory, as well as the institution's and the firms' symbiotic relationships. Within these files we also find the notes exchanged between Airy and the carpenter/chief of works of the Observatory. Despite his very rare mention in the accounts of the observatory, these notes take up the largest part of the documents. They reveal Airy's day-to-day orders to the carpenter related to the maintenance of both instruments and buildings, while a few others to the construction of general items such as boxes. The final set of documents relating to the maintenance and repair of the Transit Circle can be found within the Correspondence on instruments files. They include the most diverse range of manuscripts about the Transit Circle by

[38] See *Correspondence with tradesmen*, RGO 6/715-758.

bringing together the original plans for it, the internal notes related to the determination of the errors of the instrument, and correspondence with other astronomers about it.

The seemingly scattered distribution of the manuscripts related to the Transit Circle is a reflection of Airy's arrangement of the documents. As a result, it can be seen as an illustration of how Airy thought about the instrument. First, it is noticeable that the documents were not brought together under a collective heading of the Transit Circle. Instead, the documents were distributed according to their function within the running of the Observatory. This was the reason why the internal notes to members of staff and the correspondence with the instrument makers ended up under different headings. At the same time, such a categorisation was also helpful in collating the quarterly bills of the Observatory for which Airy was responsible. Nevertheless, Airy's final arrangements of the archives reflected the operative segmentation of the work.

While the chapter has only focused on the differences in the various sources and reports so far, it is also useful to point out the similarities between the two sets of sources. Both the Annual Reports and the Reports on the State of Instruments (RSI) consider the internal parts of the Transit Circle (e.g. micrometer screws or wires in the eye-pieces) as well as the external instruments surrounding it (e.g. thermometers, collimators, clocks etc.). For example, within the RSI under the label of "Transit Circle" the individual entries tend to refer to both to its internal parts (e.g. object glass) and external instruments surrounding it (e.g. the regulator by William Hardy[39]), as opposed to the "Transit Circle" as a standalone instrument. Similarly, instruments associated with the Transit Circle, but not directly connected to the instrument (e.g. clock Hardy, the collimators, barometers and thermometers) were mentioned in conjunction with the Transit

[39] In the current collection of the Royal Museums Greenwich clock Hardy is referred to as an 'eight-day sidereal regulator by William Hardy' (Object ID: ZAA0591).

Circle in the Annual Reports as well as in the Greenwich Observations.[40] It was only the Barrel Chronograph (to which several other instruments were connected) that was given its own separate account in the Annual Reports. As a result, it can be argued that the Transit Circle appeared as a label for the assemblage of smaller parts and instruments surrounding it instead of an instrument on its own. If this approach is taken further, then the history of the maintenance of the Transit Circle is not a single history of an individual entity. Instead, it transforms into multiple histories told through the history of the maintenance of its multiple parts.

5. Instrument Makers

The main instrument makers involved in the maintenance and repair of the Airy Transit Circle were the firms Troughton & Simms, and Ransomes & May. Both firms carried out essential repair for decades following the installation of the instrument at the Observatory in 1850. This chapter considers the role of the workmen employed by Troughton & Simms and Ransome & May, and demonstrates the role of maintenance and repair as ways for instrument makers to manage their business ties with the Observatory. Through the continuous maintenance of the instrument, the Transit Circle appears as a long-term investment for instrument makers.

Ransome & May were involved in two major repair programmes after the installation of the Transit Circle. Their first involvement related to the breaking of the chains used for raising the telescope tube. Airy's and the staff's accounts of the incident described that fortunately neither the members of the observatory staff, nor the instruments were injured. However, a new set of

[40] For a description of the thermometers and barometers as well as their uses in relation to the Transit Circle, see *Astronomical Observations made at the Royal Observatory, Greenwich in the year 1862* (London: George Edward Eyre, and William Spottiswoode, 1864) pp. lvii-lviii.

chains had to be installed on the lifting apparatus on both piers. In this repair work, the older design of small oval chain link was replaced with bigger and sturdier rectangular links.[41] The second one was the perforation of the central cube of the telescope tube in order to make the collimation error measurements easier.[42] The perforations served as means to adjust the lines of sight of the collimating telescopes without the need to lift the Transit Circle up. This project required long preparation and discussion about whether such a modification to the instrument would make it defective, and whether there was a need to remove the telescope tube from the Observatory to execute the task to the highest standard.[43] In the end, Airy and the instrument makers decided to carry out the necessary work at the Observatory without removing the telescope from its place. The project was successful, caused no new major deviations into the flexure of the telescope tube, and led to the replacement of the original collimating telescopes with two larger ones.[44] While the perforation of the central cube was not a straightforward repair of the instrument, it demonstrated a close connection with and the significance of measuring its errors. In fact, making the process of measuring the collimation error easier was so important to Airy that he was willing to make alterations to the materiality of the instrument.

Troughton & Simms were involved in the repair and maintenance of the optical parts of the instrument.[45] They also served as Airy's remote hands for creating smaller devices for the Transit Circle. The Astronomer Royal noted this point when he requested a new design for the

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[41] For the official report of the incident see, *Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory*, 1864, p. 7.; for the discussion between Airy and Charles May regarding the best way to repair the instrument and how to prevent the same accident from happening in the future, see RGO 6/741 549-560

[42] This modification was so useful that it was already implemented in the first copy of the Airy Transit Circle made for the Cape of Good Hope observatory just a few years the original one had been completed.

[43] For correspondence in relation to the preparation for the piercing of the telescope tube, see *Correspondence with tradesmen 1865* RGO 6/743, 449-475

[44] Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, 1866, p. 9.

[45] For a brief history of the individual parts of the telescope, including their repairs see Satterthwaite, *Airy's transit circle.*, and Lowne, *The Object Glass of the Airy Transit Circle at Greenwich*. For Airy's correspondence with Ransome & May on the mechanical parts of the telescope and with Troughton and Simms on the optical parts of the instrument see *Correspondence with tradesmen*, RGO 6/724-741.

micrometer screws on the eyepiece of the Transit Circle and indirectly apologised for his occasional requests for the 'humble contrivances' which he regularly designed.[46] The firm was most often contacted for the repair of the optical parts of the instrument, which included the replacement of transit wires in the eyepiece, the repair of the eyepiece sliders, and the adjustment of screws in the eyepieces of the telescope and of the micrometers in the piers.[47] However, the instrument makers also occasionally carried out maintenance work that required more specialist knowledge such as the cleaning and re-polishing the object glass of the Transit Circle. Similarly, before the Annual Visitations the firm was called upon for the thorough cleaning of the instruments of the Observatory.[48]

The maintenance and repair work was carried out both on-site and in the workshops of the firm. Towards the end of Airy's directorship, we find him complaining about the poor work done by the workmen sent by the firm to the Observatory, and therefore requesting the tasks to be carried out by the main instrument makers themselves in the future.[49] However, the journals related to the Transit of Venus expeditions kept by George Tupman (one of the supervisors of the expeditions) recorded more trust in the workman of the firm (referred to simply as Mr. Skinner); based on his frequent return, one gets the impression that he was considered almost as part of the Transit of Venus team.[50]

[46] George Airy to Troughton & Simms, 23 October 1865, RGO 6/743 1037.
[47] The correspondence between Airy and Troughton & Simms under Airy's directorship of the Observatory span from 1835 to 1881, and the majority of the letters form part of the *Correspondence with Tradesmen* documents RGO 6/715-158.
[48] For an example to this annually recurring request, see Edward James Stone to Troughton & Simms, 12 May 1869, RGO 6/747 767.
[49] George Airy to Troughton & Simms, 8 April 1871, RGO 6/749 761.
[50] The journals kept by Tupman recorded to the work carried out at Greenwich in relation to the Transit of Venus expedition 1874 under the overall superintendence of Airy. Captain George Lyon Tupman's Home Journal 2, 11 February 1874, RGO 59/56/2 60. The journal was recently digitised by Cambridge University Library and the relevant page can be accessed via: https://cudl.lib.cam.ac.uk/view/MS-RGO-00059-00056-00002/25.

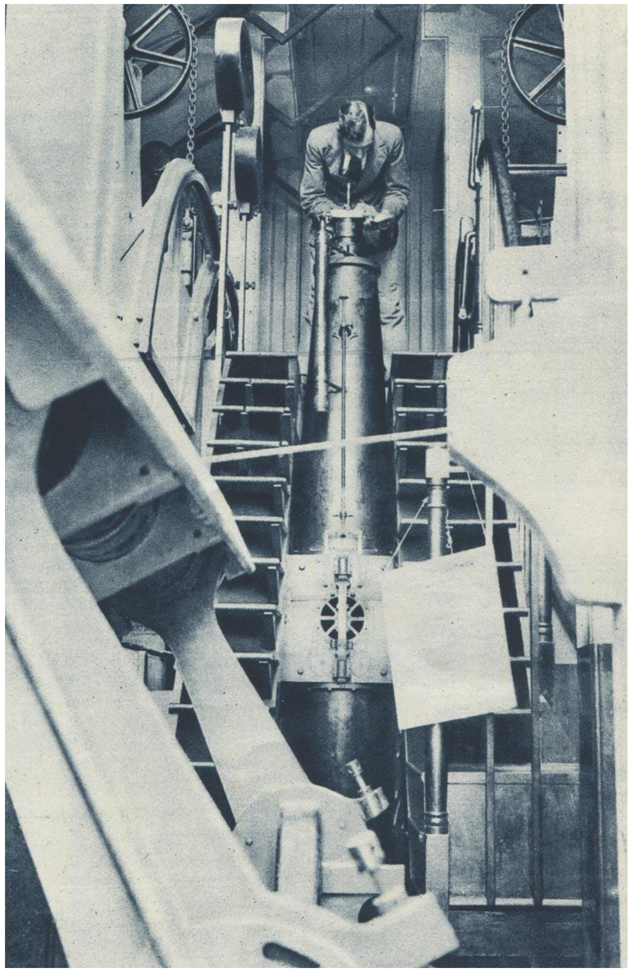

Fig. 23. Photograph showing the perforations of the central cube (1932, *Le Miroir du Monde*, 27 August 1932)

Comparing Airy's levels of trust in the two firms, we find both similarities and differences. While Charles May was still a member of Ransome & May, he was Airy's main point of contact in relation to the maintenance and repair of the Transit Circle. This was not surprising, as May had been associated with the construction of observatories before,[51] and had his own private observatory too.[52] May was just as engaged in the construction of mechanical parts of the Transit Circle, as Simms was in the making of optical parts. While unfortunately no correspondence seem to have survived between Simms and May, Chapter 2 has shown that the two instrument

[51] John Lee, 'An Account of the Observatory at Hartwell House', *Monthly Notices of the Royal Astronomical Society*, 14 (1854), 215-216 (p. 215).
[52] Minutes of Proceedings of the Institution of Civil Engineers. (London, 1861) p. 149.

makers kept in touch and helped out each other.[53] However, after May's departure from Ransome & May, the Astronomer Royal had to rely on the services of the workmen sent by the Ransomes, which demonstrated that May was the main expert in astronomical instrument making at the firm. Despite this, Airy repeatedly requested the presence of the same workman, James Hardy, to carry out the necessary repair work on the instrument.[54] This showed that Airy seemed to have been satisfied with the services and the work of James Hardy, unlike with the services of the workmen of Troughton & Simms. At this point, it is important to note that James Hardy engaged in mechanical issues, while the workmen of Troughton & Simms worked on optical issues related to the instrument. Even though optical work tends to be associated with more specialist knowledge, given the precision that had to be attained with the instrument (which relied on both high quality mechanical and optical performance), the mechanical work also had to incorporate specialist knowledge. This is not only highlighted by Airy's decision to use the specialist process chilled-iron technique for the casting of the body the telescope, but also through the solutions provided for the mechanical errors of the instrument.

The discussion about the workmen of the instrument makers highlights the hidden technicians of scientific work. A reliance on them became more apparent upon their absence. This is best illustrated with one of the letters sent by Charles May to Airy, in which the instrument maker apologises for attaching only a lesser quality schematic to his answer due to the draughtsman of the company not being present at their factory at the time.[55] Examining the involvement of these individuals provides us with a critical look into their activities. Instead of romanticising their actions, the Airy Papers reveal the hidden workmen through the errors that they made during the

[53] George Airy to Charles May, 7 Jul 1848, RGO 6/721
[54] For an example see the documents relating to the repair of the lifting apparatus RGO 6/741 552, 560 and RGO 6/742 539.
[55] Charles May to George Airy, 28 May 1849, RGO 6/722 611-612.

maintenance and repair of the Transit Circle. This was highlighted by Airy requesting his First Assistant to be present when workers carried out tasks around the instrument, or when the Astronomer Royal complained about the poor work carried out by them.[56] Airy's notes and letters show us that he expected the same reliability from the workmen as from the instrument makers they worked for (William Simms and Charles May). The failure of the workmen to live up to Airy's expectations led Airy to request the top instrument makers to be involved instead in the repair work.[57]

These examples demonstrate two significant additions to our understanding of the Transit Circle, and the materiality of scientific instruments in general. First, we see that the 'client-instrument maker' relationship did not end abruptly after the construction of the instrument was finished. Instead, the type of products and services offered by the instrument makers simply shifted away from manufacturing towards maintenance, repair, and modification. As a result, instrument makers and their practices should not be analysed only through the *making* of instruments, but also through their *re-making*. By changing this frame of reference, we are also able to perceive the Transit Circle in different ways. As opposed to considering it as a one-off product of the instrument makers, it becomes understood as a product that yields long-term returns for the instrument makers through the telescope's frequent maintenance and repair. For instance, the total cost of an instrument should not only consider the initial sum of money paid for its construction, but also the cost of maintenance and repair over the lifetime of the telescope.[58] Second, maintenance and repair works on the Transit Circle were carried out either because the materiality of the telescope underwent changes and/or because Airy wanted to inscribe

[56] For Airy's request to his first assistant to supervise the workmen, see George Airy to Robert Main, RGO 6/38 42.
[57] George Airy to Troughton & Simms, 18 January 1872, RGO 6/750 762.
[58] For the financial benefits of maintenance and repair work see Alison Morrison-Low, *Making Scientific Instruments in the Industrial Revolution* (Aldershot, Hampshire: Ashgate, 2007), pp. 43, 75 & 266-267.

alterations into its materiality. Therefore, approaching an instrument through maintenance and repair practices depict any instrument as a constantly changing artefact as opposed to one that remains in the same condition throughout its entire period of use.[59] Through this consideration, the history of an instrument needs to be seen differently at different stages of its life. At each stage, the users of the instrument had to adjust to the material conditions of the artefact at that given moment, while at the same time had to shape the materiality of the telescope. This reciprocal framing of the interactions show that the Transit Circle was not a passive bystander at the Observatory, but rather an instrument that actively shaped through its errors and malfunctions the work of individuals. For instance, the perforation of the central cube meant changing both the method and the accuracy of the measurements of the instrumental errors, thereby significantly changing the amount of time spent on the regular maintenance of the telescope, as well as achieving higher precision with the observations.

The analysis of the correspondence between Airy and the instrument makers also draws attention to the Astronomer Royal's close involvement in the maintenance and repair of the instrument. Instead of simply requesting the instrument makers to repair the Transit Circle, Airy presented them with his own ideas regarding how improvements could be made to the telescope.[60] This type of work challenges the current scholarship on Airy which depicts him as someone who was too busy to devote himself completely to the work of the Observatory due to his role as 'a scientific and technical advisor to the government', which in turn led to being distanced from the everyday operations of the instrument. For instance, Smith draws upon the criticism brought forward by James South against Airy for 'neglecting the Observatory's operations to pursue his

[59] Schaffer, *Easily Cracked*, p. 708.
[60] There are also a couple of references made to Airy participating in the cleaning of the Transit Circle. For Airy cleaning the micrometers see *Astronomer Royal's Journal*, RGO 6/25 55. For Airy cleaning the object glass of the telescope, see *RSI*, RGO 6/62 355.

advisory role'.[61] Furthermore, since Airy only made one recorded observation with the Transit Circle after the installation of the instrument, it also fuelled an image of the astronomer who was distant from the instrument.[62] However, not observing with an instrument was different from not being involved with its general management. By approaching the history of the Transit Circle through Airy's engagement with maintenance, we see that he was closely involved with the maintenance of the telescope's performance despite not making observations with it.

6. The Observatory Staff

Maintenance and repair work was not a practice carried out exclusively by instrument makers. The Observatory staff interacted with the Transit Circle on a daily basis, frequently modified it according to their or Airy's wishes, and carried out essential maintenance as well as repair on it in times of need or when the job did not require specialist equipment. Essential maintenance referred to the cleaning, dusting, oiling, and other basic tasks related to the materiality of the Transit Circle. These tasks were most often carried out by the carpenter/chief of works of the observatory: initially by the individual known only as Mr. Green, from the early 1860s by J. Simmons and Mr. Green together, and from the late 1860s by J. Simmons alone.[63] While on the surface these tasks seem to require only very basic skills, when cleaning was undertaken by other people around the Transit Circle, the main or a high ranked assistant had to be present to supervise the workmen, making sure that they did not unintentionally adjust its

[61] Robert Smith, 'A National Observatory Transformed', pp. 12-13.
[62] Satterthwaite, *Airy's transit circle*', p. 131. Airy's lack of 'practical enthusiasm' for observing was also mentioned in a letter from Romney Robinson to William Rowan Hamilton. For this see Graves, *Life of Sir William Rowan Hamilton, vol. 1*,. p. 432.
[63] Correspondence with Green can be found in the *Correspondence with tradesmen* folders until 1864 RGO 6/742. In the early 1860, Simmons and Green appear together, in the same folders, while correspondence from 1866 onward only lists Simmons.

parts.[64] Therefore, the reliance on the skills of the carpenter without the need to supervise his work demonstrates both the trust in his work as well as the expertise and in-depth understanding that he possessed of the instrument. This type of maintenance also included the weekly raising of the telescope tube and the oiling of the moving parts of the Transit Circle. The raising of the instrument served two purposes. First, it allowed access to the bearings of the instrument in order to inspect them and to lubricate the brass plates upon which the east-west axis of the telescope tube rested and rotated. Second, lifting the apparatus allowed for the use of collimating telescopes in order to measure the deviations in the optical axis of the telescope tube. Performing the two different tasks at the same time signalled their connection to each other, which opens up the possibility, discussed in the following chapter, of considering the measurement of errors (as opposed to "fixing" the material components causing the error) as a specific type of maintenance.

The connection between essential maintenance and the necessary skill set which it required was highlighted by another case, when the carpenter asked the Astronomer Royal for two weeks' leave. Airy agreed to this, but his condition for Green was to begin his leave after the weekly Monday maintenance and lifting of the instrument, so that in his absence the Observatory was only going to miss the task once.[65] The exchange of letters illuminated that neither the maintenance, nor the weekly lifting of the instrument was an easily transferable task to the other members of the Observatory. Rather, it required the specialist skill set of the carpenter. Other roles of the carpenters included the execution of minor tinkering with instruments around the Observatory and fabrication of items that Airy wished to be made. As a result of this, we find notes sent by Airy relating to the making of minor artefacts such as boxes, chairs, and tools for

[64] George Airy to Robert Main, RGO 6/38 42.
[65] Green to George Airy, RGO 6/727 504; Airy to Green, RGO 6/727 508.

specific purposes.[66] These notes demonstrate Airy's passion for fabricating objects and implementing mechanical solutions to problems. This image of Airy was recalled by James Stuart too, who stated that

> the whole of the Observatory was full of his inventions – doors which shut by contrivances of his own, arrangements for holding papers, for making clocks go simultaneously, for regulating pendulums, for arranging garden beds, for keeping planks from twisting, for every conceivable thing from the greatest to the smallest.[67]

These examples allow us to shift the interpretation of Airy's management technique away from the rigorous overseeing of tasks as they could be found in factory settings, towards a specific type of centralised micromanagement whereby the staff of the Observatory appears as the eyes, ears, and hands of the Astronomer Royal.

Micromanagement also challenges two further ideas in relation to breakdown and maintenance of instruments. First, it highlights the multiple actors involved in the maintenance process. As a result, it redistributes the attention of historical research to various people, highlighting the possibility of individual variations between maintenance practices. These variations can be measured through the level of independence that the assistants or the carpenter have in relation to tinkering with the Transit Circle. Furthermore, it could also be measured through Airy's opinion on the quality of the work carried out (as illustrated by the difference between the work of the instrument makers and their workmen). Second, it highlights the practices of managing both the maintainers and their work. In consequence, our attention is directed not only to the hands that

[66] George Airy to Green, RGO 6/743: 1037.

[67] James Stuart in his autobiography refers to these contrivances as Airy's own inventions, despite the fact that they were possibly created by the carpenter or other instrument makers after Airy's designs; see Stuart, *Reminiscences*, p. 159; for the relationship between Airy and Brunel see: R. Angus Buchanan, 'Science and Engineering: A Case Study in British Experience in the mid-nineteenth century', *Notes and Records of the Royal Society of London*, 32:2 (1978), 215-223 (p. 217).

interacted directly with the materiality of the instrument, but also to the individual who instructed, advised, or allowed the maintainer to carry out the maintenance of the instrument. In this light, the 'hand' working on the instrument (as well as the new configurations of the instrument that it creates) embodies not only the actions and intentions of the maintainer, but also the actions and intentions of the individual that instructs the maintainer to carry out the work. Therefore, it is necessary to pay attention in any research on maintenance to how the "hands" of the maintainers are challenging or channelling the instructions of the individual managing the maintainer.

Maintenance work also included the practice of modification, which refers to the rearrangement of the system of instruments. This practice most prominently featured with the galvanic wire system and the illuminating systems. Airy requested his First Assistant, Robert Main, and Mr Green to assist each other in the rearrangement of the wire system, which demonstrates the close cross-hierarchical cooperation within the Observatory ranks.[68] For cases like this, the Observatory staff had to follow Airy's detailed instructions.[69] However, Airy's oversight was exercised differently in the case of the assistants and the carpenters. While assistants were reminded not to tinker with instruments they were not assigned to,[70] the tasks of the carpenters had to be authorised by the Astronomer Royal. While acting without Airy's authorisation was not mentioned in relation to the work of Green, his successor, Simmons was reprimanded for acting without such authorisation.[71] These two different types of implementation of the restrictions allow us to compare the extent to which the roles of the carpenters and the assistants were specialised. While the assistants seemed to have a highly specialised role by being

[68] George Airy to Green, RGO 6/730 388.
[69] George Airy to Green, RGO 6/743: 1037.
[70] George Airy to John Charles Henderson, RGO 6/38 29.
[71] Astronomer Royal's Journal, 29 January 1873, RGO 6/26

associated with specific instruments, the carpenter was allowed to engage and interact with any instrument as long as the director of the Observatory gave the necessary authorisation. In consequence, what emerges is a distribution of specialisation where those at the top of the Observatory hierarchy (the Astronomer Royal and the Chief Assistant) and those at the very bottom (the carpenters and labourers) were the least specialised both in their interactions with the instruments as well as in terms of regulations, while those at the middle of the hierarchy (the general assistants and computers) fulfilled the most specialised roles.[72]

Repair work (as opposed to essential maintenance) was carried out only to a very limited extent by the Observatory staff, but a few occasions are still mentioned in the surviving documents. Most striking was Airy's instruction to strategically place a bag of stones on the top of the Western pier in order to counteract the level error caused by the very gradual sinking of the Eastern pier.[73] However, after finding it unsuccessful, he decided to place a very thin sheet of paper (1/270 inch in thickness) underneath the eastern Y bearing.[74] For this repair, Airy contacted the Ransomes again (now named Ransomes, Sims & Head) to ask for their suggestions. The firm responded by approving Airy's idea of using a very thin sheet of paper to solve the issue. Attached to the response to the Astronomer Royal were three sheets of paper of different thickness so that the Airy and his staff could decide which thickness provided the best outcome.[75] However, from the response of Airy we learn that a sheet of paper thinner than any that Ransome had sent was found at the Observatory, and was used for this purpose. In a similar

[72] The computers of the Observatory are excluded from this classification, as they were neither allowed to modify the materiality of the instrument, nor to touch the Transit Circle in the absence of an observer. Despite this, Chapter 4 will demonstrate that the computers (along with the general assistants) played an important role in the 'calculative maintenance' of the instrument; see Airy to Breen, op. cit.
[73] George Airy to Arthur Biddell, 27 August 1870, RGO 6/748 475 and 7 November 1870, RGO 6/748 476
[74] George Airy to Arthur Biddell, 14 November 1870, RGO 6/748 484
[75] These sheets of paper can still be found in the archive catalogued with the letter by Arthur Biddell; see Arthur Biddell to George Airy, 11 November 1870 RGO 6/478-482.

case, when it was found out that the collimator heat from the gas burners were affecting the piers of the Transit Circle and the collimators, tin plates were added to them by the Observatory staff in order to protect from further effects of the heat.[76] These cases illustrate that modifications and repairs were carried out by the members of the Observatory staff too, and such tasks were not exclusively in the hands of the instrument makers.

The examples described above serve the particular theoretical purpose of showing how interactions with the Transit Circle through maintenance and repair work always referred to interactions with parts of the instrument and not with the instrument as a whole. In this light, the name Transit Circle refers exclusively to the specific arrangement of the multiple smaller parts and instruments that through their interactions with each other produce the totality of the Transit Circle. By refocusing the shift from the single history of a single instrument to the multiple histories of multiple artefacts, the approach allows us to frame the Transit Circle as an assemblage of these various histories. This focus on the assemblage has the advantage of bringing forth the conditions, decisions, and operations that eventually produced the constant assembling process as opposed to limiting historical debates within the scope of the multiple interpretations of the instrument in different narratives. At this point, it is important to emphasise that assemblage is not the same as convergence. The multiple histories of the instruments do not "cross" each or converge at a unified point that transforms the piers, the galvanic wires, the telescope tube, and all the other parts of the Transit Circle into a single instrument. Instead, it refers to the interaction of the different entities with each other through their assemblage. As a result, this approach opens up the direction to consider the history of each individual part of the

[76] Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, 1861, p. 6.

instrument equally and that the Transit Circle denotes the function ascribed to the assemblage of the artefacts instead of being a single instrument with a history of its own.

7. Conclusion

Similarly to the previous chapters, this chapter has continued to demonstrate how the internal documents of the Observatory and the correspondence between Airy and tradesmen (Simms and May) provide new information about the history of the Transit Circle. Within the themes of this chapter, the new set of documents highlighted the instrument in a more fragile light. It might be built in 'the likeness of heavy machinery', as Newcomb put it, but the importance of maintaining its excellent state of repair did not vanish. In this light, the slap that Newcomb described is reinterpreted to show the close connection between the Transit Circle and its users, as opposed to the sturdiness of the instrument. By analysing the maintenance practices related to the instrument, the chapter brought forth two new sets of invisible technicians: the Observatory staff and the workmen of instrument makers. At the same time, the need to maintain and repair the Transit Circle demonstrated the continued involvement of instrument makers, even after its installation on site. As a result, it showed that being involved in the making of an instrument did not simply mean engagements throughout its construction, but also provided future work through maintaining and servicing it.

The main aim of this chapter was to demonstrate the significance of maintenance in the life of the Transit Circle. By doing so, it added to historical research on maintenance and repair practices within nineteenth-century contexts. The chapter showed that instruments were not thought of as static and infallible, but rather as being prone to error and always changing their material states due to their interactions with their users and the environment surrounding them. By analysing the vulnerability of the Transit Circle, the instrument's maintenance served the role of making it reliable. This reliability was achieved through the regular surveillance of all the actants involved in its maintenance, i.e. the surveillance of both the maintainers and the maintained instrument. The chapter showed that the division of labour related to the maintenance of the instrument served as a way to impose surveillance on the practices. The different levels of specialisation at different ranks minimised the possibility of breaking the instruments through tinkering. At the same time, the chapter demonstrated that Airy's imposed hierarchy was not reflective of the extent to which the Observatory relied on the services of a given individual. The temporal absence of the Mr. Green (the carpenter) highlighted that even the lower ranked members of staff played crucial roles in maintaining the operations of the instrument.

Through the work of Mr. Green, the chapter expanded the analysis of surveillance from the individuals to the Transit Circle too. The regular weekly maintenance tasks, and the reports produced on its state on a monthly basis served as ways to measure and to regulate the constant gradual changes of the materiality of the instrument. By doing so, the chapter highlighted that even the instrument that appeared in the 'likeness of heavy machinery' was still considered to be in a constant state of flux, which prompted Airy to put it under surveillance the same way as he managed the Observatory staff. The next chapter will expand upon this work by demonstrating how the materiality of the instrument was transformed into an immaterial state in order to place the Transit Circle under even further control. Finally, this chapter has continued approaching the Transit Circle as an assemblage of its parts and auxiliary instruments. Maintenance and repair practices highlighted exactly this nature of the instrument, since when the Transit Circle broke down, it was caused by a faulty part, as opposed to a fault in the totality of the instrument. By doing so, the approach highlighted that breakdowns disturb the relations between the multiple parts of an instrument, while maintenance practices serve the purpose of strengthening those material relations via keeping them in excellent states of repair. The next chapter will expand on this approach by showing how turning the Transit Circle into an immaterial form via pen and paper, allowed for strengthening these relations without having to alter or intervene into the materiality of the instrument.

Chapter 4 : Calculative Maintenance

1. What is Calculative Maintenance?

Direct and physical maintenance of the materiality of the Transit Circle formed an essential part of its life and operation. Such practices highlighted the dynamic relationship between the instrument and its users. While astronomers, instrument makers, and the Observatory staff engaged in these practices to keep the Transit Circle in their desired state, the instrument through its gradual breakdown and its constantly changing materiality counteracted the measures of the maintainers. To put it differently, through the material reality of the Transit Circle the instrument was un-becoming itself.[1] This was due to the material form of the instrument being in discordance with its immaterial imagined forms produced through calculations and descriptions. Approaching the Transit Circle from this perspective frames the instrument not as one that was either "on" (in working order) or "off" (broken), but rather in a state of flux where its material reality underwent continuous change. This approach to scientific instruments in general proves to be useful, since it shifts the problem away from identifying whether an instrument was either "on" or "off", and instead focuses on the 'material dialogue' between the instrument and its maintainers, i.e. the performativity of their relations. In the case of the Transit Circle, the approach further highlights how maintenance practices contributed to its precision. Through material dialogue, the precision of the Transit Circle is seen as the performativity of both the

[1] The term un-becoming is a play on the philosophical concept of becoming in its traditional use, which denotes the constantly changing order of things (as in the work of Heraclitus, Nietzsche, Bergson, and Heidegger). With the term un-becoming, I intend to emphasise the discordance between what is expected from things to change into (i.e. become), and how they deviate from such expected paths (i.e. un-become).

instrument and its users.[2] This chapter argues that through such a dialogue the maintainers of the Transit Circle were attempting to inscribe their own ideas about the instrument into its materiality, while at the same time the instrument responded by constantly deviating from such inscriptions.

As the previous chapter demonstrated, the general approach to analysing maintenance and repair of instruments focuses on the alterations made to their physical materiality. This chapter expands on this approach by showing that through the measurements of instrumental errors, the reliability of instruments was also maintained on paper during the reduction of the observations. This way, the mathematical tools employed by astronomers and computers became tools similar to those found in the workshops of instrument makers or at the shed of the Observatory's carpenter.[3] At the same time, the new mathematical tools also served as a way for astronomers to impose a hierarchy between them and the instrument makers. Within these power dynamics, the instrument makers created them, while the astronomers brought the instruments even closer to perfection through numerical calculations. In this chapter, such practices will be labelled *calculative maintenance*. The term will refer to the measurement of the errors of the Transit Circle, and to the mathematical corrections that were subsequently used during the reduction of the observations (calculations that took into account environmental, instrumental, and human factors affecting the observations).

This chapter will begin with an overview of how instrumental errors were treated within nineteenth-century astronomy. The values of such errors changed quite often due to environmental (e.g. temperature changes, or movement of the ground) and human factors (e.g.

[2] This can be read as an attempt to demonstrate how it is not only humans bringing forth the ontologies of the order of things, but similarly, the things bringing forth human beings. See Annamarie Mol, *The Body Multiple* (Duke University Press, 2002), pp. 6-7.
[3] See Aubin, *Mathematics as Tool and Instrument in Observatories*, pp. 177-196.

observers misadjusting the instrument). As a result, astronomers had to make frequent and repeated measurements of these errors. While astronomers had been aware of the impact of instrumental errors before the nineteenth century, the chapter argues that the implementation of increased division of labour into astronomical work as well as the increased precision of astronomical instruments contributed to the more widespread reliance on calculative maintenance during the nineteenth century. The chapter will then examine Airy's introduction of calculative maintenance practices into the operations of the Cambridge Observatory during his early career. It will be followed by an analysis of how calculative maintenance was implemented into the operations of the Observatory at Greenwich. By doing so, the chapter will show the differences and the similarities that were involved in the calculative maintenance of instruments at the two different observatories (i.e. between a university observatory and a national observatory). Calculative maintenance within the context of the Greenwich Observatory will demonstrate how it was shaped according to a factory mentality that was introduced by Airy into its management. It was transformed through the division of labour and the surveillance of both the instruments and the staff. Through an analysis of calculative maintenance, the Transit Circle will be approached as part of the assemblage of the larger organisational context that contributed to the production of astronomical data at the Observatory.

2. Instrumental errors during the nineteenth century

Even though ever-greater precision was attained through the new methods of instrument makers during the nineteenth century, astronomical instruments were not considered to provide perfect measurements. As noted in Chapter 2, Herschel did not consider instrument makers to have the ability to create perfect (as in faultless) instruments.[4] Despite this, it was not impossible to go beyond the accuracy attainable through the materiality of the instrument. Noting this point, Herschel emphasised that the material obstacles can be overcome through the work of the practical astronomers who directed their attention 'to the detection and compensation of [instrumental and observational] errors, either by annihilating, or by taking account of, and allowing for them.'[5] This and similar statements were significant for two reasons. First, they demonstrated that instruments continued changing their states even after their construction process was finished: through the measurements of instrumental errors, astronomers continued transforming their immaterial forms on paper. Second, the distinction highlighted by Bessel between the physical and calculative maintenance of instruments imposed a hierarchy between the astronomers and the instrument makers. This was a belief that Airy also shared and noted in a memo to his Chief Assistant, Robert Main: an astronomer should never consult an optician until he checked the theory behind the fault, as 'we [the astronomers] understand the theory far better than they [the artisans] do.'[6] Airy's instruction to Main highlighted the superior position of theoretical (and calculative) correction of instrumental error in this hierarchy.

Even though Bessel emphasised the making and remaking of astronomical instruments, it was not yet a commonplace practice at the beginning of the nineteenth century. It was even less frequent to publish the individual values used for the numerical corrections of the instruments. This is where Bessel contributed to the history of calculative maintenance of astronomical instrument. David Aubin described him as one of the originators of the use of mathematics as a tool within the Observatory as well as within astronomical research.[7] His contribution was also

[4] Herschel, *Outlines of Astronomy*, p. 76.
[5] Ibid. p. 77.
[6] Airy to Main, 1852, RGO 6/29 97.
[7] Aubin, *Mathematics as Tool and Instrument in Observatories*.

highlighted by the late nineteenth-century astronomer Simon Newcomb, who considered him the founder of the 'German School of practical astronomy'.[8] The main feature of the German School was related to the treatment of instrumental errors. Rather than considering an instrument to be inherently 'innocent', i.e. free of any errors, it was 'tried for every possible fault [… until] it has proved itself correct in every point.'[9] Christoph Hoffmann, writing about Bessel's contribution to investigations of personal equations, located these developments within the larger reflexive turn towards the observation of the observers themselves.[10] Hoffmann expanded on the work of Schaffer and Canales to demonstrate how Bessel's management of 'constant differences' between observers was implemented at Greenwich.[11] He argued that the rigorous disciplining of the astronomical observers was not inevitable in positional astronomy but, rather, it was a unique feature of the Greenwich observing regime originating from its highly organised division of labour.[12]

While Hoffmann and Schaffer focused on observers and personal equation, this chapter attempts to expand their studies to the surveillance of the instruments through the practice of calculative maintenance. The main challenge to applying Hoffmann's analysis directly to instruments remains in his connection of observers with astronomical instruments. For Hoffmann, discussions about the 'involuntary errors' of the observers were reflections of how the observers began to be thought of as instruments.[13] He located this within what Shickore considered the

[8] Simon Newcomb, *A compendium of spherical astronomy* (New York: The Macmillan Company, 1906), p. 343.
[9] Ibid.
[10] Hoffmann, *Constant differences,* pp. 335-336.
[11] Schaffer, 'Astronomers Mark Time'; and Jimena Canales, 'Exit the Frog, Enter the Human: Physiology and Experimental Psychology in Nineteenth-Century Astronomy', *The British Journal for the History of Science*, 34:2 (2001), 173-197.
[12] Hoffmann, 'Constant differences', p. 364.
[13] Ibid., p. 362.

reflexive turn within approaches to observations.[14] Accordingly, personal equations or constant differences between observers were controlled the same way as the errors of the instruments. This chapter expands on this idea by arguing that while observers were reduced to instruments, the instruments were also thought of as the observers with their own characteristics and personalities. In relation to the life of the Transit Circle, the chapter argues that the errors of the instrument appeared as its own personality, which had to be accounted for during the reduction of the observations.

Within this framing, calculative maintenance served as a way to expand the surveillance of instruments during astronomical work, while at the same time considered them as companions with their own idiosyncrasies. Such an approach to instruments was labelled by John Tresch as the romantic framework of Humboldtian science.[15] He demonstrated this framework through an analysis of Alexander von Humboldt's treatment of instruments as companions. According to Tresch, Humboldt did not perceive instruments to be the 'antithesis of human, organic, or natural.'[16] Instead, within Humboldt's approach 'the new instruments of nineteenth-century science were often seen to embody the qualities of the human subject.'[17] In addition, 'the process of [their] standardization and calibration built an a priori principle into the instrument, a categorical imperative ruling over its "desire"'.[18] This was because each instrument responded freely to its milieu and its particular circumstances. From this arose a cooperation between the Humboldtian tool and the human: '[t]he observer had to gain the instrument's assent by entering into a dialog with it, "playing" with it, becoming familiar with its limits and habits.'[19] Through

[14] Schickore, *Ever-present impediments*, pp. 126-146.
[15] Tresch, *The romantic machine*.
[16] Ibid., p. 65
[17] Ibid., p. 78
[18] Ibid., p. 80
[19] Ibid.

these dialogs, interactions, and plays, 'tool and human became a single unit: an instrument that was humanized, and the human incorporated into the machine.'[20] This chapter argues that while both Hoffmann and Schaffer analysed through the concept of 'personal equation' how the human observer was incorporated into the machine, they did not provide a detailed description of how the instrument was humanized. It is this gap in the scholarship, which this chapter attempts to fill. Within this "romantic" or "Humboldtian" framing of the instrument, clockworks and constantly laborious machines were the companions of the astronomical labourers, the extensions of their senses, and the instruments going awry. In this light, instruments were not solutions eradicate personalities from human work, but rather the entities that were placed under even more rigorous surveillance than their human counterparts. Such an approach questions the role of instruments such as clocks in the disciplining of the workforce and society. While they appear to be consenting servants to the wishes of their makers, their recurring errors and need for their maintenance demonstrate their flamboyant nature and ascribes the reliability into the human practices maintaining them as opposed to their materiality. In brief, within the framework of romantic machines, the perfection of instruments was based on knowing (or being able to measure) their errors (or characteristics), as opposed to the instruments being inherently devoid of errors. To put it differently, perfection was immaterial and strived for only through practices, as opposed to being a quality of material reality created by the artisans. This chapter argues that the *German School* and the Besselian approach of making instruments the second time on paper were reflections of this type of engagement with instruments, and it was an approach that Airy implemented into the maintenance of the Transit Circle.

3. Airy and the Besselian approach in Cambridge

[20] Ibid.

Hoffman pointed out that Airy was already aware of the 'constant differences' between observers during his directorship of the Cambridge Observatory, but he did not take them into account into his calculations of the positions of celestial bodies.[21] However, as this chapter will now show, Airy introduced other Besselian ideas into the reduction of observations during his early career. In fact, he was among the first proponents of the Besselian approach in Britain.[22] While still the director of the Cambridge Observatory, he was asked to write a report on the progress of astronomy during the nineteenth century to be presented at the second meeting of the British Association for the Advancement of Science. Within this report, he proposed several possible avenues that astronomical research could take. Within one of these proposals he called for reducing Bradley's observations using Bessel's approach.[23] In addition to the works of Bessel, Airy was also familiar with Humboldt's views of science. In 1836, he co-authored a report on Humboldt's letter to the Royal Society, which became one of the pieces fuelling the Magnetic Crusade.[24] Besides his familiarity with the works of Bessel and Humboldt, Airy's education and circle of close friends in Cambridge promoted ideas and works of the Romantic Movement from continental Europe.[25] The most direct evidence to this comes from William Whewell's translation of Schiller's ballad, *The Count of Habsburg*, which was made at the request of the Airy family.[26] Such connections make us reconsider the extent to which Airy was

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[21] Hoffmann, 'Constant differences', p. 359.
[22] Satterthwaite, *Airy and positional astronomy*, p. 103.
[23] Once appointed Astronomer Royal, Airy secured funding for the reduction of these observations (simply referred to as "Planetary Reductions"), and for his work on it he was awarded the Gold Medal of the Royal Astronomical Society in 1846. For Airy's Report, see George Biddell Airy, 'Report on the progress of astronomy during the present century', *Report on the First and Second Meetings of the British Association for the Advancement of Science* (London: John Murray, 1835), pp. 125-189.
[24] Jean Theodorides, 'Humboldt and England', *The British Journal for the History of Science*, 3:1 (1966), 39-55 (pp. 47-48). Similarly, Cawood's study showed the important role that a group of British men of science also played in supporting funding for the Magnetic Crusades. Cawood, *The Magnetic Crusade*, p. 502.
[25] Hoffmann, 'Constant differences', p. 363.
[26] Isaac Todhunter, *William Whewell* (London: Macmillan and Co., 1876). p. 171.

suffering from 'unimaginativeness',[27] and whether such a coupling has mostly been fuelled by the tendency to view him as the disinterested manager of the observatory labourers.

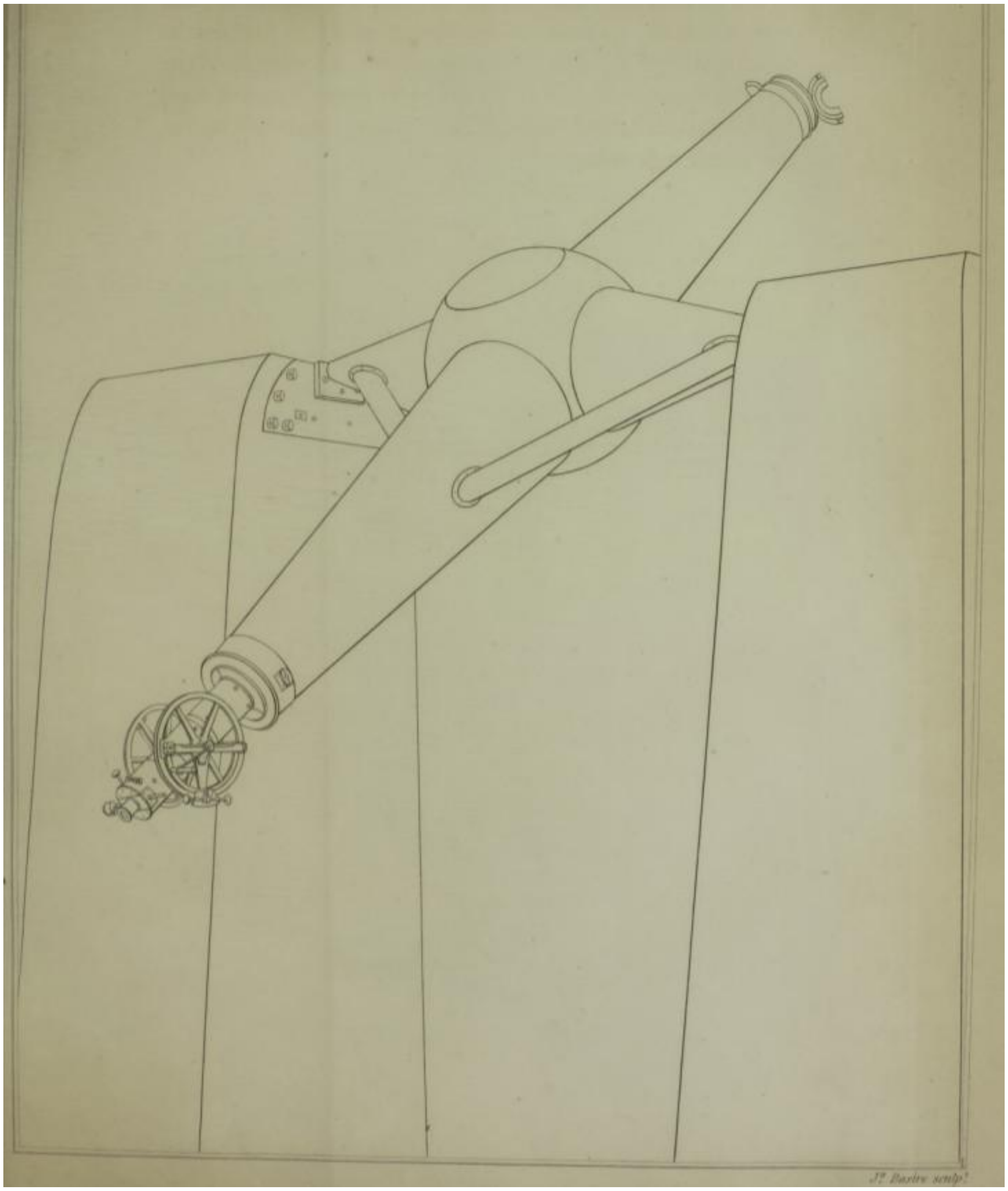

Fig. 24. Illustration of the Cambridge Transit Instrument (Plate for Robert Woodhouse, 'Some account of the transit instrument made by Mr. Dollond, and lately put up at the Cambridge Observatory', *Philosophical Transactions*, 31 December 1825, Vol 115, pp. 418-428)

[27] Daniel Brown, 'William Rowan Hamilton and William Wordsworth: the Poetry of Science', *Studies in Romanticism*, 51:4 (2012), 475-501 (p. 497).

Since Airy's association with Bessel and Romantic ideas can be traced back to his time in Cambridge, it is important to look at how his astronomical practices were affected by them during his formative years prior to being appointed as the Astronomer Royal. Upon being appointed as the Plumian Professor of Astronomy at Cambridge University, he also became director of Cambridge Observatory. He wasted no time after his appointment, and within a year he published the first volume of the *Cambridge Observations*.[28] Within its preface he outlined his preference towards publishing the reduced observations in the Besselian manner (i.e. ones that incorporated all sources of instrumental errors) as opposed to publishing solely the 'rough' observations. This was a radical difference from the *Greenwich Observations*, which at the time published their observations reduced to a lesser extent than the Besselian approach provided.[29] In relation to the 'management of the Transit Instrument' of the Observatory, he professed a similar preference towards 'applying numerical corrections for the errors of positions, instead of relying on the mechanical removal of these errors.'[30] He justified this laborious application of numerical corrections on the basis of achieving greater accuracy. In brief, Airy engaged in the Besselian second making of the instrument through measuring its errors and accounting for them during the reduction of observations.

While the transit instrument was not a transit circle, both instruments suffered from the same three instrumental errors: azimuth, level, and collimation. Each one of these errors caused a different type of optical misalignment of the telescope tube with respect to the meridian upon which the optical axis of the instrument rested. Because of these errors, the measured time of the

[28] George Biddell Airy, *Astronomical Observations made at the Observatory of Cambridge* (Cambridge: J. Smith, 1829).
[29] Airy, *Cambridge* Observations, 1829, pp. iv-v.
[30] Airy, *Cambridge Observations*, 1829, p. vii.

transits (right ascension) occurred either earlier or later than the real transit would.[31] The impact of these errors on the transit instruments and transit circles was continuous, which meant that they were never in a perfect, or ideal state. Section II of the *Cambridge Observations* detailed the process with which such instrumental errors were reduced numerically as opposed to mechanically. Airy introduced the section by criticising the reliance on mechanical adjustments only. In this introduction he declared that despite the mechanical adjustments, instruments always remain 'subject to continual oscillations', i.e. 'instruments are always out of adjustment'. According to him, the solution to the problem was found in the detection and measurement of errors as opposed to the modification of their materiality: '[while] it is always easy to measure an error with great exactness it is not always possible to correct it with the same exactness.' These passages reflected Herschel's theory of instruments, which was based on the belief that the perfect instrument was an impossibility. Such an approach was supported by members of the recently established Royal Astronomical Society, who emphasised the need to analyse the 'individuality' of instruments,[32] and their 'inverse constructions'.[33]

4. Maintaining the Cambridge Transit Instrument

Level error (figure 25) referred to the pivot of the instrument not being perfectly horizontal, which usually manifested itself in one of the piers being higher than the other. This was caused by the gradual sinking of the piers over time, or due to problems with the ellipticity of the pivots.

[31] Since transit circles were also used to measure the declination of a celestial object, these errors also affected those measurements.
[32] 'On the Differences of Declination of Certain Stars, according to Different Astronomers; and on Refraction, &c. Extracted from a Letter of M. J. J. Littrow, Director of the Imperial Observatory at Vienna, to the Foreign Secretary' -dated Vienna, 3 January 1823', *Memoirs of the Astronomical Society*, 1:2 (1825), 341-348 (p. 342).
[33] Benjamin Gompertz, 'On the theory of astronomical instruments', *Memoirs of the Astronomical Society*, 1:2 (1823), 349-372 (p. 350).

This error affected the observations of stars by making them appear to cross the middle vertical wire of the instrument sooner or later than it actually crossed the meridian. Unfortunately for astronomers, the value of this error could not be derived from the observations only. Instead, it required the use of a spirit level. The one used with the Cambridge Transit Instrument was re-examined by Dollond half a year after Airy began his directorship. While the instrument maker found it in good condition, the spirit level showed different values upon repeated measurement of the level error of the transit instrument. This was not surprising, since as Robert Main also pointed out in his textbook on practical astronomy, 'even the observer's breath or the warmth of his body […] tend to alter the length of the bubble [inside the spirit level], and therefore […] vitiate the result.'[34] Similarly, Airy argued that his failures with the spirit level were due to the inability to fix it in a stable position, thereby once again emphasising the inherent imperfections of instruments. As a result, he decided to measure the value shown by the spirit level six times, each time reversing the instrument on its horizontal axis. After measurement, the difference between the readings were calculated by taking into account the radius of the pivots, and the difference between the heights of the Y bearings upon which the pivots rested. The results of the calculations were entered into printed forms which aided the visual organisation of the values, and the final results were kept in what Airy referred to as the Level-Book. These results were then applied to the observations made of celestial bodies. In brief, the level errors were maintained and repaired through their materiality and through calculations too.

[34] Robert Main, *Practical and Spherical Astronomy* (Cambridge: Deighton, Bell, and Co., 1863), p. 23.

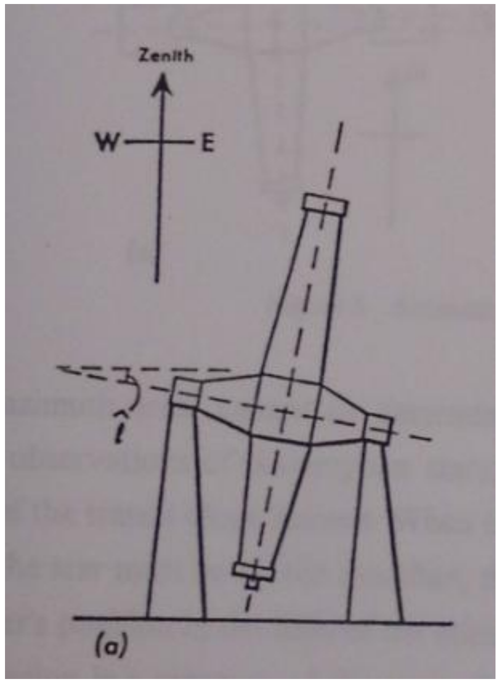

Fig. 25. Level error of a transit instrument (figure from Satterthwaite (1995), p.10.)

Collimation error (figure 26) was defined as the state when the optical axis of the instrument was not perpendicular to its horizontal axis. Out of the three instrumental errors mentioned here, collimation error was considered by Airy to change its value with the least frequency.[35] While level errors could be neglected in special cases of observations, the collimation error always had to be determined. This was because observations without accounting for the level error were still able to provide the correct distance between the various celestial objects. By contrast, due to the nature of collimation error, the measured distances between the stars were not uniformly deviated. Airy initially used a commonplace technique of establishing this value, which relied on comparing the observations with the Cambridge Transit Instrument with the observations published in the Greenwich Catalogues. However, he found this method unreliable due to the

[35] Airy, *Cambridge observations*, 1829, p. 42.

inaccuracies within the Greenwich publications. Instead, he decided to measure it using a meridian mark.

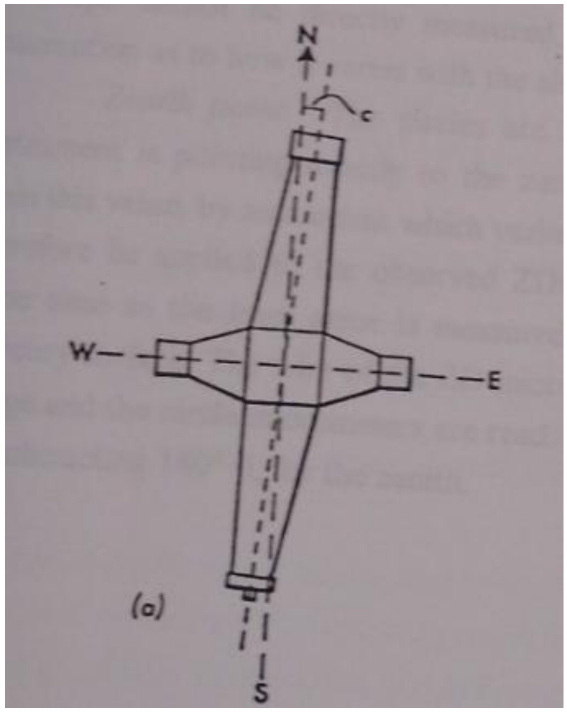

Fig. 26. Collimation error of a transit instrument (figure from Satterthwaite (1995), p.12.)

The use of meridian marks was an already established method in astronomy. It consisted of placing an object at a large distance away from the observatory, but still visible through the instrument. By pointing the telescope at this object, and comparing the deviations of the middle transit wire from it, the astronomer was able to measure the collimation error. This technique had been in use at least from the beginning of the 18th century. For example, when Maskelyne took over the position of Astronomer Royal in 1765, he spent several months trying to find out which one of the meridian marks made by his predecessors was used for adjusting the Bird Transit Instrument (usually known as the Bradley Transit Instrument) at the Royal Observatory, Greenwich.[36] A meridian mark was also set up for the Paris Observatory shortly after its founding at the end of the seventeenth century. Airy implemented a similar system in Cambridge. A meridian mark (i.e. a board containing a series of white circles painted on a black ground) was attached to the steeple of the Grantchester church.[37] However, the mark was deemed insufficient for the determination of the error, and upon the suggestion of Richard Sheepshanks, it was replaced with a lamp. The process of measuring the collimation error using the meridian mark included three steps in the case of the Cambridge Transit Instrument. First, the position of the middle wire was measured with a micrometer. Second, the micrometer wire was made to coincide with the lamp. Third, the instrument was reversed and the micrometer was once again made to coincide with the lamp. Once this error was found, the inequality of the screw of the micrometer (this was the screw used for moving the micrometer wire) was also measured. Finally, the calculations had to account for the effect of aberration

The final instrumental error of the transit instrument was called azimuth or meridian error (figure 27). It referred to the deviation of the positioning of the instrument from the local meridian. This was usually due to the pivots being misplaced to either a southern or northern direction. In order to find this error of the instrument, astronomers relied on the observation of the transit of Polaris with another known celestial object closely following it. Since it relied on this comparison of transit times, before determining the deviation from the meridian, both collimation and level errors (as well as other astronomical constants) had to be accounted for, since all of those measured affected the time of transit.[38]

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[36] Nevil Maskelyne, *Astronomical Observations Made at the Royal Observatory at Greenwich* (London: W. And J. Richardson, 1776), p. iv.
[37] Airy, Cambridge Observations, 1829, p. 35.
[38] Airy, *Cambridge Observations*, (1829), p. 44; William Wallace Campbell, *The Elements of Practical Astronomy* (New York: The Macmillan Company, 1899), pp. 142-143.

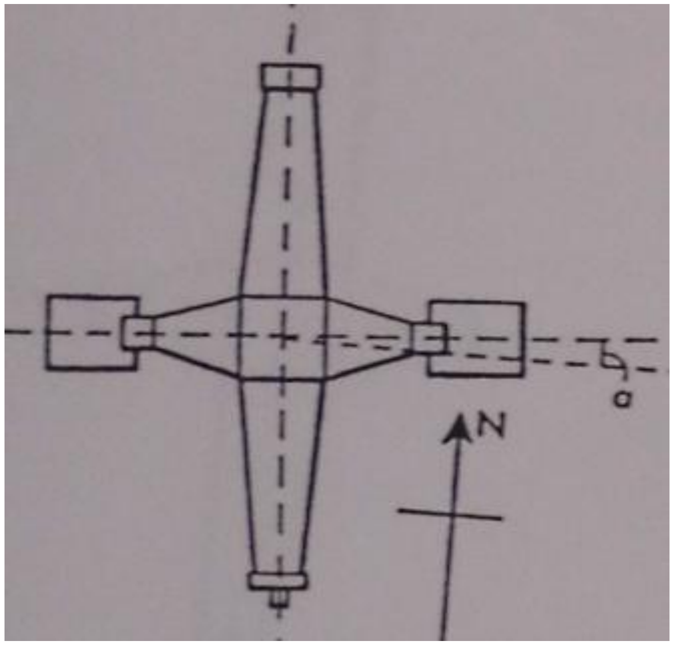

Fig. 27. Azimuth error of a transit instrument (figure from Satterthwaite (1995), p.11.)

After measuring and finding the errors for level, collimation and azimuth, they were brought together in a form prepared by Airy (figure 28). This form helped to order the calculations as a simple chain of arithmetic additions and subtractions. Interpreting the form from the top to the bottom, we find the following details for the observation. The top row showed whether the instrument was in a reversed state or not (East meaning the reversed state, while West meaning the general state). This determined the positive or negative value of the errors. The second row showed the solar time as well as the name of the star. The third row of columns consisted of the observed time of the transits over each wire that was used. The next row showed the observed time as derived after taking into account the mean of the transit wires. Below it, the value for the level error followed, also noting which end of the axis was lower, thus determining whether the value was positive or negative. In the row below, the value for the collimation error was added to it. Finally, the error of meridian was taken into account, which produced the ‘Time of True Transit’ in the row below. Two other rows noted the name of the observer as well as that of the person carrying out the calculations. Finally, general remarks about the observation were made at the bottom that provided further information for sources of errors and on the reliability on the observation. These remarks varied from clouds blocking observations to noting the observer being fatigued at the time.

Illuminated end of axis	West.	
Solar Time and Star's Name.	Sep. 21 . 1 . 30. Spica.	
1st wire		6,4
2d........		24,6
3d........		42,8
4th........		0,9
5th.......		19,0
6th.......		37,2
7th.......	13 . 18 .	55,6
		7) 36,5
		5,21
Add......		5,71
Observed time......................	13 . 18 .	0,92
E. end of axis lowest.............	−,91 × ,032	−,03
		0,89
Line of Collimation to E.......	1,4 × ,068	+ ,10
		0,99
W. end of axis to S..........	4,7 × ,060	+ ,28
Time of True Transit............	13 . 18 .	1,27
Observed by........	G. B. A.	
Reduced by........	G. B. A on Oct. 15.	
Remarks	Steady, but not well observed.	

Fig. 28. Skeleton form implemented and used by Airy for the reduction of observations at the Cambridge Observatory (*Cambridge Observations 1829*, p. 32)

Airy's form used at the Cambridge Observatory for the reduction of transit observations demonstrates the main features of calculative maintenance. First, the errors of the instrument were measured, and then fixed through the final calculations on paper as opposed to altering the materiality of the instrument. Second, it demonstrated the use of mathematical calculations as a tool for correcting and maintaining the instrument. Third, through the calculative maintenance, the paper produced an imagined and immaterial form of the instrument that was impossible to arrive at through material alterations. Finally, it demonstrated that through these calculations, the immaterial form of the instrument continued being made and re-made even after the instruments were made ready to use.

Since transit circles were combinations of transit instruments and mural circles, they were affected by the instrumental errors of mural circles too. Since mural circles focused on the measurement of the declination, the key feature of the instruments was the graduated (or divided) circle attached to it. Graduated circles were subject to several inherent material errors. Most importantly, even though the craft of dividing circles had attained unprecedented levels of accuracy, the final circles always suffered from minor errors of divisions. In relation to the Cambridge Mural Circle, Airy carried out a close examination of the division errors in order to exclude it as a source for an unknown error affecting the observations. While he found that the divisions suffered from errors, he considered their effects to be negligible.[39] As we will see, the graduated circle of the Airy Transit Circle underwent a similar examination of the divisions, which will be discussed later in this chapter. Another source of inherent error for the divided circles was caused by the changes in temperature. The materials out of which the circles were made reacted to temperature changes, which resulted in small changes in their shapes that were

[39] Airy, *Cambridge Observations*, (1834), p. xxx.

amplified in the cases of precision instruments. Another significant source of error arose from the use of microscopes with micrometers for the precise reading of the divisions. As Airy pointed out in his Cambridge Observations, the precise number of revolutions of the screw that moved the micrometers constantly shifted as a result of the changing shape of the divided circles.

One of the corrections for instrumental errors accounted for, but not explicitly stated in the dataset was the revolutions of the screw of the micrometer microscopes. This was caused by the material being viewed through the microscopes expanding or contracting after larger changes in the temperature. While initially five turns of the micrometer screws were designed to measure the distance between two adjacent divisions on the circle, the changing shape of the circle due to temperature made this rate constantly changing. As a result, Airy implemented the rule to re-measure the number of revolutions when there were larger changes in the temperature. The variations of the runs of the micrometers over the weeks of a year were then published as a small table in the introduction. Once again, taking these errors into account, the user of the Cambridge Observations could reduce the observations even further. In brief, the Cambridge Mural Circle underwent a similar calculative maintenance that the Cambridge Transit Instrument did.

5. From Cambridge to Greenwich

By comparing how the instrumental errors were maintained at Cambridge and Greenwich, we can see how Airy implemented the same calculative maintenance to the management of instruments at Greenwich. The two observatories were very different in their sizes and their aims. In Cambridge, Airy had only one other assistant to work with, which meant that the two of them carried out the reduction of the observations themselves. Furthermore, since it was a university observatory, the aims of the observatory were more widespread into various areas. By contrast, the Observatory at Greenwich had more assistants, and was founded with the very specific aim of contributing to the ever more precise determination of longitude. With more assistants, Airy had the possibility to focus the attention of each assistant on different instruments, and to employ computers to carry out the reduction of the observations. With this, Airy's tasks relating to the management of the 'observatory business' took up more of his time than previously. The calculative maintenance of the Transit Circle fell within this similar task, since the measurement of the errors, and accounting for them during the reduction process were assigned to the Observatory staff as opposed to being carried out by Airy himself. However, this meant that Airy had to create rigorous rules and instructions for calculative maintenance, which the assistants and the computers had to follow. These rules were described in the introduction of every volume of the Greenwich Observations. In relation to the Transit Circle, the official description of the instrument similarly described how the errors of the instruments were measured upon installation at the Observatory.

The level and collimation error determinations formed a crucial starting point for the Transit Circle. Its official description finished with an outline of the methods and measurements of 10 different sources for its errors. The method of determining the level error changed most significantly in comparison to the instruments at Cambridge. This was because unlike the Cambridge Transit Instrument, the Transit Circle was not designed to be reversible (i.e. reverse the position on which piers the pivots rested), which meant that the level error observations had to be carried through 'reflection'.[40] This referred to the pointing of the telescope tube perpendicularly into a filled mercury trough. Then, by using a special eyepiece, light was emitted

[40] Airy, *Greenwich Observations*, (1854), p. v.

towards the object glass so that the both the wires of the telescope and their reflection in the mercury became visible. By repeatedly placing the middle transit-wire so as to coincide with its reflection, and measuring the position of the coincidence with the use of a micrometer, it was possible to take the means of the readings to ascertain the numerical value for the level error. Throughout the first year of its use, the level error was determined twice a day, but since no measurable differences were found, they were only made once a day afterward.[41] The level errors were published in two formats. First, the level error for each day of the year was compiled and published in a separate table forming part of the *Greenwich Observations.* This table (figure 29) showed the day and the hour of observation, the mean of the readings made with the micrometer, the line of collimation adopted for that day, the difference between the reading of the level error and the line of collimation, and finally the adopted level error. As can be seen from the table, despite the daily measurements, errors were usually adopted for a period of few days.

[41] Airy, *Greenwich Observations*, 1854, p. xxvi.

MEAN READINGS of the TRANSIT MICROMETER for Coincidence of the Direct and Reflected IMAGES of the CENTRAL TRANSIT WIRE of the TRANSIT CIRCLE, and Determination of the ERROR of LEVEL of the AXIS of REVOLUTION.

(Each Number is usually the Mean of Six Observations.)

Day and Hour of Observation.	Mean Reading of Transit Microm. for Coincidence of Images.	Adopted Reading for Line of Collimation.	Excess of Reading for Line of Collimation above Reading for Coincidence; or Error of Level.	Error of Level expressed in Arc.	Adopted Error of Level of Axis of Revolution.
1852. d h	r	r	r	"	"
Jan. 1. 0	31 ·577	31 ·486	−0 ·091	−1 ·34	
7	31 ·567		−0 ·081	−1 ·19	
21	31 ·548		−0 ·062	−0 ·92	
2. 8	31 ·564		−0 ·078	−1 ·15	−1 ·32
23	31 ·607		−0 ·121	−1 ·79	
3. 8	31 ·590		−0 ·104	−1 ·54	
5. 0	31 ·619	31 ·510	−0 ·109	−1 ·61	
5. 5	31 ·620		−0 ·110	−1 ·63	
5. 22	31 ·654		−0 ·144	−2 ·13	
6. 7	31 ·656		−0 ·146	−2 ·16	
7. 1	31 ·667		−0 ·157	−2 ·32	
13	31 ·672		−0 ·162	−2 ·40	−2 ·08
22	31 ·676		−0 ·166	−2 ·45	
8. 6	31 ·667		−0 ·157	−2 ·32	
9. 0	31 ·650		−0 ·140	−2 ·07	
9. 7	31 ·649		−0 ·139	−2 ·05	
10. 8	31 ·627		−0 ·117	−1 ·73	
12. 0	31 ·672	31 ·495	−0 ·177	−2 ·61	
7	31 ·707		−0 ·212	−3 ·14	
21	31 ·689		−0 ·194	−2 ·87	
13. 7	31 ·695		−0 ·200	−2 ·96	
13. 23	31 ·703		−0 ·208	−3 ·08	
14. 6	31 ·698		−0 ·203	−3 ·00	−3 ·09
23	31 ·717		−0 ·222	−3 ·29	
15. 22	31 ·736		−0 ·241	−3 ·56	

Day and Hour of Observation.	Mean Reading of Transit Microm. for Coincidence of Images.	Adopted Reading for Line of Collimation.	Excess of Reading for Line of Collimation above Reading for Coincidence; or Error of Level.	Error of Level expressed in Arc.	Adopted Error of Level of Axis of Revolution.
1852. d h	r	r	r		"
Feb. 5. 11	31 ·807	31 ·578	−0 ·229	−3 ·39	−3 ·75
21	31 ·834		−0 ·256	−3 ·79	
6. 7	31 ·835		−0 ·257	−3 ·80	
21	31 ·822		−0 ·244	−3 ·61	
7. 7	31 ·804		−0 ·226	−3 ·34	
9. 8	31 ·782	31 ·600	−0 ·182	−2 ·69	
10. 8	31 ·736		−0 ·136	−2 ·01	
11. 7	31 ·753		−0 ·153	−2 ·26	
22	31 ·707		−0 ·107	−1 ·58	−2 ·10
13. 8	31 ·723		−0 ·123	−1 ·82	
14. 9	31 ·752		−0 ·152	−2 ·25	
16. 9	31 ·791	31 ·640	−0 ·151	−2 ·23	
17. 8	31 ·870		−0 ·230	−3 ·40	−2 ·82
18. 8	31 ·832		−0 ·192	−2 ·84	
19. 8	31 ·784		−0 ·144	−2 ·13	
20. 8	31 ·748		−0 ·108	−1 ·60	−1 ·75
21. 7	31 ·743		−0 ·103	−1 ·52	
23. 9	31 ·752	31 ·654	−0 ·098	−1 ·45	
24. 8	31 ·798		−0 ·144	−2 ·13	
25. 6	31 ·796		−0 ·142	−2 ·10	
26. 8	31 ·781		−0 ·127	−1 ·88	−1 ·92
27. 7	31 ·787		−0 ·133	−1 ·96	
28. 12	31 ·788		−0 ·134	−1 ·98	
Mar. 1. 7	31 ·781	31 ·608	−0 ·173	−2 ·55	

Fig. 29. Table showing the adopted level errors for the year 1852 (*Greenwich Observations 1852*, p. 109)

The second format in which the measurements appeared formed part of column 15 of the Transit Observations table, where the adopted level error value appeared alongside the collimation and azimuth errors. The observations could then be reduced to take into account the level error by using the following equation:

$$\text{Error of Level} \times \frac{\text{cos zenith distance.}}{15 \text{ sin N.P.D.}}$$

Collimation error was also determined differently in the case of the Transit Circle, than in the case of the Cambridge Transit Instrument. In Greenwich, this error was determined with the two collimating telescopes facing each other along the meridian in the northern and southern ends of the Transit Circle Room. The measurement of the error was carried out by raising the telescope tube and the horizontal axis of the Transit Circle, setting the wires in the two collimating telescopes to match each other's lines of sight, then lowering the transit circle tube and measuring the differences between the images of the northern and southern collimating wires.[42] The collimation errors measured this way were not repaired by modifying the materiality of the telescope. Instead, they were only accounted for during the final reductions of the observations, when the exact positions were calculated.[43] Therefore, this example represents that maintenance can apply to both the materiality of the instrument and to its immaterial presence/products at the same time.

$$\text{Error of Collimation} \times \frac{1}{15 \sin \text{N.P.D.}}$$

The determination of the azimuth error of the Transit Circle initially took the same form as that of the Cambridge transit instrument: it relied on the measurements of the transits of Polaris. The numerical correction of the transits were then achieved by applying the following formula:

$$\text{Azimuthal error} \times \frac{\text{sin zenith distance south.}}{15 \times \sin \text{N.P.D.}}$$

This method was later modified to include the use of the north collimator. This meant that the usual measurements of the azimuthal error were compared to the azimuthal error of the north collimator, since this collimator was found to be more reliably steady. The difference between the azimuth of the Transit Circle and the collimator then offered the azimuthal error of the Transit Circle. Variations within the error values of the azimuth gained Airy's further interest

[42] This method was changed in the 1860s, once the central cube of the transit circle cube was pierced through to enable setting the images of the wires of the two collimating telescopes without having to raise the transit circle.
[43] Yet, its close connection to the maintenance practices engaging directly with the materiality of the transit circle was symbolised through carrying the observations out during the weekly essential maintenance (cleaning and oiling) of the Transit Circles on Mondays.

towards the end of the 1850s. He ordered his assistants to compare the historical values of the error recorded throughout the decade. The investigation was later expanded to include an analysis of the level error too. The results of the analysis were then presented at a meeting of the Royal Astronomical Society by William Ellis (an astronomical assistant at the Observatory),[44] and eventually published in the Memoirs of the Society in 1861 (figure 30).[45] The paper demonstrated through historical data and graphs the correlation between the fluctuation of the temperature, the level error, and the azimuth error.

The following curves show the relative changes of the azimuth of the transit-circle, and azimuth of the north collimator, and the general connexion with temperature, from the mean of the six years' observations 1853 to 1858. The thick line represents the azimuth of the transit-circle, the thin line the azimuth of the north collimator, and the dotted line the curve of temperature.

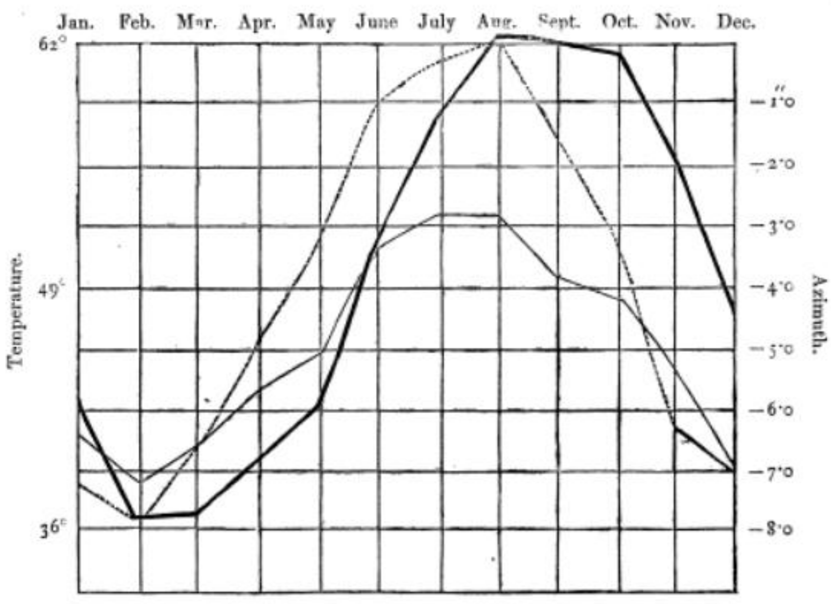

Fig. 30. Graph and explanatory description from William Ellis's paper (1861)

[44] During the years 1860 and 1861 Ellis made regular observations with the Transit Circle, and contributed to the reduction of the observations made with the instrument. In addition, he was in charge of the chronographic registry of the transits, the dropping of the time-ball, the distribution of time signals, keeping the manuscripts of the Observatory in order, and arranging the money accounts of the Observatory. See Airy, *Greenwich Observations*, 1861, pp. i-ii.
[45] William Ellis, 'On the periodical variations of Level and Azimuth of the Transit Circle at the Royal Observatory, Greenwich', *Memoirs of the Royal Astronomical Society*, 29 (1861), 45-57.

The errors of the divided circle attached to the horizontal axis of the Transit Circle were accounted for in a similar manner. Due to the effects of the temperature, and of the weight of the instrument, the divisions did not accurately reflect the angle at which the transit of the celestial body was observed with the instrument.[46] Attempts were made to minimise the effects of these factors and were implemented into the original design of the Transit Circle through the choice of materials and the use of extra micrometers for reading the divisions. However, the errors that occurred after the installation of the instrument were not repaired through modifying the materiality of the graduated circle, but instead were measured through a rigorous and tedious analysis of the accuracy of its divisions. This was carried out by Edwin Dunkin, who recorded the deviation of every single point of graduation on the divided circle in order to apply those measurements during the reduction of the observations.[47] This was a unique task due to the time-consuming nature of the work. By the end of the nineteenth century, graduated circles consisted of 10,800 divisions in average for transit circles.[48] Since the Observatory employed a relatively large number of astronomical assistants, Airy was able to devote a person to carrying out the entire work.

The official description of the instrument details the painstaking and disciplined work that was required for ascertaining their original error values of the graduated circle, which were later applied to the reductions of observations. The design of the Transit Circle helped in carrying out the task with more efficiency, as the graduated circle could be observed with 6 different microscopes inserted into the western pier. Rather than placing them horizontally on the sides of the circle (as in the case of the Cambridge Mural Circle), the microscopes were positioned in an

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[46] The method of dividing up the graduated circle also imposes limitations on the accuracy of measurement with the Transit Circle. For a historical treatment of the subject see Chapman, *Dividing the Circle*.

[47] Documents showing the Sisyphean work that Dunkin had to carry out can still be found today within the correspondence on instruments folders of the RGO archives; see RGO 6/166, and RGO 6/170-173.

[48] Campbell, *The Elements of Practical Astronomy*, p. 183.

angle, so as to make readings with them quicker and easier. The examination of the division of the errors of the graduations began by determining the errors of the six cardinal divisions (every 60 degrees). Each one of these divisions was observed 120 times. By taking the mean of the observations, the errors of these divisions were recorded. The recorded errors then served the basis for determining the errors of every graduation of 20 degrees. These were observed 20 times with four microscopes to ascertain their initial errors, and then further reduced by applying to them the errors of the cardinal divisions. The error values of 20 degrees then served as the basis for determining the errors of every 5 degrees graduations of the circle. Each one of these graduations underwent 16 readings, and was then adjusted to the errors of the circle determined by the readings of the 20-degree graduations. A similar process was used to determine every 1 degree of graduation from the mean of four readings. While Airy characterised the results as good, he was still worried about the effect of a focal adjustment during the last part of the operation, which prompted him to propose the redetermination of the errors in the future.[49] The final table (figure 31) showing the errors of every 1 degree of graduation was then printed as part of the official description of the instrument.

[49] Airy, *Description of the Greenwich Transit* Circle, 1854, p.21. There was no mention in the second edition of the official description published in 1869 whether this redetermination of errors had taken place or not.

Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.
°	r	°	r	°	r	°	r	°	r	°	r	°	r	°	r
0	0·054	45	0·057	90	0·076	135	0·085	180	0·050	225	0·029	270	0·073	315	0·070
1	·053	46	·062	91	·078	136	·087	181	·046	226	·033	271	·071	316	·071
2	·050	47	·066	92	·081	137	·095	182	·043	227	·039	272	·061	317	·075
3	·053	48	·073	93	·073	138	·089	183	·045	228	·041	273	·059	318	·077
4	·052	49	·069	94	·078	139	·082	184	·047	229	·050	274	·058	319	·071
5	·053	50	·061	95	·073	140	·081	185	·042	230	·053	275	·063	320	·078
6	·053	51	·058	96	·072	141	·084	186	·037	231	·054	276	·063	321	·074
7	·051	52	·064	97	·071	142	·083	187	·043	232	·058	277	·067	322	·069
8	·054	53	·086	98	·070	143	·091	188	·045	233	·062	278	·072	323	·079
9	·050	54	·071	99	·075	144	·086	189	·038	234	·058	279	·072	324	·075
10	·052	55	·076	100	·075	145	·080	190	·028	235	·052	280	·066	325	·075
11	·061	56	·075	101	·067	146	·073	191	·019	236	·040	281	·068	326	·073
12	·061	57	·077	102	·073	147	·078	192	·026	237	·043	282	·069	327	·065
13	·057	58	·080	103	·069	148	·078	193	·034	238	·052	283	·070	328	·063
14	·065	59	·079	104	·065	149	·072	194	·032	239	·061	284	·065	329	·067
15	·058	60	·074	105	·064	150	·073	195	·036	240	·064	285	0 59	330	·063
16	·060	61	·072	106	·066	151	·068	196	·038	241	·072	286	·061	331	·057
17	·055	62	·065	107	·061	152	·073	197	·036	242	·069	287	·055	332	·068
18	·062	63	·064	108	·059	153	·081	198	·039	243	·073	288	·057	333	·072
19	·062	64	·074	109	·067	154	·081	199	·044	244	·064	289	·057	334	·074
20	·064	65	·067	110	·065	155	·087	200	·038	245	·062	290	·055	335	·075
21	·052	66	·063	111	·064	156	·088	201	·046	246	·052	291	·056	336	·076
22	·052	67	·060	112	·067	157	·075	202	·044	247	·045	292	·069	337	·070
23	·051	68	·062	113	·068	158	·069	203	·040	248	·038	293	·065	338	·067
24	·055	69	·068	114	·073	159	·070	204	·040	249	·043	294	·072	339	·066
25	·053	70	·065	115	·072	160	·072	205	·043	250	·046	295	·076	340	·067
26	·062	71	·060	116	·078	161	·067	206	·041	251	·045	296	·072	341	·069
27	·057	72	·054	117	·078	162	·061	207	·045	252	·046	297	·070	342	·076
28	·057	73	·047	118	·071	163	·059	208	·045	253	·050	298	·063	343	·073
29	·060	74	·045	119	·077	164	·060	209	·045	254	·054	299	·065	344	·069
30	·062	75	·058	120	·079	165	·067	210	·052	255	·061	300	·082	345	·070
31	·069	76	·056	121	·084	166	·065	211	·052	256	·066	301	·079	346	·067
32	·065	77	·055	122	·087	167	·062	212	·042	257	·069	302	·074	347	·068
33	·067	78	·056	123	·095	168	·056	213	·042	258	·065	303	·078	348	·068
34	·064	79	·061	124	·100	169	·057	214	·037	259	·058	304	·083	349	·061
35	·061	80	·065	125	·088	170	·052	215	·031	260	·065	305	·079	350	·053
36	·055	81	·072	126	·093	171	·055	216	·039	261	·074	306	·080	351	·050
37	·054	82	·076	127	·090	172	·053	217	·034	262	·073	307	·080	352	·044
38	·055	83	·077	128	·087	173	·049	218	·040	263	·074	308	·077	353	·049
39	·066	84	·077	129	·082	174	·046	219	·031	264	·076	309	·074	354	·047
40	·065	85	·077	130	·079	175	·041	220	·035	265	·078	310	·070	355	·041
41	·068	86	·075	131	·087	176	·044	221	·034	266	·079	311	·077	356	·046
42	·072	87	·083	132	·070	177	·057	222	·031	267	·086	312	·073	357	·050
43	·070	88	·074	133	·076	178	·053	223	·035	268	·083	313	·074	358	·053
44	·062	89	·076	134	·080	179	·051	224	·036	269	·075	314	·075	359	·054

Fig. 31. Table from the official description of the Transit Circle showing the errors of every 1 degree of graduation (1854)

The errors measured during the analysis of the graduated circle, like the collimation errors, were applied only during the final calculations, as opposed to being directly repaired through the materiality of the instrument. In brief, if we approach the maintenance of the instrument from this angle, maintenance referred not only to the repair of its materiality, but rather to the ever more precise measurements of its errors that were then corrected through calculations during the final reductions of the observations made with the Transit Circle. Therefore, this type of maintenance can also be categorised as calculative, as it repaired the errors of the instrument not through the materiality of the Transit Circle, but through the final numerical calculations.

6. Technologies of discipline or technologies that required discipline

In relation to the practice of calculative maintenance, this chapter has demonstrated how the Transit Circle was repaired and maintained through the measurement of its errors using mathematical calculations. It also demonstrated the extent to which not only the Observatory staff but also the instruments were put under surveillance. While the observatory staff provided written and verbal feedback to Airy on their work, the measurements of the errors of the Transit Circle served the similar role: it made the instrument speak in order to receive feedback from it, and to adjust the final calculations according to the errors that the instrument made. Through this surveillance of humans and things both observers and instruments were approached as Herschelian wonders capable of committing errors as opposed to miracles that brought forward perfection. This was due to the inherent understanding of both human observers and instruments as entities that constantly changed their qualities. In light of this, within Airy's surveillance of astronomical work at Greenwich both observers and instruments were approached the same way. Simon Schaffer argued that this similarity in approach demonstrated the way in which observers were thought of as machines. For such statement, the underlying assumption is that through disciplining the observer, and through taking into account their personality, the effect of the individual's agency on the calculations can be minimised.

The problem for this argument originates in its assumption that machines and instruments (to which the observers were reduced) were considered as entities without a personality, without agency, and in a relatively static state. However, as this chapter on the calculative maintenance of the Transit Circle has demonstrated, the instrument was assumed to possess a similar personality, which manifested itself in the fluctuations of the error values. In light of this, the instruments were considered to have a personality similar to that of the observers as opposed to being machines without any agency. This way of thinking about instruments and observers remains compatible with Schaffer's approach to the disciplined observers. However, rather than considering disciplining of machines (and observers) as a possibility based on the complete removal of error, it demonstrates that instruments were required to be disciplined precisely because they were seen just as erroneous as humans were. In consequence, Schaffer's statement that 'habits could be disciplined with the new technology' can also be applied if reversed: new technology and instruments could be disciplined with the habits of calculative maintenance performed by humans.[50]

Calculative maintenance raises the question about how we can connect it to the 'factory mentality' upon which the Observatory was organised under Airy. Schaffer showed how personal equation was used by Airy to minimise the effect of the differences between the perceptions of transits by the various observers.[51] Managing personal equations can also be characterised as a form of calculative maintenance since it did not alter the vision of the observer, but instead corrected them post-measurement through calculations during the reduction of the observations of transits. Accounting for personal equations created an imagined immaterial form of the observer that could undergo calculative maintenance with mathematical

[50] Schaffer, *Astronomers Mark Time*, p. 124.
[51] Ibid.

tools on paper. In Schaffer's stance, this regime of control was set up to determine the 'personality' of the individual observers' eyes to take them into consideration during the final calculation of positional data.[52] In relation to the work with the Transit Circle, personal equations were similarly accounted for during the reduction of the observations. The presence of both personal equations and the instrumental errors in the same process demonstrated that both factors contributed to the calculative maintenance of the Transit Circle by producing an ideal form of it via mathematical calculations.

To expand further on Schaffer's analysis, this chapter argues that through the calculative maintenance of the Transit Circle, a similar 'personality' was ascribed to the instrument too. In this light, the attempt to calculate the effects of azimuth, level, and collimation errors served as a way to regulate the 'personality' of the Transit Circle. The analysis of factory mentality tends to ascribe almost exclusive emphasis on how the observers were reduced to subjects who could be controlled in the same ways as the instruments/machines that they minded. Going beyond this framework towards the romantic machines approach, we can reinterpret the same assemblage of the Transit Circle in a manner that demonstrates the agency of the material parts of the instrument. In this framework, the emphasis is not on the relationship of control that is established through the measurement of personality, but instead on the fact that such a personality is ascribed to the instrument in the first place. As it was mentioned above, the calculations to take into account the errors of the instrument were controlled the same way as the personalities of the observers. Such an assumption of a personality ascribed to the instrument implies that they were not thought of as passive mechanical artefacts, but rather as instruments that actively participated (with their personalities) and responded freely to their milieus during

[52] Ibid.

the observation process.[53] This reframing of the instrument as an artefact with personality allows for a different consideration of interaction with the instrument and its parts. Maintenance no longer appears as a simple, routine act, but rather, as an intimate interaction with the instrument that serves to establish a relationship of care as opposed to a relationship of control. In consequence, maintenance practices can be categorised as acts focused on stabilising the 'well-tempered' status of the instrument, while repairs turn into practices that restore the instrument into a condition where the stability once again can be attained.[54] As Main highlighted in his textbook, the spirit level of transit instruments respond even to the breath of the observer.[55] Finally, Newcomb's tale of the assistant giving a good slap to the instrument no longer appears as a demonstration of the mechanical sturdiness of the Transit Circle, but rather as the "friendly pat" on the back of one's companion.[56]

7. Conclusion

The aim of this chapter was to demonstrate through the example of the Transit Circle the use of mathematical calculations as a tool to tackle the problem of instrumental errors. The chapter focused its attention on four main instrumental errors: azimuth, collimation, level, and the divisions of the graduated circle. However, the Transit Circle was affected from various other instrumental errors too. While an extensive analysis of every source of instrumental error that affected the Transit Circle is beyond the limits of this dissertation, it is worth mentioning in these

[53] Tresch, *The Romantic Machine*, p. 80.
[54] Ibid.
[55] Main, *Practical and Spherical Astronomy*, p. 23.
[56] As Tresch demonstrated, the instruments as companions idea was prevalent in the views of Alexander von Humboldt. While it is beyond the scope of this chapter, it would be interesting to investigate the extent to which Airy was influenced by Humboldt's thinking.

concluding paragraphs a few others. In addition, their mentions will demonstrate that a detailed analysis of instrumental errors and their management within a nineteenth-century context is yet to undergo a general overview that spans across the boundaries of various fields of science.

The eyepiece of the telescope tube suffered from several errors. On many occasions the wires inside them either broke and disappeared, or were destroyed by careless observers. As a result, they had to be replaced whenever they broke. However, this produced minor changes in the distance (or intervals) between each one of the vertical wires. These new intervals similarly had to be accounted for every time one or more of the wires changed. Another instrumental error arose from the gradual changes occurring in the shape of the pivots. The attention, care, and detail that went into the production of the pivots was highlighted in Chapter 2. It was also mentioned that the pivots gradually changed their forms over time. While Airy made sure to account for the possible effects, he considered their accuracy so great that their effect on the observations was deemed negligible. Finally, flexure was also one of the instrumental errors that had to be accounted for during the reduction of the observations. This error referred to the bending of the telescope tube over time under its own weight. It affected the two ends of the telescope tube as they were the least supported parts of the tube. To minimise this problem, other transit circle designs opted for the use of small telescope tubes or for connecting the tube to the rotating circles (wheels) besides the tube (as in the case of the Harvard Transit Circle). Flexure affected the observations by altering the angle at which the celestial body appeared in the field of view of the instrument. In brief, instrumental errors of astronomical instruments require a more in depth analysis in order to demonstrate the differences and the similarities between their treatment, and how such practices reflected nineteenth-century considerations of mental and physical engagements with science and its tools.

Focusing on the maintenance of the Airy Transit Circle allows us to gain new insight into one of the most frequently used astronomical instruments of the nineteenth century, and into the workings of the Observatory that housed it. Through the lenses of maintenance (as communicated through Airy's correspondence as opposed to the *Annual Reports*), the instrument appeared not as a stable object, but instead as an object that was in a constant state of change: both decaying and being improved. This duality of states of change showed the instrument becoming the Transit Circle (through adopting the functions ascribed to it by the various entities) as well as the ways in which the materiality of the Transit Circle counteracted its intended functions. Therefore, the history of the instrument was not only its process of becoming the Transit Circle, but also the parallel process of un-becoming the Transit Circle. If becoming was manifested through modifying the instrument to suit functions ascribed to it by its users, then the process of un-becoming was the constant decay and counteractions of the instrument, i.e. its personality. Therefore, the history of the maintenance of the Transit Circle illuminates the latter, and demonstrates how the act of maintenance served the purpose of directing the instrument to become the Transit Circle as imagined by George Airy and the Observatory. In this light, calculative maintenance used mathematics as a tool and technology of discipline, which played the role of countering the un-becoming of the Transit Circle.

Maintenance of the Transit Circle was not limited to inscribing the "fixes" into the materiality of the instrument. Instead, it also took the form of the measuring the errors of the instrument, and then applying the repairs to it theoretically during the final process of calculating the exact time and position of the observed celestial bodies. This action demonstrated that the constant un-becoming of the Transit Circle was a process that the individuals who interacted with it were aware of. However, rather than attempting to control it exclusively through the instrument's materiality, the process of un-becoming was countered with immaterial paperwork. As Charles Dickens ironically described the work of astronomers, they had the tendency to 'arrange the starry universe solely by pen, ink, and paper' inside windowless rooms.[57] This demonstrated that maintenance was not a process focusing exclusively on applying fixes directly to the materiality of the instrument, but was also implemented on the immateriality of the same instrument. This distancing of the maintenance practices of the Transit Circle allowed us to move away from the confines of the Transit Circle Room into the realm of actions devoted to (re-)presenting immaterial forms the instrument. Such a shift in the approach opened up the possibility to consider other aspects of the Observatory life that focused on the maintenance of the "immaterial" side of the Transit Circle.

This chapter also showed that calculative maintenance was a longstanding practice within the field of astronomy. However, during the first half of the nineteenth century efforts were made for its systematisation. The contribution of Bessel was especially significant to these developments. As the chapter showed, Airy and his British contemporaries were aware of Bessel's contributions, and Airy himself adopted the technique. By doing so, this chapter highlighted the international influence on Airy's thought, and subsequently on the design of the Transit Circle. Through such an approach, the Transit Circle and its operations embedded the practices of the wider international astronomical community as opposed to only those of the British astronomical culture.

Finally, the emphasis on calculative maintenance in the operations of the Transit Circle was reflective of the hierarchy imposed by many astronomers (including Airy and Herschel) on the labours between artisans and practical astronomers. It was reflective of the belief that the

[57] Charles Dickens, *Hard Times* (London and Toronto: J. M. Dent & Sons Ltd. & E. P. Dutton & Co., 1920), p. 85.

boundaries of physical engagements with materiality could be improved upon by the immaterial calculations. This belief also appeared in the chapter on the construction of the mechanical parts of the Transit Circle, which demonstrated how this idea was later manifested in nineteenth-century debates about material artefacts defining standards.

Chapter 5 : Status Maintenance

1. Introduction

The previous two chapters have demonstrated the importance of maintenance in the everyday operations of the Transit Circle. Chapter 4 further expanded on this theme by demonstrating that both the materiality and the immateriality of the instrument underwent maintenance. It also showed that the immaterial form of the instrument produced through mathematical calculations was able to go beyond the boundaries of the Transit Circle Room and the Observatory. This chapter expands on that analysis by focusing on another immaterial form of the instrument: its image in the eyes of the astronomical community and the general public. It argues that the image of the instrument also had to be maintained, which included maintaining the reputation and status of the Transit Circle alongside the reputation of the Observatory. As the examples within this chapter will demonstrate, the image of the instrument was inherently linked to its reliability, which served a key part in making the observations with the instrument trustworthy. In consequence, Airy's task as the Astronomer Royal extended to maintaining the reputation of the instruments too.

The term maintenance (as used in the previous two chapters) tends to refer to tasks that are directly connected to the materiality of an instrument. A good example of this was the oiling of the pivots by Green (the carpenter of the Observatory). Calculative maintenance was similarly linked to the materiality as it involved the direct measurement of the errors of the instrument. This chapter argues that the reputation and the image of the instrument within the astronomical community were similarly grounded on the materiality of the Transit Circle. They were derived mainly from the instrument's performance and the measurements produced with it. As the second half of this chapter demonstrates, the criticisms of the Transit Circle were focused on exactly these issues: whether the performance was as good as Airy described, and whether the measurements produced with it were reliable at all. Additionally, models, illustrations, and descriptions were examples of material engagements with the immaterial forms of the Transit Circle. Such maintenance of the reputation of an instrument can also be referred to as 'image management'. Within the history of scientific instruments it has usually been applied to managing the reputation of the instrument makers. For instance, Morrison-Low described how instrument makers used Royal commissions to heighten their reputation.[1] The 'Astronomers at War' episode can also be understood as an attempt by a group of astronomers to manage the image and reputation of the instrument makers Troughton & Simms.[2] However, by using the term 'maintenance', the chapter emphasises as the source of the close link between the reputation and the materiality of an instrument.

This chapter considers communicating descriptions, images, and models of scientific instruments to audiences as acts of presentations. Through these communications the immaterial "images" of the instruments are presented to audiences. Such an "image" of a scientific instrument becomes its immaterial persona. For example, an instrument maker could present "images" of instruments that would attract the customer.[3] In other cases, presentations could 'vouch for the quality of the instruments.'[4] In an extensive study of early-modern visual representations of machines, Marcus Popplow categorised images according to being presented to the public, to the individuals crafting the machines, to craftsmen for future use, and

[1] Alison Morrison-Low, *The Scientific Instrument Trade in Provincial England during the Industrial Revolution* (Doctoral dissertation, University of York, 1999), pp. 182-183.
[2] Hoskin, 'Astronomers at war'.
[3] Morrison-Low, *The Scientific Instrument Trade*, pp. 181-198.
[4] Sven Dupre, 'Newton's Telescope in Print: The Role of Images in the Reception of Newton's Instrument', *Perspectives on Science*, 16:4, (2008), 328-359 (p. 330).

to specialist audiences for theoretical consideration.[5] The case studies in this chapter demonstrate how different groups of people attempted to create different “images” of the Transit Circle, and to use them for different purposes. For example, the discussions about the models of the instrument for the Exposition Universelle in 1855 pitted against each other the purpose of showcasing the historical reputation of the instruments, Airy’s new set of instruments, or the Transit Circle only. Each one of these options would have presented a different “image” of the instrument. By understanding which networks of individuals supported which “images”, we can derive how they perceived the Transit Circle and for what purposes they were attempting to use it. Such an analysis provides us with a more complete understanding of the role that the instrument played in nineteenth-century science and technology. In addition, it also shows how the different immaterial “images” attached to the instrument shaped the final material forms of the models, thereby once again highlighting the interconnected nature of the material and immaterial forms of instruments.

Throughout the working life of the Airy Transit Circle, physical access to the instrument was limited to selected members of the Observatory staff.[6] Despite the relative physical isolation of the instrument, the Transit Circle was communicated to a wider audience beyond the gates and walls of the Observatory.[7] Such communications took several forms: articles about the Observatory, specialist astronomical research papers, models at exhibitions, illustrations, and photographs. By analysing the ways in which the Transit Circle was depicted via these media,

[5] Marcus Poppow, ‘Why draw pictures of machines?’, in Wolfgang Lefevre (ed.), *Picturing Machines 1400-1700* (London; Cambridge, MA: The MIT Press, 2004), 17-49.
[6] Admittance to the ROG was allowed upon invitation only. As a result of this, a large collection of documents survives on admission of visitors to the Observatory alongside the cards of the visitors. These can be found at the RGO 6/706-714, encompassing the period from 1835 to 1880. The annual Visitation by the members of the Board of Visitors remained a similarly restricted event until 1880. In that year, ladies were first allowed to the event, and restrictions on the admittance of members of the general public was also weakened. For more detail on the gradual transformation of the Visitation day see Laurie, *The Board of Visitors*, pp. 344-346.
[7] There has not yet been a comprehensive account of how the ROG was communicated to the public or the scientific communities, but the scholarship on matters related to the history of the Observatory tends to utilise these accounts (especially the *Greenwich Observations*). An abundant, but not yet complete collection of "Contemporary accounts" of the ROG has been made available online by Graham Dolan at http://www.royalobservatorygreenwich.org/articles.php?article=3 [Accessed 29/12/2017]

the chapter reveals the differences between interpretations over the uses of the instrument, and the different ways the instrument was communicated to different audiences.[8] The chapter also highlights the extent to which Airy and other members of the Observatory had control over the content of the descriptions. In cases when descriptions were written by people not associated with the Observatory, and when Airy was unable to exercise control over the communications, the Transit Circle was put under more critical analysis, thereby questioning the reputation of the Observatory as well.

The Transit Circle was communicated through both textual and visual means. Many of the illustrations depicting the instrument (appearing in both popular and scientific accounts) were derived from an illustration supervised by Airy himself. This illustration attempted to show as much of the assemblage of the instrument and in as much detail as it was possible in order to be an accurate depiction of the instrument.[9] By contrast, other illustrations of the Transit Circle tried to capture the experience of seeing the instrument for the first time or being used. These illustrations only accompanied popular descriptions of the instrument, which resulted in the visual implementation of the dramatised depiction of the Transit Circle. Finally, some depictions went beyond the two dimensionality of the page, and entered the realm of three-dimensional objects through models made of the instrument and parts of it. The distinction between the types of models with which the two different subsets of the public encountered continued to exist even within this type of representation. While non-specialist audiences were presented with complete models of the Transit Circle, specialist audiences were shown smaller models of parts of the instrument demonstrating the mechanical novelties implemented into their designs.

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[8] As we will see, Airy distinguished between the "political press" (*Morning Chronicle*) and the "scientific press" (*Athenaeum*). This distinction allowed him to frame his response as coming from an authority in scientific matters as opposed to from an astronomical officer of the Government.

[9] This image was labelled in the original description of the Transit Circle as ‘Plate 1’. This dissertation will adapt ‘Plate 1’ for the illustration, which is shown in fig. 31.

This chapter introduces four case studies about the history of maintaining the status of the instrument. The first case analyses the letters exchanged between Airy and the artist Benjamin Sly to demonstrate how Airy exercised control even on the visual depictions of the instrument. It demonstrates a form of what Daston and Galison labelled as 'policing the artist', in order to remove the 'subjective alterations' made during the process of creating the visual image.[10] The letters show that Airy not only exercised close control of the Observatory staff, but also extended it to any individual working for the Observatory. The second case examines Airy's involvement in the making of the models of the Transit Circle for the 1855 Exposition Universelle in Paris. The story of the model highlights the multiple and often contradictory meanings and narratives within which the instrument was framed, and Airy's difficult task to negotiate these meanings. This case study serves as another example of Airy's struggle for control over how the instrument was communicated to different audiences. Both of these case studies focus on how the visual language of the images was controlled (both successfully and unsuccessfully). Furthermore, they were instances when Airy was directly involved in the production of the final products. By contrast, the third and fourth case studies analyse how the status of the instrument was maintained via texts and in cases when Airy was excluded from the initial communication of the pieces. With this in mind, the third case study examines Airy's reaction to articles in the *Morning Chronicle* criticising the Observatory and its instrumentation, and demonstrates how he tackled criticisms in public light. The final case study focuses on the publication of an article by the astronomer Albert Marth, who highlighted several shortcomings of the Transit Circle and its uses. Labelled by William Henry Smyth as the 'Marthiad', the case demonstrates how Airy handled criticism of the Transit Circle among the astronomical community, and how he relied on his network of friends to halt the publication of the paper in Britain.

[10] Lorraine Daston and Peter Galison, 'The Image of Objectivity', *Representations*, 40 (1992), 81-128 (p. 103).

2. The first illustrations of the Transit Circle

The first illustration of the Transit Circle (figure 32) was published in 1851 in a guidebook for visitors to the Great Exhibition.[11] While the book only mentioned the editor, John Weale, several people contributed to it. One of these contributors was Robert Main, who was the Chief Assistant of the Observatory at the time. His chapter provided descriptions of both public and private observatories in London and around its vicinity.[12] The parts of the chapter describing the Observatory gave a relatively detailed account of the Transit Circle. This was accompanied by an illustration of the instrument. Given that the account was published after the installation of the Transit Circle, both the description and the illustration depicted it as installed within the Transit Circle Room. The text highlighted the 'solidity and the firmness' of the Transit Circle as its main distinguishing features, and gave a lengthy description of its manufacturing process by Ransomes & May.[13] The rest of the description mentioned the graduated circle, the size of the object glass, observations by reflections, and the measurements of the errors of the instrument, ending with a summary of the shutters in the roof of the room. Comparing the text and the illustration, it can be seen that the illustration supported the text by showing the multiple parts of the instrument, including the features of the room within which it was placed.[14] This was also reflected in the label for the accompanying illustration: 'Transit-Circle Apartment.' By doing so, the instrument was illustrated not just as a simple telescope tube, but rather as an assemblage of various instruments sharing the same space.

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[11] John Weale, *London Exhibited in 1851* (London: John Weale, 1851), pp. 652-656.
[12] Ibid. pp. 630-699. While Main's contribution was unacknowledged in Weale's book, Main referred to himself as the author of the chapter/article in one of his books. See Robert Main, *Rudimentary Astronomy* (London: John Weale, 1852), p. 29.
[13] Weale, *London Exhibited*, pp. 652-656.
[14] The illustration can be found in Weale, *London Exhibited*, p. 653.

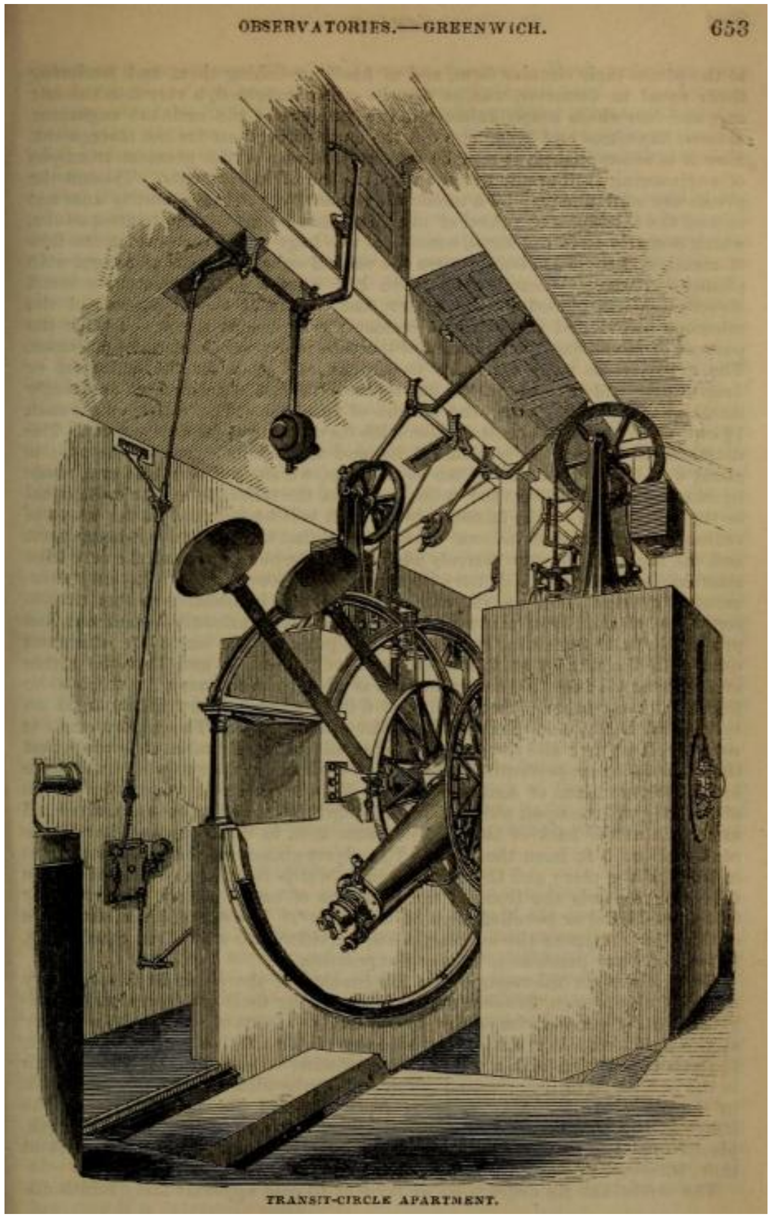

Fig. 32. Illustration of the Transit Circle from Weale's *London Exhibited*

The name of the artist who created the illustration was not mentioned in the book. However, from Airy's correspondence with tradesmen, we learn that he was Benjamin Sly.[15] His illustration foreshadowed the dominant depiction of the instrument during the rest of the century by placing the viewer in the north-west corner of the room. However, his illustration was not a

[15] See Benjamin Sly to George Airy, 3 March 1851, RGO 6/724 760. Relatively little is known about Benjamin Sly, but a few engravings of buildings made after Sly's work still survive within the Wellcome Collection.

completely accurate representation of what a visitor would see. Sly omitted the steps covering parts of the instrument between the piers, and the two columns on the northern ends of the pit, which would otherwise obstruct the view of the instrument. Through the exclusion of these features of the room and the instrument, other parts of the Transit Circle were made visible. These acts of exclusion and inclusion made explicit the significance assigned to the different parts of the instrument, and showed how Airy directed the work of the artist.

Sly's illustration served as the basis for the first of the 16 plates attached to the official description of the Transit Circle (figure 33).[16] These plates were detailed technical drawings of the instrument from various angles and perspectives. Similarly to the contents of Weale's guidebook, the text and the plates complemented each other. Parts of the instruments were labelled with letters on the illustrations, which were then explained in the description. The description was written by Airy himself between 6 October 1853 and 13 November 1853.[17] However, work on the illustrations had begun as early as 1851. An offer was made to Sly to visit the Observatory during the spring of 1851 to make initial drawings of the instrument.[18] Sly had had to delay his visits due to other 'engagements', but by autumn he proceeded to draw the sectional views of the various parts of the instruments based on both Airy's instructions and the original plans.[19] Airy kept a close eye on the progress of Sly's work and issued detailed instructions on how to improve the illustrations. The Astronomer Royal's attention to detail was best exhibited with the remarks he offered on one of the first versions of Sly's drawing of Plate 1 that showed the entire instrument as placed in the Transit Circle Room:

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[16] *Astronomical and Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich in the year 1852* (London: George Edward Eyre and William Spottiswoode, 1854), Appendix I.
[17] See notes for 3 October 1853 and 13 November 1853, *Astronomer Royal's Journal*, RGO 6/25.
[18] George Airy to Benjamin Sly, 8 April 1851, RGO 6/724 761 and Airy to Sly, 26 April 1851, RGO 6/724 763.
[19] Sly to Airy, 31 October 1851. RGO 6/724 771.

> Wanted the spring which connects the galvanic wires with the rings on the conical axis. The perspective of the bearing of the axis of the left-hand upper wheel is not correct. I think the said left hand upper wheel is too low for true perspective. A long hook's joint might be represented. I should judge by the eye that the microscopes are in too large a circle.[20]

Despite Airy's close supervision, Sly was frequently delayed in returning the work to Airy. Initially, the engravings were to be finished by September 1852, then November of the same year.[21] However, by the end of 1852, the Astronomer Royal still did not receive any news on the progress of the illustrations. In January 1853, Airy wrote to Sly to express his anger: 'I am perfectly astonished at the delays you have made in regard to the plans of the Transit Circle.'[22] In the same letter, Airy stated that if the plates were not going to be finished by the end of February, then a new artist was going to be employed. These requests had a positive effect, and Sly soon sent to Airy the finished illustrations. While Sly's letter accompanying the final drawings did not survive, Airy responded to it on 15 February 1853, and Sly's bills were settled by the end of March.[23]

[20] Airy to Sly, 4 October 1851, RGO 6/724 767-768
[21] Sly to Airy, 28 August 1852, RGO 6/725 907 and Sly to Airy, 2 November 1852, RGO 6/725 912.
[22] Airy to Sly, 15 January 1853, RGO 6/726 911-912.
[23] Airy to Sly, 15 February 1853, RGO 6/726 914 and Sly to Airy, 28 March 1853, RGO 6/726 917.

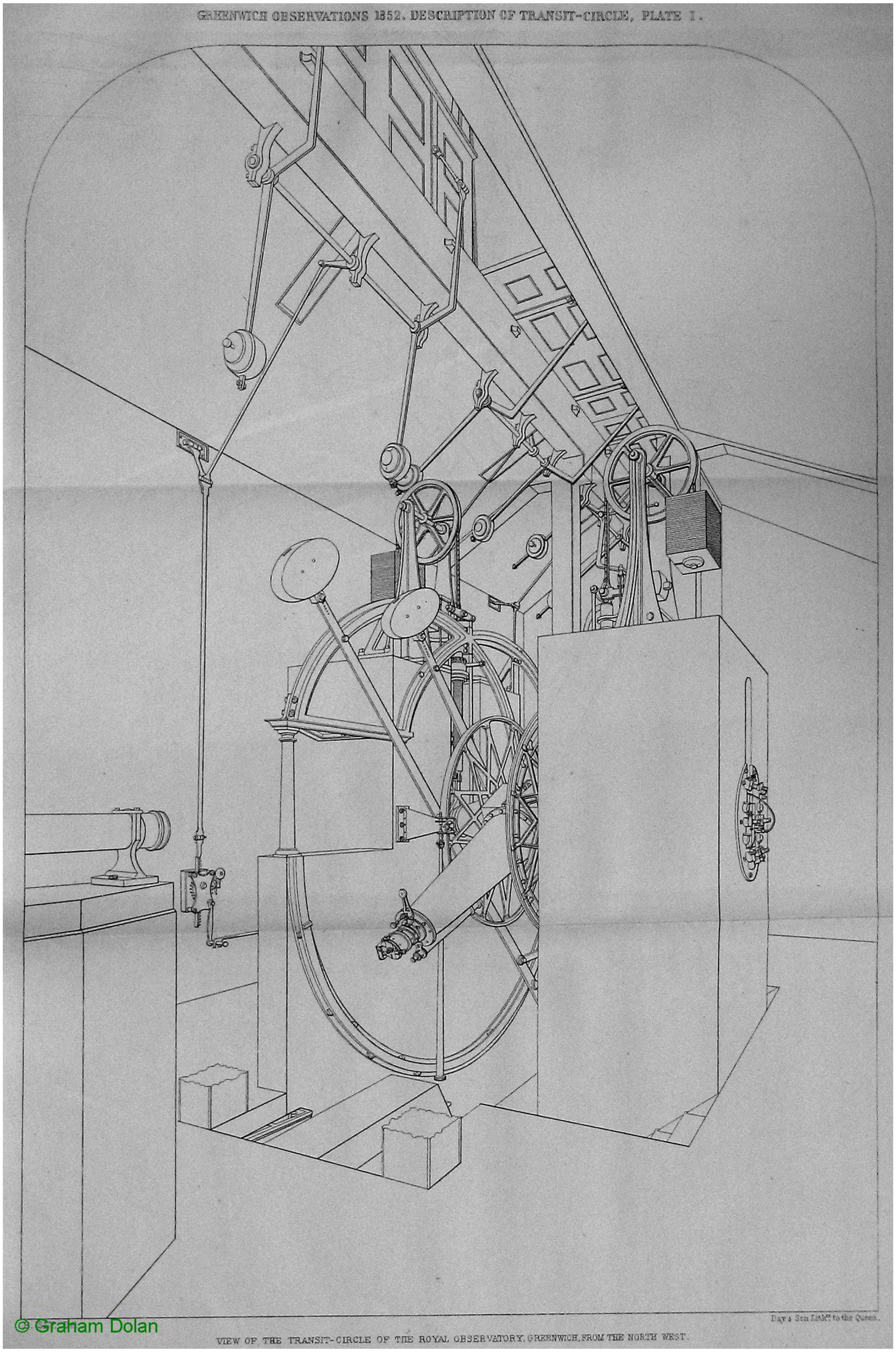

Fig. 33. Plate 1 from the official description of the Transit Circle (scanned by Graham Dolan)

Among the illustrations made by Sly for the description of the Transit Circle, the first one, labelled simply as 'Plate 1' stood out. It became a cornerstone image in how the Transit Circle was represented and communicated to the public in the future. The image and its variations were used for illustrating the instrument in both periodicals and textbooks. Furthermore, the same view was used for the illustration of the Transit Circle for the Royal Observatory at the Cape of Good Hope.[24] As mentioned previously, while 'Plate 1' provided a fairly accurate image of the instrument, there were still important parts of the room and the instrument missing from it. For example, the steps covering the circle and the horizontal axis of the instrument were not represented on it. Similarly, two of the columns that would otherwise block the view from the depicted perspective were also only partially represented as two squares on the Eastern and Western sides of the Northern end of the instrument. Meanwhile, the two columns at the Southern end of the instrument were part of the illustration. Finally, the small chimney system used for directing the heat generated by the gas-burners were not shown on the western pier of the instrument. However, the exclusion of these parts served the purpose of showing other parts of the instrument that Airy deemed more important. For instance, if the steps covering the horizontal axis were represented, it would have blocked any view of the central cube of the telescope tube, or the counterpoises of the mercury trough. In brief, Plate 1 did not provide a depiction of the instrument that showed the entire assemblage of the Transit Circle, but the exclusion of parts served as a way to highlight aspects and parts of the instrument that Airy considered more important.

[24] Though it was depicted from the left of the instrument as opposed to from the right. Fascinatingly, that illustration did not exclude the pipe/chimney placed above the light-source in one of the piers. See 'Dr. Livingston's Astronomical Observations. Royal Observatory, Cape of Good Hope.' *Illustrated London News*, 21 March 1857, p. 271.

The story of the production of the engravings demonstrated that Airy was closely involved in the making of the publications, and attempted to control every aspect of it even when he was not the person carrying out actual work. It was an example of what Daston and Galison referred to as the 'policing of the artist' in order to remove the artist's interpretation from the final work.[25] This policing also reflected Airy's general management of the everyday operations of the Observatory. By placing Sly within this framework, we see that Airy considered individuals and tradesmen working outside the Observatory to be part of the larger assemblage of the Observatory, which resulted in applying to them the same techniques of control and surveillance. However, despite Airy's close supervision of the work, he was unable to prevent the delays made by other individuals, and eventually had to resort to issuing an ultimatum to the artist. With the delays in mind, Airy's dictatorial attitude is reframed as grounded not exclusively on the factory management techniques of the time, but also on his negative experiences and distrust in the reliability of work that was outsourced from his hands. Finally, Airy's attention to detail in relation to the illustrations also demonstrated that their intended purpose was not only to depict the Transit Circle in its glory, but to provide technically accurate plans that could serve either as the basis for further plans, or for consultation in the construction of other transit circles.

3. The model of the Transit Circle at the 1855 Exposition Universelle at Paris

Plate 1 was used as an illustration for an article about a model of the Transit Circle sent to the Exposition Universelle in Paris in 1855. However, the illustration was mistakenly labelled as the 'model of the Transit Circle exhibited in Paris'. Unfortunately no illustration survived of the

[25] Daston and Galison, *The Image of Objectivity*, p. 103.

model that was exhibited in Paris. Despite this, an extensive set of correspondence survives concerning the production and the reception of the model.[26] These documents give us a detailed view of the network that contributed to its production. Within the alphabetical index to the manuscripts, one can find the Bank of England listed next to the French scientist Jean-Baptiste Biot, Airy's internal notes sent to the Observatory's carpenter, John Green, next to correspondence with the Grubb Telescope Company, and receipts from ship and commercial agents Lightly & Simon following letters from Urbain Le Verrier (director of the Paris Observatory). The documents demonstrate the participation of commercial, industrial, scientific, and political entities in the production and display of the model. This is important in demonstrating that the Observatory and its activities were not isolated from society. Instead, their day-to-day operations relied on the stable performance of a network of other entities. In addition, it similarly demonstrates the extent to which Airy's decisions were influenced by the needs of the members of this network. Finally, the documents offer an insight into how the different entities approached and thought about the model. It demonstrates how different social groups give different meanings to artefacts such as the model of the Transit Circle, and that the problems related to the artefact 'are defined within the context of the meaning assigned by a social group or a combination of social groups'.[27] For instance, while for the Board of Trade carrying out the project within the allocated timeframe and budget were the key considerations, Airy focused on the quality and accuracy of the models being made, which resulted in clashes between them. Similarly, while for the shipping company the model only appeared as group of packages that had to be handled together and with care, for the workmen who set up the instruments in France the boxes followed a logical order for setting up the different parts of the

[26] These can be found in under the class number RGO 6/422.
[27] Bijker et al, *The Social Construction of Technological Systems*, p. 12.

model. The different meanings demonstrate once again the ways in which the final form and presentation of the models were shaped by the multiple individuals involved in its history. As a result, despite Airy's oversight, the models did not embody exclusively his vision, but the multiple meanings attached to them by others as well.

The Exposition Universelle of 1855 in Paris was considered to be both a response to the Great Exhibition of 1851, and a 'peace-making mechanism' during the Crimean War.[28] It was also the first universal exhibition to bring together both fine and industrial arts.[29] On the British side of the exhibitors, the Board of Trade asked the Royal Society to set up a committee to oversee the selection of industrial and scientific instruments to be exhibited in Paris.[30] Airy's role in this Committee was to contact instrument makers about whether they were interested in exhibiting in Paris.[31] He was also asked if he wanted to exhibit anything from the Observatory. To this, he suggested exhibiting models of the instruments recently constructed for the Observatory: the Altazimuth, the Transit Circle, the Reflex Zenith Tube, and the Barrel Chronograph.[32] Since funding for the exhibition from the British side was quite limited, the Committee offered to display only a set of models of the Transit Circle. In light of this, the Board of Trade requested Airy to provide details on the space that the set would take up as well as an estimate of the associated costs. In response, Airy emphasised the difficulty of accurately estimating the costs,

[28] Margueritte Murphy, 'Becoming Cosmopolitan: Viewing and Reviewing the 1855 Exposition Universelle in Paris', *Nineteenth-Century Contexts*, 32:1 (2010), 31-46 (p. 32).
[29] Patricia Mainardi, *Art and Politics of the Second Empire: The Universal Expositions of 1855 and 1867* (New Haven and London: Yale University Press, 1987), pp. 39-42.
[30] H. C. Owen to Lord Wrottesley, 14 December 1854, RGO 6/442 17-18.
[31] Unfortunately, almost all of the instrument makers declined on the basis of being too busy with orders from clients.
[32] From the same letter we learn that Airy's proposal to exhibit models of the instruments (except for the American Barrel Chronograph) at the Great Exhibition of 1851 was rejected. See Airy to H. C. Owen, 23 December 1854, RGO 6/442 21-22.

and the need for a large space for the models.[33] Meanwhile, the original instrument makers of the Transit Circle declined to undertake the making of the models because they were too busy with other orders.[34] Due to such obstacles, and the time constraints, Airy decided to withdraw his application for the exhibition.

Even though the model was not yet in existence, the different actors of the network already interpreted it in several different ways. Airy's aim was to exhibit the Transit Circle alongside the other instruments that formed part of his re-instrumentation programme. It showcased them as a suite of instruments that contributed to the operations of the Observatory, as opposed to being isolated from each other. By contrast, the Board of Trade approached the model and the display as a financial expenditure, thereby shaping the extent to which Airy was able to execute his vision. Finally, the instrument makers interpreted the model as an unnecessary diversion from their more profitable orders. These different approaches to the model highlight how the network shaped its final form at the stage of negotiations already by imposing financial, spatial and production limitations.

Airy's withdrawal prompted the Board of Trade to give in to the Astronomer Royal's demands, and shortly afterwards, work began on a few of the models.[35] Airy's change of heart was partly induced by his friend, William Henry Smyth, who asked him not to withdraw; to which Airy responded that 'winking at the time, some difficulties might be overcome.'[36] Further complications at this stage arose when the Committee decided to exhibit the 'ancient instruments' of the Observatory too, in order to demonstrate the progress of the instruments over

[33] See the correspondence between Airy and various members of the Board of Trade (H. C. Owen, Lyon Playfair, Cpt. Francis Fowke), January 1855, RGO 6/422 25-40.
[34] Airy to Playfair, 29 January 1855, RGO 6/422 40.
[35] Playfair to Airy, 30 January 1855, RGO 6/422 41-4; Airy to Playfair, 3 February 1855, RGO 6/422 48.
[36] Admiral William Henry Smyth to Airy, 30 January 1855, RGO 6/422 447-448; Airy to Smyth, 30 January 1855, RGO 6/422 449.

time.[37] By doing so, the Committee attempted to display the connection between the historical aim of the Observatory (i.e. the quest for longitude) and the institution's excellence in the instrumentation used in line with that aim. Airy once again had to challenge the proposal about the exhibition, by arguing that he could not guarantee the safety of the instruments.[38] In the end, Airy managed to convince the Committee and was able to refocus his energies on the making of the models.

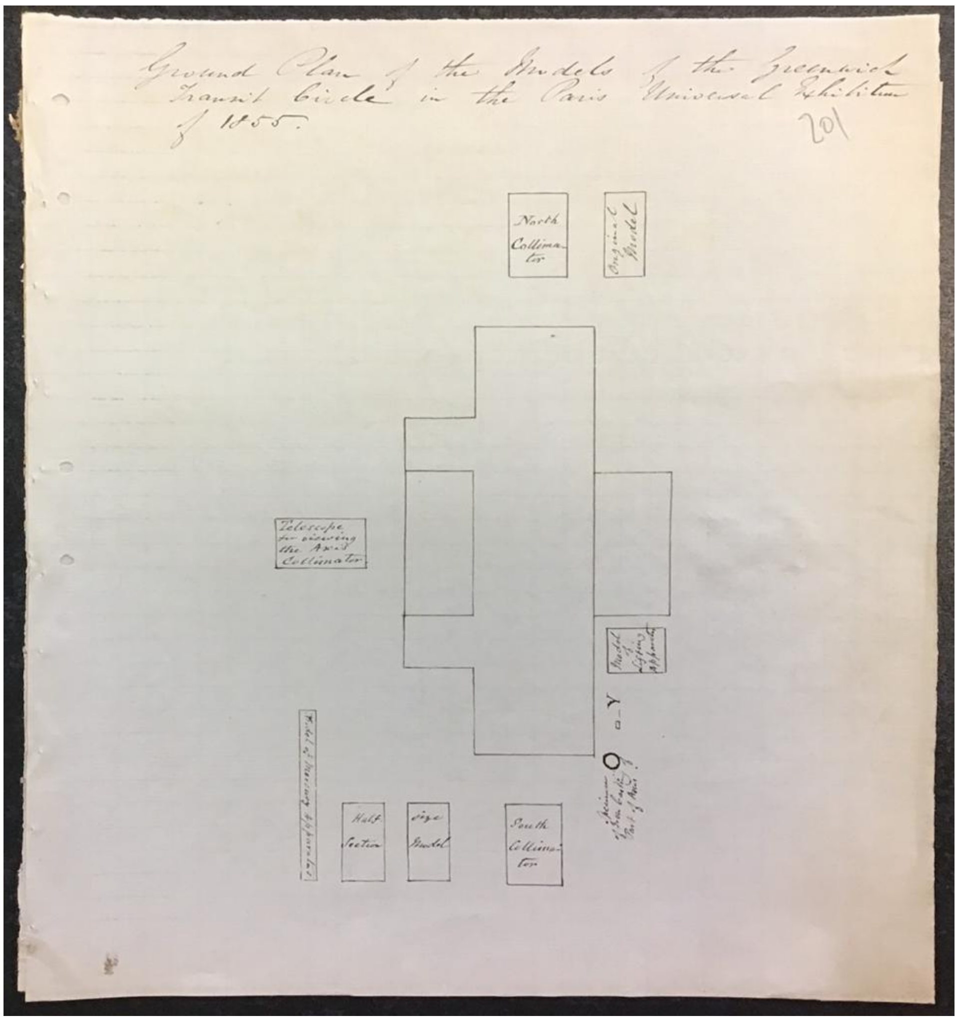

Fig. 34. Airy's plan for the arrangement of the display of the models in Paris (RGO 6/442 201)

[37] Fowke to Airy, 6 February 1855, RGO 6/422 51.
[38] Airy to Fowke, 7 February 1855, RGO 6/422 52-53.

4. Making models, linking longitudes

The nearing of the opening of the exhibition meant that the construction of the models had to be rushed. Airy's plan was to create a display consisting of 9 models in total: one half-sized "complete" model (with an excavated pit for turning the telescope tube), the original small model used during the construction of the instrument (which was in the possession of the Royal Astronomical Society), three collimators, a small model of the lifting apparatus, two half-section models, and a full sized model of the counterweights for the mercury trough.[39] The list of models showed that Airy did not strive to present models that mirrored the operations carried out with the Transit Circle. Instead, he focused on displaying the internal and external parts contributing to its operation. By doing so, the models were visual manifestations of the technical description of the instrument (which description was chained to some of the models during the exhibition).

Based on Airy's plans, the set of models exhibited three different definitions of the term model, each based on the historical network from which the actual model emerged.[40] The main large model of the instrument was intended to show an impression of the totality of the instrument. This was visible through the non-working/non-operational state of the model. The lack of a functioning state made it clear that it was a display of the design of the instrument as opposed to a replica of the instrument. The sectional models provided a different definition of the model. It was used to demonstrate both the arrangements of the internal parts of the Transit Circle, while at the same time displaying the accuracy and firmness attainable through the use of chilled iron technique. While the former turned the model into a three-dimensional illustration of Airy's

[39] Ground Plan of the Models of the Greenwich Transit Circle in the Paris Universal Exhibition of 1855, RGO 6/422 201.
[40] Soraya de Chadarevian, and Nick Hopwood (eds.), *Models: The Third Dimension of Science* (Stanford, CA: Stanford University Press, 2004).

description of the instrument (i.e. an explanatory model), the latter provided a sample of the material used for the construction. Similar samples in the form of models of the pivots were exhibited at the Meetings of the British Association for the Advancement of Science in 1850 and 1851.[41] Finally, the small complete model of the Transit Circle was already in existence when the construction on the original instrument began. This small model was created in order to convince the Board of Visitors about the final design features and the viability of the project. It also served the role of a small-scale instructive model that enabled Airy and the instrument makers to discuss and illustrate their ideas through a three dimensional medium. In brief, the models of the Transit Circle exhibited multiple definitions of a *model* as opposed to following one strict definition of it.

Initially, Airy oversaw the making of the models himself, but by the end of March he assigned the responsibility to one of his assistants, Edwin Dunkin.[42] In relation to the construction of the models, his main tasks included overseeing their completion, and arranging the logistics behind shipping them to Paris. Furthermore, Dunkin and Green (along with a few workmen) were assigned to go to Paris to set up the instrument. As a result, it is through Dunkin's letters to Airy that we can get a glimpse into the chaos that ruled over the organisation of the exhibition. Dunkin's first letter from Paris complained about the shipping packages being distributed without any order, and that the allocated space for the models was not yet finalised.[43] When space for the models was finally allocated, it was not according to the original plan that would

[41] 'British Association for the Advancement of Science', *Morning Post*, 9 August 1850, p. 3.; Charles May, 'On the Application of Chilled Cast Iron to the Pivots of Astronomical Instruments', in *Notices and Abstracts of Miscellaneous Communications to the Sections, Report of the Twenty-First Meeting of the British Association for the Advancement of Science* (London: John Murray, 1852), p. 115.
[42] Airy's direct involvement was reflected in his internal notes sent to the carpenter of the ROG, John Green. See ROG 6/422 218-228. For Airy assigned the responsibility to Dunkin see Airy to Dunkin, 26 March 1855, RGO 6/422 177-178.
[43] Dunkin to Airy, 12 April 1855, RGO 6/422 181-182.

have placed the main model along the meridian.[44] The next letter recounted the story of the organisers' objections to excavating the ground for the pit of the main model, which led to further delays.[45] Problems continued to mount as the opening of the exhibition approached. The excavation of the pit was not yet ready, and no help was provided by the organisers to carry out the digging. Furthermore, objections against setting up the smaller models were raised.[46] Airy was alarmed by this development as he considered the small models to be 'more instructive than the great one.'[47]

A few days before the opening the organisers once again objected to the position of the smaller models, and threatened to separate them from the large one by placing them into a different hall.[48] Both Airy and Dunkin wrote to Captain Francis Fowke (one of the heads of the organising committee) to stress the importance of the models as a set.[49] Fortunately, the British authorities responded quickly and managed to keep the models together, with the exception of three smaller models (the two half sections, and the original small model owned by the Royal Astronomical Society).[50] The emphasis on exhibiting the models together (especially the collimating telescopes) highlighted that the Transit Circle consisted of several spatially separate elements. Applying this idea of a spatially separated instrument to the Transit Circle allows for expanding its history to consider how the different parts of the assemblage were interlinked, and how modifications made to one part of the assemblage affected the operation of the other parts. For instance, without the use of the collimating telescopes, the instrumental errors of the Transit Circle could not be determined. Without the measurement of instrumental errors, the observed

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[44] Dunkin to Airy, 15 April 1855, RGO 6/422 184-185.
[45] Dunkin to Airy, 19 April 1855, RGO 6/422 186-187.
[46] Dunkin to Airy, 22 April 1855, RGO 6/422 188-189.
[47] Airy to Playfair, 24 April 1855, RGO 6/422 88-89.
[48] Dunkin to Airy, 3 May 1855, RGO 6/422 196.
[49] Dunkin to Fowke, 3 May 1855, RGO 6/422 91-92; Airy to Fowke, 5 May 1855, RGO 6/422 93-94.
[50] Airy to Playfair, 10 May 1855, RGO 6/422 97-98.

position of the stars could not be calculated with the high level of reliability expected from the Observatory. By considering the Transit Circle as an assemblage of spatially separate but operationally interconnected parts also opens up the question of how it interacted with other instruments within the Observatory. Although such a question was hinted at through the suggestion of exhibiting the Transit Circle with previous meridian instruments (connecting present and past instruments), and Airy's original suggestion was also to exhibit all four of the new instruments, the final display did not pose the question to the visitors of the exhibition. Despite this, Airy was aware and conscious of the significance of the 'ancient' meridian instruments, and had them displayed on the walls of the Transit Circle Room at the Observatory.

While Green and the workmen left Paris before the opening of the exhibition, Dunkin stayed behind to look after the models for a couple more days and to finalise the displays (e.g. by attaching descriptions of the instrument to the models).[51] After the opening of the exhibition, the models received mixed responses from the press, most of which focused on their unusual design. The *Illustrated London News* referred to it as 'the mysterious transit circle from Greenwich.'[52] The same article noted that a French writer described it as a 'model of the Greenwich Observatory' as opposed to one of its instruments.[53] The inability to comprehend the displayed model was highlighted by the Board of Trade too. Playfair asked Airy to place a 'popular description' on the display, as the French visitors thought it was a steam gun and repeatedly asked to see it in action.[54] The inability to categorise the instrument was also reflected in the reports of local newspapers that labelled it an 'architectural sculpture'.[55] The press picked up on the chaotic organisation of the event too (as emphasised by Dunkin), and used the story of the

[51] Dunkin to Airy, 30 April 1855, RGO 6/442 195; Dunkin to Airy, 4 May 1855, RGO 6/442 197-198.
[52] 'The Opening of the Paris Exhibition', *Illustrated London News*, 9 June 1855, p. 583.
[53] Ibid.
[54] Playfair to Airy, 8 May 1855, RGO 6/422 95-96.
[55] 'Palais de l'Industrie', *Norfolk Chronicle,* 19 May 1855, p. 4.

model as an example to criticise the inability of the British government to arrange the smooth preparations for the Exhibition.[56] Despite this, Admiral Smyth, who attended the exhibition, praised the display. He reminded Airy of the distinguished location of the models in the exhibition hall, and assured him that even the fiercest looking workers stopped to admire them (figure 37).[57]

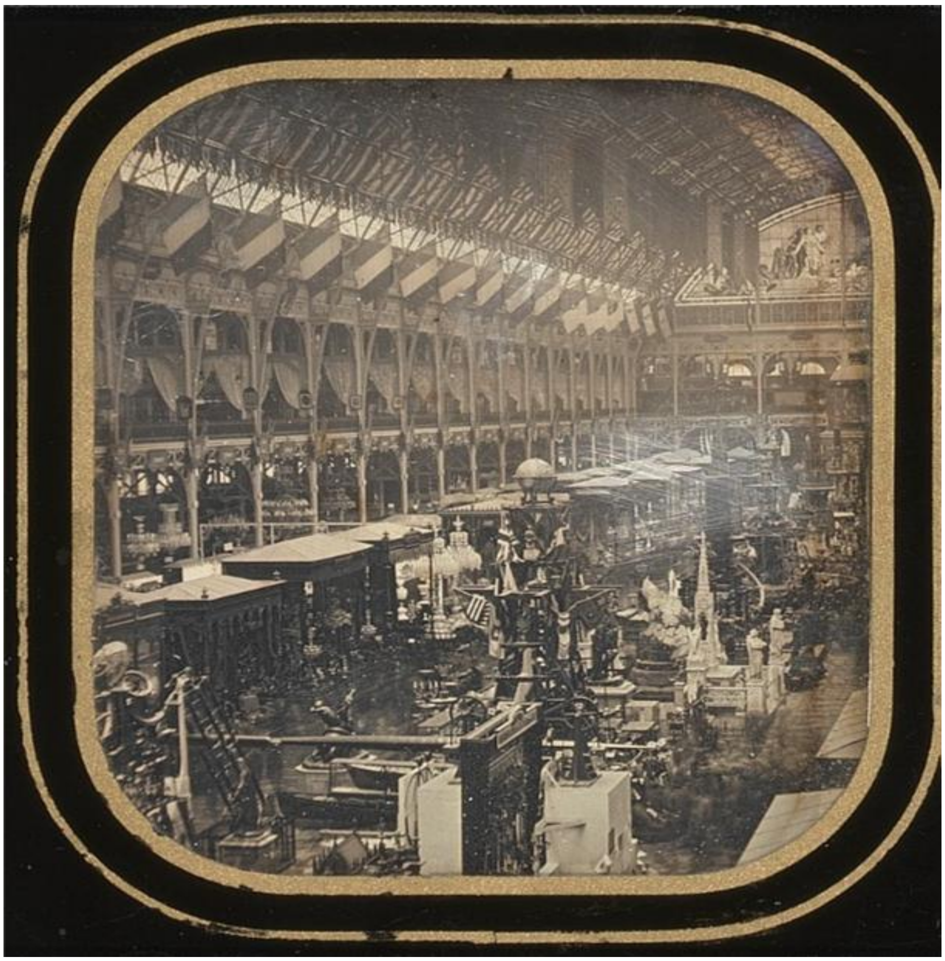
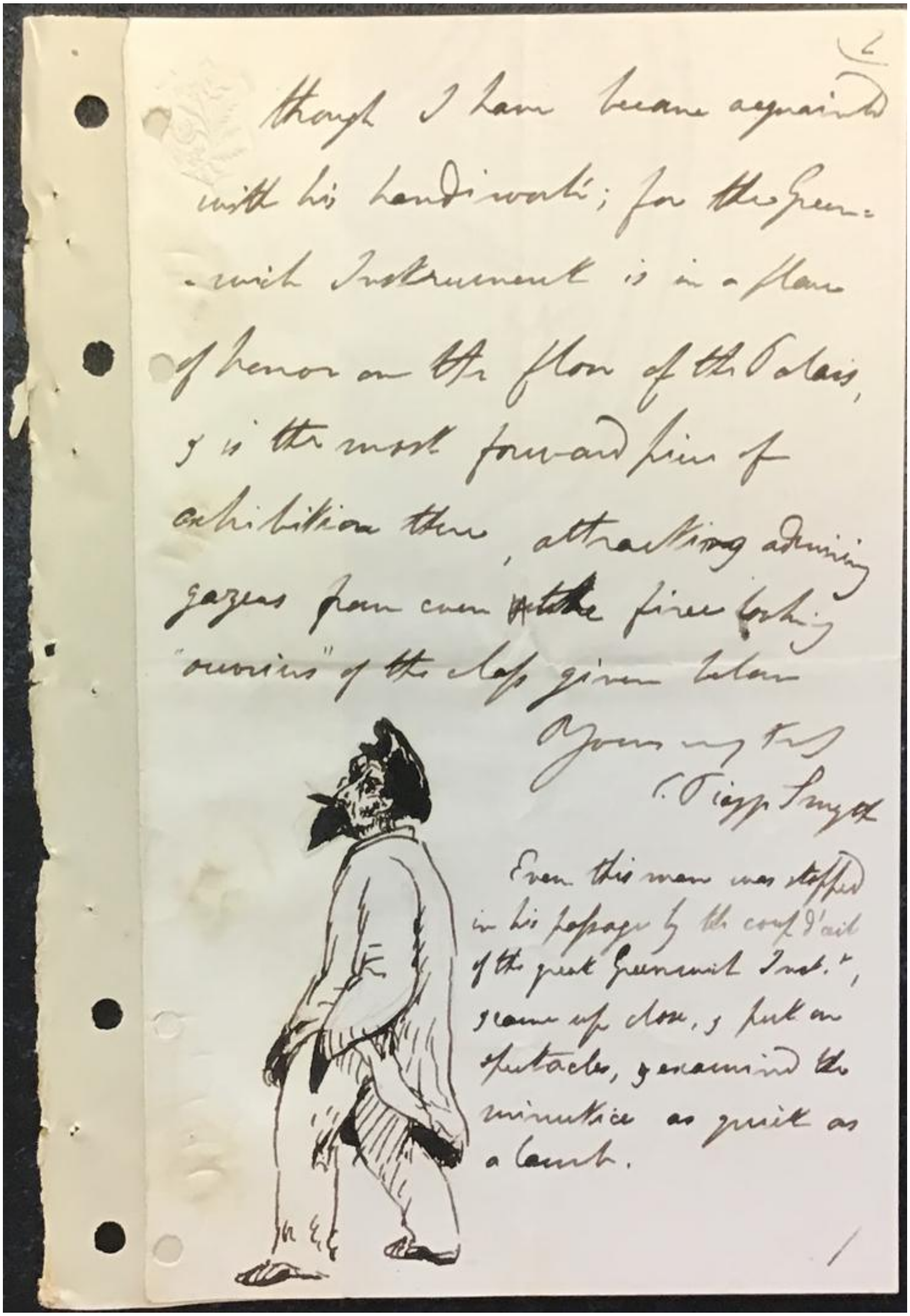


Fig. 35. Detail of a stereograph showing the main exhibition hall. The main model of the Transit Circle is visible at the mid-bottom of the image.

[56] [Untitled], Art Journal, May 1855, p. 165; [Untitled], Daily News, 16 April 1855.
[57] Smyth to Airy, [undated], RGO 6/442 451.

Fig. 36. Detail of the previous stereograph showing an obstructed view of the model in which only the two piers with the lifting machinery on top of them are visible.


though I have become acquainted
with his handiwork; for the Green-
-wich Instrument is in a place
of honor on the floor of the Palais,
& is the most forward piece of
exhibition there, attracting admiring
gazes from even the fierce looking
"ouvriers" of the class given below
Yours very truly
C. Piazzi Smyth

Even this man was stopped
in his passage by the coup d'oeil
of the great Greenwich Inst.t,
came up close, & put on
spectacles, & examined the
minutiae as quiet as
a lamb.

Fig. 37. Letter from Admiral Smyth to Airy with a sketch of a visitor to the exhibition (RGO 6/442 451)

5. From Greenwich to Paris, and then to London

The fate of the model after the exhibition was not clarified between Airy and the Board of Trade when it was commissioned. The Board of Trade assumed that since it was the body paying for the construction of the models, the items would remain the Board's property. In light of this, once Dunkin began the installation of the models in Paris, Airy instructed his assistant to ask around whether 'Le Verrier or any body else' wanted to keep them.[58] None of the Parisian institutions initially signalled any interest, though Le Verrier agreed to keep an eye on the models.[59] After the exhibition, Airy sent two members of the Observatory staff (John Green and Alexis Albert de Lajugie) to Paris to remove the models. Lajugie was further instructed to consult Le Verrier and Jean-Baptiste Biot, asking whether any of them would like to have the models. However, upon arriving to Paris, Green and Lajugie found the models in pieces and ready to be sent back to England. They were informed that the president of the Board of Trade had given instructions concerning the removal of the display.[60] If Airy wanted to leave the models in Paris, he now had to convince Playfair and Henry Cole. Meanwhile, Lajugie was unsuccessful in speaking to Le Verrier, and Biot said that the Bureau des Longitudes did not want the models. Since, Airy was still waiting for a formal response from Le Verrier, he told the Board of Trade that models had been offered to the Paris Observatory.[61] By the time Cole received this response from Airy, they had already been returned to London. However, the offer to a prestigious institution like the Paris Observatory could not be withdrawn. As a result, Cole's proposed solution to this matter was to make Le Verrier pay for the shipping of the models back

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[58] Airy to Dunkin, 30 April 1855, RGO 6/442 193-194.
[59] Airy to Le Verrier, 29 May 1855, RGO 6/442 263-264.
[60] Lajugie to Airy, 1 November 1855, RGO 6/442 248-249.
[61] Airy to Fowke, 15 November 1855, RGO 6/442 130-131.

from London to Paris.[62] Airy's response was a complete rejection of this idea, and subsequently withdrew his offer to Le Verrier.[63]

The possibility of giving the models to scientific institutions in Paris represented a fourth meaning for the model. The previous meanings framed the models as explanatory models (Airy's interpretation), displays of reputation (Board of Trade's interpretation), and displays of historical continuity (Royal Society). The proposal to leave the models in France as gifts constituted the models as artefacts that disseminated technological knowledge to other scientific communities. By doing so, the emphasis of the models was shifted away from the large main model to the smaller models that provided technical insights into the instrument's design.

The models remained in the possession of the Board of Trade for a while, except for the small original model, which was returned to the Royal Astronomical Society.[64] With the future site for the models still undecided, Airy received at least one request to display the models. E. J. Loseby asked Airy if they could be transferred to the Royal Polytechnic Institution.[65] However, Loseby's question arrived at a time when Airy was still entertaining the possibility of gifting the models to the Paris Observatory, which led him to reject Loseby's offer.[66] The possibility of exhibiting the models at the Royal Polytechnic Institution signalled a misreading of the display in Paris. The Polytechnic specialised in the exhibition of "interactive" and useable artefacts/machines, but the model offered none of that. However, it raised the potential for further modifications of the models in order to fit such aims of the Institution. Within such a context, the models would have been interpreted in a fifth way, whereby they offered a functioning display of the instrument.

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[62] Henry Cole to Airy, 27 November 1855, RGO 6/442 134-135.
[63] Airy to Cole, 29 November 1855, RGO 6/442 136-137.
[64] Dunkin to Lightly & Simon, 4 December 1855, RGO 6/442 28.
[65] E. T. Loseby to Airy, 22 October 1855, RGO 6/442 296.
[66] Airy to Loseby, 23 October 1855, RGO 6/442 297.

It took around another year and a half for the models to finally be installed at a new location. The large model with the models of the collimating telescopes were given to the South Kensington Museum. While the letters relating to this transaction do not survive within the Airy papers, later correspondence between Airy and the Museum does. The Museum's director wrote to Airy asking him to write a description of the instrument for the visitors of the museum.[67] Since the Astronomer Royal was busy at the time, he assigned the task to Robert Main. Despite this, when Main handed his new description to Airy, the Astronomer Royal found it unsuitable for a general audience since it focused too much on the technical details.[68] As a result, Airy decided to write his own description that shifted the focus away from the technical details of the instrument towards how positions of celestial bodies were determined using transit circles. In addition, he took the opportunity to highlight what made the Transit Circle stand out among similar instruments:

> The chief merit of this Greenwich Transit Circle is, that it is able to carry an object glass of larger diameter than has hitherto been mounted on meridional instruments, and that it gives great facility for examination of its defects and its errors of position. In its optical power, its accuracy, and its convenience for observations it has no equal in Europe.[69]

In order to provide the technical details of the Transit Circle to inquisitive minds, this description was accompanied by the official description of the instrument. The differences between Main's and Airy's descriptions also highlight more approaches to the model and its display. Main considered the audience to be interested in the technical details of the instrument, thereby maintaining the interpretation of the model as a tool for the dissemination of technical

[67] Cole to Airy, 20 March 1857, RGO 6/4 497-498.
[68] Airy to Cole, 11 June 1857, RGO 6/4 505.
[69] Airy, [Description attached to the model of the Transit Circle exhibited at the South Kensington Museum], RGO 6/4 511.

knowledge. By contrast, the Astronomer Royal's description offered an educational account to the visitors on how it contributed to positional astronomy. In this light, the model was re-interpreted within the aim of the Educational Collection of the South Kensington Museum, by providing an instructive description of the instrument that the model represented.

Fig. 38. Photo of the South Kensington Museum showing the model of the Transit Circle (1857, V&A, Museum Number: 1955-1938)

Fig. 39. Photo of the South Kensington Museum showing the model of the Transit Circle on the right hand side of the image (ca. 1859, V&A, Museum Number: 32055)

The large model and the other items surrounding it survived on photographs taken in 1857 and 1859 (shown on figures 38 and 39).[70] The first one shows the model installed in the Educational Section of the site, with one of the collimators set at the southern end of the telescope.[71] A second collimator is also visible next to the western pier. In its original state, this collimator

[70] For the first photograph see ‘South Kensington Museum (Brompton Boilers), Educational Museum, Mechanics gallery(?)’ (1857; V&A Collections, Museum number: 1955-1938). For the second photograph see ‘ Interior view of the Educational Museum, South Kensington Museum, (‘the Brompton Boilers’)’ (ca. 1859; V&A Collections, Museum number: 32055).
[71] The northern and southern ends can be determined based on the positioning of the counterpoises (running around an arch) that are always attached to the eastern pier of the Transit Circle.

would have been placed in a smaller hole cut into the western wall of the Transit Circle Room. The extent to which these collimators were considered insignificant in comparison to other parts of the display by the Museum was signalled by the placement of one of the globes on the pier holding the southern collimator. Between the other items on display, the observation pit can be seen excavated between the piers. The inseparability of the instrument and the pit (both at the Paris exhibition and at the South Kensington Museum) demonstrated how the space engulfing the model formed part of the instrument just as much as the additional instruments set up around it. The photograph served as the basis for an illustration that appeared in the *Illustrated London News* reporting on the opening of the Museum. The only major difference between the original photograph and the illustration was the artist's inclusion of people in the image. Unfortunately, none of the visitors were depicted as observing the displayed model. While these two images showed the instrument in a pre-exhibition state, a later photograph from circa 1859 showed the instrument in a more complex environment. Taken from the northern side of the model, it shows that maps were placed on the side of the eastern pier, as well as the label for the display: 'Model of the Transit Circle – Royal Observatory Greenwich'. The placement of the model between the globes and the maps further exemplifies the close connection that the instrument maintained between astronomy, geography, and navigation.

The model remained part of the South Kensington Museum within the Educational Collection.[72] Reference was also made to it in the catalogue of the Special Loan Exhibition of 1876.[73] The last entry about the instrument appeared in the 1895 Physiography Catalogue of the Museum. As

[72] *Catalogue of the Educational Division of the South Kensington Museum* (London: George E. Eyre and William Spottiswoode, 1867), p. 337.
[73] *Catalogue of the Special Loan Collection of Scientific Apparatus at the South Kensington Museum* (London: George E. Eyre and William Spottiswoode, 1877), p. 395.

opposed to calling it a transit circle, the entry mistakenly labelled it as a 'Transit Instrument'.[74] This way, the catalogue moved away from Airy's description of the instrument (that targeted a general audience), and used a description similar to that of Robert Main's technical explanation. The technical file of the instrument further specifies that in 1914 repairs were made to the model. However, the repairs did not extend the life of the model much longer, as it was deaccessioned in 1928.

6. "The sublime wrath of the Astronomer Royal"

So far, the chapter has only discussed ways in which the Transit Circle was depicted in relatively positive light. Articles critical of the Observatory and the Transit Circle also appeared within periodicals and the astronomical community. For the purposes of illustrating them, the next two sections will focus on two such criticisms. The first one was published by the *Morning Chronicle* in 1856, describing the instruments of the Observatory as mere 'rattletraps', and it prompted a written response from the Astronomer Royal. The second criticism originated from the astronomer Albert Marth, through an article submitted to the Royal Astronomical Society in 1858 and 1859, and subsequently published in the *Astronomische Nachrichten* in 1861. While the impact of the article was downplayed by both Airy and the members of the RAS, Airy provided an in-depth response to the article to the Board of Visitors, which showed that he considered it a significant attack on the reputation and status of the instrument. These two cases highlighted how Airy reacted to pieces critical of the Observatory, and on what grounds he

[74] Entry from the 1895 catalogue in the technical file of the model, Science Museum.

justified the need to respond. Furthermore, the examples also demonstrate that the Transit Circle and the practices associated with it were not universally accepted.

On 20 August 1856, the *Morning Chronicle* published an article about the state of the Observatory based on the reports of the Astronomer Royal.[75] It used the Crimean War as a reason for comparing how astronomy was supported in England and in Russia: ‘how does the governing class in England, with all our celebrity for arts and arms, and unbounded wealth, support this magnificent science? And how does the Czar, alleged to be despotic, and his subjects attend to that science in Russia?’[76] The article then compares the Observatory with the Russian national observatory at Pulkovo (each institution being a state funded, i.e. national, observatory). Beginning with a description of Greenwich, the article cited the latest Annual Report of the Astronomer Royal to the Board of Visitors, which according to the journalist described the instruments of the institution as ‘mere rattletraps - such as might be picked up amongst the old metal curiosities in a marine storedealer’s shop.’[77] From this, the author inferred that the government did not supply the Astronomer Royal ‘with instruments necessary to accomplish his duty’, nor had it done so ever since his appointment. Such ‘rattletraps’ of instruments led to previous failures of the Observatory, such as letting John Couch Adams (and the ‘Nation’) lose out on the discovery of Neptune, as well as allowing ‘individuals to rival the national observatory’ in terms of its instrumentation. Ultimately, the writer extended the criticism to include the members of the Board of Visitors too, who were supposed to oversee the Observatory, but in light of the Neptune controversy and the poor instrumentation, failed to do so. Leaving the Observatory behind, and moving onto Russian territories, the article ventured

[75] [Untitled], *Morning Chronicle*, 20 August 1856, p. 4.
[76] Ibid.
[77] Ibid.

into a very brief description of the Pulkovo Observatory. However, instead of providing an interpretation of the recent report of the Pulkovo Observatory, the author briefly characterised it as ‘celebrated for its completeness and achievements.’ Bringing the piece to a quick end, in the final remarks the author reminded their readers of the shame that an ‘Englishman’ had to feel about ‘a less civilised kingdom overtaking Britain in matters of science’, and expressed hopes for the governing class learning from this comparison, just as they ‘[had] learned a useful lesson from our late antagonistic dealings with Russia.’[78]

The author’s main point about the improvement of instrumentation of the Observatory was not an end in itself (i.e. for the sake of the Observatory or astronomy in general), but rather as means to an end (i.e. to criticise the actions of the government). Such a framing of the article explained the superficial comparison offered by the writer, where the ‘completeness and achievements’ of the Pulkovo Observatory that surpassed the Observatory was not expanded upon. In consequence the criticism was aimed at the means of funding and the supervisory bodies of the Observatory (the government and the Board of Visitors) as opposed to at Airy. In light of this, it can be characterised as a political attack on the British government using the Observatory as an example, as opposed to being a direct criticism aimed at the Observatory itself. Despite this, the article was also able to touch upon another characteristic feature of nineteenth-century astronomical work, which was the rise of private or smaller observatories. Unfortunately, the treatment of the subject was not expanded upon, but it was enough for George Airy to pick up on it in his subsequent response.

Since the *Morning Chronicle* article did not do so, it is useful to expand upon the relationship between the two observatories. This era was remarkable for the close astronomical and personal

[78] Ibid.

ties between the two observatories. Airy was a close friend of the Struve family which went on to produce two subsequent directors of the Pulkovo Observatory.[79] Airy also praised the Pulkovo Observatory by calling it a model for any modern observatory.[80] However, rather than considering the excellent qualities of Pulkovo 'a shame to an Englishman', Airy welcomed the addition of Pulkovo into the international network of astronomical community, and looked forward to its contribution to the collaborative projects between national observatories.[81] Another example of the close connection between the two observatories was Airy's sending of a paper punch to Pulkovo, thereby demonstrating that they exchanged not only astronomical knowledge (such as the *Greenwich Observations*), but also smaller items related to the efficient running of the two observatories.[82] Despite the praise that the establishment and instruments at Pulkovo received, they also had their shortcomings. As astronomer Francis Diedrich Wackerbarth noted in a private letter to Airy, Struve himself did not consider the object glass of Pulkovo's famous great refractors good enough, but had to maintain the high reputation of the instrument since due to the 'jealousy with which he is looked upon in Russia, the consequences [otherwise] might be unpleasant to him.'[83] Rivalry was similarly maintained by the Struve family towards Airy's instrumentation. Struve had a generally critical attitude towards Troughton & Simms, Airy's preferred instrument makers. Reflective of this was another comment made by Wackerbarth to Airy. He mentioned that Struve considered Simms 'merely a Plagiarist of German

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[79] Alan H Batten, *Resolute and Undertaking Characters: The Lives of Wilhelm and Otto Struve* (Dordrecht, Boston, Lancaster and Tokyo: D. Reidel Publishing Company, 1988), p. 90; Airy, *Autobiography*, pp. 342-343.

[80] Simon Werrett, 'The Astronomical Capital of the World: Pulkovo Observatory in the Russia of Tsar Nicholas I', David Aubin, Charlotte Bigg, and H. Otto Sibum (eds.), *The Heavens on Earth*, (Durham and London: Duke University Press, 2010), 33-57 (p. 33).

[81] Steven J Dick. 'Pulkovo Observatory and the National Observatory Movement: An Historical Overview', in Jay H. Lieske, and Victor K. Abalakin (eds.), *Inertial Coordinate System on the Sky* (Dordecht, Boston and London: Kluwer Academic Publishers, 1990), 29-38 (pp. 33-34).

[82] For the paper punch being sent to Pulkovo see Airy to Winnecke, 1864, RGO 6/148 235. For miscellaneous items and the Greenwich Observations being sent to Pulkovo see Airy's correspondence relating to Pulkovo in RGO 6/151.

[83] Wackerbarth at the time was asking for Airy's advice about new instruments for the Observatory at Uppsala, Sweden. Wackerbarth to Airy, 28 April 1853, RGO 6/166 161.

Improvements, & makes no Improvements himself.'[84] In brief, the quality of instrumentation at both the Pulkovo and Greenwich were topics of discussions at the time, but regardless of their qualities, the two observatories maintained strong and supportive ties.

Fig. 40. Artwork depicting The Pulkovo Observatory in 1855

Airy's response (titled "Science and the Government") to the *Morning Chronicle* article was published in a different periodical - the *Athenaeum* - 10 days after the original piece appeared.[85] Airy justified his decision to publish in a different journal by arguing that his statements applied only to science, and therefore found it necessary to communicate through the 'scientific press'

[84] Wackerbarth to Airy, [undated], RGO 6/166 166-167.
[85] George Airy, 'Science and the Government', *Athenaeum*, No. 1505, 30 August 1856, pp. 1086-1087.

(i.e. the *Athenaeum*) as opposed to the 'political press' (i.e. *Morning Chronicle*).[86] The *Athenaeum* can be characterised as part of the scientific press due to regularly reporting of the meetings of scientific societies, and for publishing articles by men of science. However, it also incorporated literary works, which meant that it was not exclusively focused on matters of science. Therefore, Airy's characterisation of it as part of the 'scientific press' had to refer to its use and wide readership among the scientific community. The first point that Airy refuted was the idea that the instruments at the Observatory were old. The Astronomer Royal showed that 'ninety nine hundredths' of the work at the Observatory was being carried out by instruments that had been installed since 1847. Refuting the criticism that the instruments were of poor quality, Airy listed why each possessed a high quality, remarking of the Transit Circle that it was 'without doubt the finest instrument of its class in Europe.'[87] In terms of the financial grants allowed to the Observatory, Airy pointed out that since 1835, the government had not a single time 'refused to grant the funds required [by the Astronomer Royal].'[88] He also countered that poor instrumentation played any role in the Neptune controversy. Instead, he highlighted the division of astronomical labour between the observatories of Pulkovo, Paris, and Greenwich, each limiting its objects of research and specialising in smaller segments of astronomy. Airy, quoting from his own reports, demonstrated that such a division of astronomical labour, and the refusal to install a new equatorial telescope, had been reflective of his own personal direction of the Observatory, as opposed to being the command of the Government.[89] Finally, regarding the criticism about non-national observatories being better equipped than Greenwich, Airy

[86] Ibid.
[87] Ibid.
[88] Ibid.
[89] This lack of proper instrumentation was not brought up during the Neptune Controversy as a contributing factor. Similarly, historians writing about the subject Chapman, Kallstrom, and Smith, did not consider it as a possible factor. Despite this, due to the failing states of smaller equatorials, Airy recommended supplying the Observatory with a new Equatorial in the following years.

highlighted that the institutions were not in competition with each other. Instead, each one of them carried out research in different segments of astronomy on purpose. To conclude his piece, Airy reflected upon the what the factually erroneous writing of the *Morning Chronicle* meant to the London journals in general: 'by [the author's] unfounded and reckless statements, the scientific character of the *Morning Chronicle* is ruined, and that of every London journal is imperilled.'[90]

Airy's point-by-point rebuttal of the *Morning Chronicle* article highlighted two important aspects of the Transit Circle. First, it demonstrated that Airy considered the instrument not only to be the best in England, but also in the whole of Europe (remarking at the same time that it was only superseded by its copy at the Royal Observatory, Cape of Good Hope).[91] This was based on the grounds that no other meridian circle in existence was able to carry an object glass as large as that of the Transit Circle, therefore providing the ability to measure the positions of fainter celestial objects too. Second, Airy's framing of the Transit Circle within the set of new instruments installed since the 1847 demonstrated that it formed part of a larger project in which he intended to replace the existing instruments with better ones, and also to introduce new instruments into the Observatory's work regime. In this light, the Transit Circle did not appear out of nowhere as an isolated instrument, but emerged as part of a larger renewal project of the Observatory initiated by Airy. Finally, Airy's emphasis on the division of astronomical labour among observatories highlighted the extent to which the Observatory relied on the orderly functioning of the Transit Circle, since it was the main instrument used for positional astronomy, the area of research that had historically been assigned to the Observatory.

[90] Ibid.
[91] Ibid.

The *Morning Chronicle* responded to Airy's remarks with an attack similar in nature to that of its first article. The response was published on 10 September 1856, but remained unanswered by the Astronomer Royal or anyone else, making it the last article in Airy's encounter with the *Morning Chronicle*.[92] The writer of the column began by characterising the tone of Airy's piece in the *Athenaeum* as 'the sublime wrath of the Astronomer Royal', thereby foreshadowing that while the original article had considered Airy as a person caught up in the incompetence of government, the following words were going to target the astronomer himself.[93] The article moved on to clarify that the source of information upon which the paper's original allegations had been based was the recent report of the Astronomer Royal to the Board of Visitors. To further prove the points of the initial article, the author quoted a lengthy passage from the Report where Airy made the case for a new equatorial telescope. In this report, Airy described both equatorials currently in use at the Observatory (the Shuckburgh and Sheepshanks Equatorials) as suffering from defects. However, neither in the quoted extract, nor in other parts of the Report, did the Astronomer Royal describe the other instruments (i.e. the meridian instruments) to be in poor condition as the *Morning Chronicle* had argued. Therefore, Airy was right in his criticism that the first article projected a problem currently being fixed (through proposing the construction of a new equatorial) onto other instruments of the Observatory.

In light of this, the *Morning Chronicle* decided to take a different line of attack. The writer of the article repeatedly emphasised that the original criticism was aimed exclusively at the equatorial instruments, in order to illustrate the lack of completeness of the instrumentation of the Observatory and its 'instrumentation [being] unfit for certain branches of astronomy.'[94] This

[92] [Untitled], Morning Chronicle, 10 September 1856, p. 4.
[93] Ibid.
[94] Ibid.

statement, however, shifted the discussion away from the quality of the instruments towards the division and organisation of astronomical labour between observatories and nations. With this move, the *Morning Chronicle* modified its original criticism that had attacked all the instruments in the Observatory. It moved to ask another question whether 'perfection [...] in one department excuse[d] imperfection elsewhere.' Airy's thought on this issue had already been expanded upon in his response, where he had summarised it as every observatory devoted itself to one specialised area of research. Within this division of astronomical labour, the Observatory's role was to maintain the long running frequent meridional observations in line with its historical aim. Other national observatories were able to devote their energies to similar large-scale and long-term projects that required continuous funding and large numbers of personnel for longer periods of time. In contrast to Airy's explanation, the *Morning Chronicle* entertained an idea of astronomical division of labour where national observatories were able to contribute to various projects at the same time throughout all the branches of astronomy, as opposed to being institutions, each specialised to a single part of astronomical work.[95] Based on such an idea, it can be understood why the *Morning Chronicle* repeatedly emphasised the lack of completeness of the Observatory. However, by doing so, they demonstrated a misunderstanding of Airy's view on the division of astronomical work and about the historically specialised aim of the Observatory.[96]

Airy's encounter with the *Morning Chronicle* highlighted the extent to which Airy was willing to engage in maintaining the reputation of both the Observatory and its instruments. Rather than

[95] According to Dick (1990), the Pulkovo Observatory was "modern" precisely because of devoting its attention (though not equal attention) to many branches of astronomy at the same time.
[96] The article also raised two other issues: (1) that Airy was the mastermind behind this type of division of astronomical labour and for the lack of equatorials at the time of the discovery of Neptune, which placed the blame of losing out on the discovery on Airy; and (2) the salaries of the assistants are way too small (comparable only to that of junior clerks in a bank).

offering an active defence against the claims made by the 'political press' (since he only answered the first article), he reluctantly countered the accusations within the pages of a different periodical. By classifying the *Athenaeum* as a 'scientific press', Airy signalled that issues relating to the Observatory were not matters relating to politics, but rather to that of the scientific community. In brief, Airy's attempt to change the battlefield where he wanted to counter the arguments of his critic(s) demonstrated what segment of the public was considered by him to be the target audience for his involvement in the maintenance of the reputation of both the Observatory and the instrument.

7. The Marthiad - a story of personal vanity, mathematical pedantry, and malice

Criticism of the Transit Circle and the Observatory did not only surface in the political press, but in journals published by astronomical communities too. An example of this was Albert Marth's critical piece (1860) on the Transit Circle and its possible errors as derived from the *Greenwich Observations*. While the piece by the *Morning Chronicle* did not seem to have made a lasting impact on Airy, the attack by Marth was noted even in Airy's autobiography:

> On Sept. 13th I circulated amongst the Visitors my Remarks on a Paper entitled 'On the Polar Distances of the Greenwich Transit-Circle, by A. Marth,' printed in the Astronomische Nachrichten; the Paper by Mr Marth was an elaborate attack on the Greenwich methods of observation, and my Remarks were a detailed refutation of his statements.[97]

[97] Airy, *Autobiography*, p. 240.

The story of Marth's article highlights how Airy was directly involved in halting the publication of a critical article on the Transit Circle, which led to its subsequent appearance in the *Astronomische Nachrichten*, and to Airy's explanatory letter of over 30 pages addressed to the Board of Visitors.

Albert Marth has rarely appeared in histories of astronomy. The most extensive account of his life was the obituary produced by the Royal Astronomical Society.[98] He was born and educated in Germany, and devoted his life to astronomy from an early age. His fascination and skills led him to work under the supervision of major astronomers of the time such as Friedrich Bessel. After completing his early education, he moved to England to assist and be in charge of private and university observatories. In 1858 Marth finished writing an article about the errors of the Transit Circle and the methods with which those errors were determined. This was submitted for publication in the *Monthly Notices*, but the referees rejected it upon undisclosed grounds. While Airy was notified about the submission of the paper, based on his letters to the members of the Royal Astronomical Society, he did not want a copy.[99] Despite knowing only the topic of Marth's paper, Airy nevertheless suggested that it was read at one of the meetings of the Royal Astronomical Society, on the assumption that it might be useful to the people attending.[100] Similarly, we also learn from the same letters that Marth had not contacted Airy while writing the piece, which the Astronomer Royal both lamented and found surprising.[101] Under these

[98] *Albert Marth*, Monthly Notices of the Royal Astronomical Society, 58:4, 11 February 1898, 139–142.
[99] Airy to Carrington, 28 April 1858 RGO 6/236 712.
[100] Ibid.
[101] Ibid.

circumstances, the first part of the article was read out at the meeting of the Royal Astronomical Society on 9 April 1858.[102]

Marth resubmitted his article to the *Monthly Notices* towards the end of 1859. This time, Airy received a copy of the paper, but due to time constraints he asked Robert Main to create a summary, with a special focus on 'what may seem like improvement in [the Observatory's] practice.'[103] This note demonstrated that Airy was still unaware of the paper's critical stance on the Observatory. Main's summary was detailed, but highlighted that all of the errors mentioned by Marth had already been remedied and implemented into the operations of the instrument.[104] However, even in the light of this, Main considered it to be an attack on the reputation of the Transit Circle, the status of the Observatory, and the expertise of the Astronomer Royal. Main also informed Warren De La Rue (one of the officers at Royal Astronomical Society and Airy's close friend; figure 41) about Airy's reaction. According to Main, Airy felt that the publication of the piece would serve as a way of both accepting and legitimising Marth's criticism, which both Airy and Main considered to be unfounded and outdated. However, at this point, the Astronomer Royal intended to restrain himself from 'entering into consideration of the value or the justice of Mr Marth's animadversions.' In the event that the piece were to be published, Main argued that Airy's astronomical reputation would be considered severely damaged by the hostile attack, which would lead to the Astronomer Royal's resignation from the Council of the Royal Astronomical Society.[105]

[102] 'Papers read before the Society from February 1858 to February 1859', *Monthly Notices of the Royal Astronomical Society*, 19:4, 11 February 1859, p. 157.
[103] Airy to Main, 17 November 1859, RGO 6/236 714.
[104] Main, Robert, [*Notes on Marth's paper*], RGO 6/236 716-719.
[105] Main to De La Rue, 19 November 1859, RGO 6/236 722.

Two days after Main's letter, Airy himself also sent a letter to De La Rue. This was prompted by learning from Main that De La Rue (besides another member of the Royal Astronomical Society, Richard Carrington) was one of the individuals aiding financially the independent publication of the piece in case if it was going to be rejected by the Royal Astronomical Society again. In his letter, Airy urged De La Rue to read through the paper before proceeding with the publication. Similarly, we learn from the letter that Carrington falsely depicted the work to Airy as 'a comparison of English system with foreign systems' and, as a result, Airy found it to be '[Carrington's] continued malevolent criticism and hostile attack on [me] and on the Greenwich Observatory.' Airy was unable to tell what the original intention was behind the production of the work, but could not deny the harsh style of the piece: '[w]hether it is the fruit of vanity or of malice I cannot tell; but if of vanity, it is the most fiendish vanity that I ever saw.' Despite all this, Airy mentioned that if there was going to be 'sufficient public allusion' to it, he had to give in to the will of the people.[106]

De La Rue's response to Airy provided additional information on what the referees of Marth's paper thought: '[it] contained much valuable matter which ought to be published in some way, although, on account of criticisms it contained, they did not consider it adapted for our Transactions.' De La Rue also reassured Airy that he was going to read through the piece and give his fullest attention to it. If the paper was as hostile as Airy depicted it to be, De La Rue offered to immediately stop financing its publication, which might prompt the other financial supporter, Carrington, to revoke his support too. De La Rue further clarified that his intention was to provide support for publication by foreigners who considered the lack of foreign publications in the Transactions a 'natural jealousy on our [British] part.' However, even in light

[106] Airy to De La Rue, 21 November 1859, RGO 6/236 726-727.

of this, De La Rue exclaimed that he did not want to publish a hostile attack under the 'garb of science' that would have at the same time caused even 'the slightest annoyance' to Airy.[107]

Once De La Rue finished reading through the paper, he declared that he found the style of Marth's paper excessively critical:

> [i]ndeed the paper appears to have only one object, namely, the depreciation of work done & instrument employed as far as possible. The paper seems to have been written with an intentional hostility not consonant with a purely scientific criticism.[108]

Fig. 41. Print portrait of Warren De La Rue (1855, NPG, P120(38))

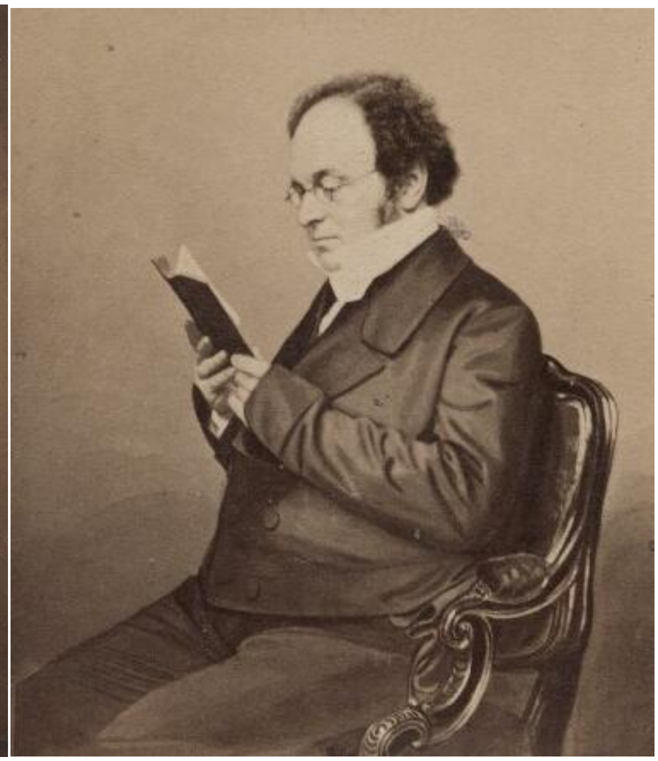

Fig. 42. Print portrait of Augustus De Morgan (c. 1860, NPG, x45715)

[107] De La Rue to Airy, 21 November 1859, RGO 6/236 729.
[108] De La Rue to Airy, 10 December 1859, RGO 6/236 734.

Based on this reasoning, De La Rue decided to revoke his intent to finance the publication of the paper, but mentioned to Airy that it might still end up being published in one form or another. However, even in such a case, the paper would not have the disastrous effect that Airy feared, though it might require him to respond. Airy's final letter to De La Rue added that it was not his intention to suppress the paper. Instead, he wanted to express its poor quality, that he and Main were both aware of the errors and criticism highlighted by Marth, and that it added nothing new to the current state of knowledge. Yet, to finish his letter, the Astronomer Royal repeated his earlier over characterisation of the paper as 'a mass of personal vanity, of mathematical pedantry, and shall I say of malice? as I never before saw.'[109]

Besides De La Rue, Airy also contacted another one of his friends, Augustus De Morgan (figure 42). In his letter, Airy raised the issue that the future of the RAS was in danger from an attack by Carrington, and explained the various steps with which Carrington had been attempting to cement his position within the RAS. The Astronomer Royal argued that Marth's recent paper was part of this larger scheme by Carrington, therefore being an imminent danger to the Society. Airy's disapproval of Carrington was quite clear in this letter, and he argued that whether the paper was going to be published or not determined which of Airy or Carrington was going to have to leave the RAS.[110] De Morgan's two responses were calm and measured. In both he emphasised that the issue was probably going to 'blow over', and that regardless the outcome, Airy was going to have to accept the decision of the council, since 'they may spend their money as they please.'[111] De Morgan's (and De La Rue's) responses demonstrated that while the paper had its shortcoming, not even Airy's close friends shared the view that Carrington was

[109] Ibid.
[110] Airy to De Morgan, 21 November 1859, RGO 6/236 724-725.
[111] De Morgan to Airy, 21 November 1859, RGO 6/236 728; and De Morgan to Airy, 24 November 1859, RGO 6/236 731-732.

attempting to wage a war against the Observatory for the sake of increasing his influence in the RAs.

With both De La Rue and Carrington halting the funding of Marth's paper, the piece was ultimately not published in England. Instead, it found an outlet beyond the shores of England in the most prestigious astronomical journal at the time, *Astronomische Nachrichten*. In the first footnote of the published article (on the front page of the journal), reference was made to its intended publication in England. Despite this, no reference was made to it being rejected twice by the RAS. The version as it appeared in the *Astronomische Nachrichten* criticised both the design of the Transit Circle and the ways in which its errors were determined. The four main errors of the calculations that Marth raised were the (1) unsuitability of Bessel's refraction tables to the Greenwich environment, (2) the lack of explanation given on determining the errors of the thermometers used in conjunction with the observations of the Transit Circle , (3) the inaccurate determination of the flexure of the telescope, and (4) the possible errors of the micrometer screws. Furthermore, as a problem found in the main design of the instrument, Marth criticised its large size, and especially that of the divided circle, to as impractical.[112]

Unfortunately, the impact of Marth's paper within the wider astronomical community remains unclear. The only reference to it was found in a letter from William Henry Smyth to Airy, who mentioned that he heard rumours about it.[113] Despite this, Airy was well aware of its publication. It prompted a similar response to that anticipated in his letters to De La Rue: instead of defending himself at the meeting of the RAS, he chose to write a response to the members of the Board of Visitors in which he provided a counter argument and additional information in relation

[112] Albert Marth, 'On the Polar Distances of the Greenwich Transit Circle', *Astronomische Nachrichten*, Nos. 1260-1263, pp. 177-230.
[113] W. H. Smyth to Airy, 1 October 1860, RGO 6/236 307.

to the state of the Transit Circle.[114] Furthermore, Airy's lengthy response (of 34 handwritten pages) offered an insight into how he saw his role in relation to the maintenance of the reputation of the Observatory. According to the Astronomer Royal, the paper would have remained unanswered due to its poor quality, but the obligations attached to Airy's role as the director of the Observatory necessitated a written explanation to the Board of Visitors.[115] Unfortunately, Airy's handwritten response has faded over time, and only small parts of it can be deciphered. From the little that remains readable, we can infer that Airy provided a point-by-point rebuttal of Marth's paper. One such passage that survives described how the errors of the barometers were determined, and how Marth did not reference the explanation for it in one of the introductions in the *Greenwich Observations*.[116] Another example provided by Airy attempted to demonstrate the high quality of the micrometer screws. Besides offering a short description of how they were made, Airy also remarked 'I think it probabl[e] that all the micrometer-screws of the Greenwich Transit-Circle are greatly superior to any with which Mr Marth has been practically acquainted.'[117] The lengthy written address to the Board of Visitors finishes by repeating the justification offered before by Airy for the large size of the Transit Circle: the size being determined by the 8-inch object glass, which the telescope tube carried, as opposed to Airy's personal preference towards large instruments.[118]

Among Airy's correspondence, two exchanges of letters survives relating to the distribution of his response. The first was with Smyth, who coined the name Marthiad for the affair, and upon reading through Marth's paper concurred with Airy's view of it as being an attack in disguise,

[114] [Comments on Marth's paper], 13 September 1860, RGO 6/13 272-305.
[115] Ibid. 275.
[116] Ibid. 284-287.
[117] Ibid. 288-289.
[118] Ibid. 302-303.

Marth being nothing else but a tool for an 'anguis in herba.'[119] Furthermore, Smyth urged Airy to prepare 'for a tilt with the form which Ithuriel's spear shall expose', thereby revealing the person (possibly Carrington) who had been providing support for Marth's paper.[120] Airy's response argued that Marth's paper was possibly a product of his own vanity, but that despite this, his opinion on Marth had reached an all time low. Highlighting why he did not want to respond in public or at the RAS, Airy stated that 'I will not condescend to soil my fingers in public by troubling such a dirty dog as Marth.' Despite this, the Astronomer Royal did not doubt that Carrington was behind blowing the paper out of proportion by encouraging him throughout the way. As a result, he once again called for the gradual removal of Carrington from the RAS. As for why he responded to Marth's paper, he repeated his reasoning offered in the address to the Board of Visitors, by describing it as his 'duty to your Visitors in possession of my views on any points which seems to affect the honor of the Observatory.'[121]

While the attack of the *Morning Chronicle* on the Observatory and the Astronomer Royal demonstrates how Airy handled criticism that came from the "political press", the Marthiad served the purpose of highlighting Airy's reaction to defending the instrument from attacks originating within the astronomical community. In the case of the Marthiad, Airy inferred an intention behind the criticism, which led to his accusing Carrington for scheming against him and the RAS (though this view was not supported by the Astronomer Royal's close associates). The Transit Circle itself was in the crosshair of the Marthiad, as the astronomical instrument that, according to Marth, possessed a lesser quality than the *Greenwich Observations,* the Observatory, and Airy claimed to have. However, Airy and Main were quick to point out that the

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[119] W. H. Smyth to Airy, 29 October 1860, RGO 6/236 309.
[120] Ibid.
[121] Airy to W. H. Smyth, 30 October 1860, RGO 6/236 310.

shortcomings of the Transit Circle identified by Marth were limitations of the instrument that had either been highlighted in specialist publications, or falsely portrayed as "new findings" due to Marth not communicating with the ROG during the preparation of his article. Unlike in the case of the *Morning Chronicle,* Airy did not provide a public defence of the criticisms, decided to change the "battleground" by considering the impact of the paper only to matter to individuals supervising the work of the Observatory (i.e. the Board of Visitors). In brief, Airy's attempts to maintain the reputation and the status of both the Observatory and the instrument was always targeted at an audience whom the Astronomer Royal considered to care about the criticisms, as opposed to countering arguments in public. Through this strategy Airy was able to limit the impact of the criticisms (by classifying them as unworthy of response), and also helped in focusing the maintenance of any harm caused in the status of the instrument and the institution to immediate supervisors of the ROG (i.e. the Board of Visitors).

8. Conclusion

A scientific instrument is always more than a sum of its material components. It can take various immaterial forms through different types of representation. In turn, they create an "image" or competing "images" of the instrument that contribute to establishing its reputation and status. Similarly to its materiality, an image of an instrument undergoes constant changes, and as a result, it has to be maintained and managed by individuals. By using the term maintenance instead of management, this dissertation further emphasised the interconnected nature of an instrument's materiality and its image, whereby changes in one of its aspects evoke changes in the other. This chapter applied this analytical framework to the Transit Circle in order to better understand how its image was managed by Airy. Such an analysis provided insights into how Airy's oversight of the Transit Circle operated, and the extent to which he considered maintenance of its image part of his duty as Astronomer Royal. In addition, the chapter showed that the Transit Circle was not universally considered a reliable and high quality instrument, which prompted Airy to actively respond to critics, in order to maintain the reputation and status of the Transit Circle. Finally, even among those who considered the instrument reputable, there existed a difference of opinion on how its image should have been presented to different audiences.

The chapter began by demonstrating Airy's close involvement in the maintenance of the image of the Transit Circle. It used as an example the production of the illustrations of the instrument that accompanied its official description. Airy's interactions with the artist Benjamin Sly added another example to how he exercised personal oversight of the Transit Circle; this time by monitoring Sly's work and sending instructions about what parts of the instrument and its surroundings should be included and excluded. It demonstrated that Airy's close involvement in the construction of the Transit Circle was not a unique event throughout his directorship. Instead, he was closely involved in any matter related to the instrument and attempted to exercise oversight of it as much as possible. Finally, the example of the illustrations adds a new dimension to Bessel's statement that instruments were made twice. Considering the "image" as part of an instrument shows that instruments are made not twice, but three times: (1) at the instrument maker's workshop, (2) on the paper by the astronomer through mathematical calculations, and (3) by any person involved in creating an "image" to maintain its reputation and status.

The story of the models of the instrument considered different aspects of maintaining its image. The example showed that the presented "image" of the instrument was not always agreed upon. When plans for proposed for what how to display the instrument at the Exposition Universelle, different individuals wanted to present it differently. Each of these representations would have created a different "image" of the instrument. By doing so, the story demonstrated that not only people participated in the creation of an "image" for an instrument, but there were multiple competing "images" for its representation. While the final material form of the models did not incorporate all the different "images", their presence during the initial planning altered the final form of the models.

The story of the models also showed that creating an "image" of an instrument was not a task carried out by a single individual. Instead, it involved various networks and individuals. Moreover, creating an "image" was a process similar to the construction of the instrument. Focusing on the making of three-dimensional models further highlighted these similarities. The documents relating to the construction, installation, and administration of models showed how practical factors such as funding, shipping, and personal preferences of the organisers affected the final "image" presented to audiences. In this light, even though Airy tried to exercise close oversight of the entire process, it did not guarantee that the final "image" of the instrument was the one that he desired to represent.

The presented "images" of the model continued being contested even after the exhibition in Paris. As the discussions around the model's display at the South Kensington Museum demonstrated, Airy and Main had two different visions of how to present the instrument. While Main provided a technical description, Airy considered the model to be a tool of education about positional astronomy. This demonstrated that the same model could take on different functions and images over time, and that such images were shaped by the setting where it was exhibited as well as by the individuals who had oversight of the models.

Maintaining the reputation of an instrument involved both producing images of it and defending its reputation from criticisms. The attack of the *Morning Chronicle* on the quality of the Greenwich instruments, and Airy's subsequent response to the article served as a key example of this. Even though the *Chronicle*'s criticisms were refuted by the Airy point by point, the case demonstrated that there was not a complete agreement on the quality of the Transit Circle. In fact, his response argued that attack on the reputation of the instrumentation was used for political purposes. In this light, the presented image of the instrument was not only used to maintain the reliability in connection to the astronomical data produced, but also to maintain the public reputation of the Observatory. As a result, despite the isolation of the materiality of the Transit Circle at the Observatory, through the immaterial "image" created of it both specialist and non-specialist audiences were able to actively engage with it. This required from Airy a constant maintenance of its "image".

The Marthiad episode provided an example to maintaining the reputation of the Transit Circle within the astronomical community. Similarly to the attack by the *Morning Chronicle*, it showed that the quality of the Transit Circle and the observations made with it were not considered reliable by every astronomer. As a result, Airy had to engage in the maintenance of the instrument's image within the astronomical community too. Since the paper by Marth was first submitted to the Royal Astronomical Society, the case also provided insights into how Airy used his network to maintain the reputation and the image of the instrument. Through this example, Airy's system of oversight appeared to be composed of an extensive network of individuals who regularly provided advice to him and helped him in executing his decisions. It asks us to reconsider the maintenance of the "image" of the Transit Circle not as a task carried out exclusively by Airy, but as a series of actions made by various individuals. Additionally, the Marthiad episode showed that Airy considered it part of his role to defend the reputation of the Observatory and its instrumentation from any attack. This further strengthens the view that Airy's actions have to be considered through his position as scientific public servant who has to manage and maintain a scientific institution funded by the Government.

Chapter 6 : From a working instrument to a museum object

1. Introduction

'Stand astride the world-famous Meridian Line!'[1] 'Grab an iconic selfie on the historic Prime Meridian Line of the world and share using #PrimeMeridian!'[2] Anyone who visits the Observatory today will be tempted to follow these suggestions of the Royal Museums Greenwich, found on their website promoting the Prime Meridian. This practice has in fact become a ritual for almost anyone visiting the Observatory (figure 43). Even though the same websites clarify that the Line was defined by the Transit Circle, and that the 'cross-hairs in the eyepiece of the telescope precisely defined Longitude 0 for the world',[3] up until today there remains more focus on the Line than on the processes and instrument (the Airy Transit Circle) that produced it. But why is this the case? Why are the products of scientific and technological processes more iconic than the painstaking labour that produced them? How and why have such preferences towards the end-products been maintained in the museums, and especially in the displays of the Transit Circle and the Prime Meridian? And has this always been the case? By asking such questions, the following chapter will attempt to navigate the narrow path shared among approaches in History of Science, Museum Studies, and Science and Technology Studies. It will do so in order to demonstrate how the focus on the end product as opposed to on the astronomical labour producing it helped to maintain its status as a standard for the British Empire

[1] https://www.rmg.co.uk/discover/explore/prime-meridian-greenwich [Accessed on 11 February 2019]
[2] https://www.rmg.co.uk/SEE-DO/WE-RECOMMEND/ATTRACTIONS/STAND-WORLDS-HISTORIC-PRIME-MERIDIAN [Accessed on 11 February 2019]
[3] Ibid.

and later for the world.[4] It is within these processes that the role of the Transit Circle emerges as inseparable from the history of the Prime Meridian, and shifts the focus of historical research back to the instrument itself. By doing so, the chapter outlines the case for why #AiryTransitCircle has not been a "hip" way to engage with public audiences on social media, and how the lack of such a hashtag reflects the long-running trend of the Museum's focus on the Line as opposed to the instrument that produced it.

Fig. 43. Collage of photographs showing people standing on both sides of the Greenwich Meridian

The chapter will begin with an overview of the narrative frameworks that were used for telling the history of the instrument in magazines and newspapers from the 1850s to the 1950s (when operations with the instrument stopped). It builds on the approach taken by Tom Ritchie who explored the often-contradictory stories within which a rebuilt version of the Hartree Differential

[4] For a discussion on the link between the meridian and international politics see Howse, *Greenwich time*, pp. 116-151; Rebekah Higgitt and Graham Dolan, 'Greenwich, time and 'the line'', *Endeavour* 34:1 (2009), pp. 35-39;Trish Ferguson, 'Introduction', in Trish Ferguson (ed.) *Victorian Time: Technologies, Standardizations, Catastrophes* (Basingstoke, England: Palgrave Macmillan, 2013); Withers, *Zero degrees*.

Analyser exhibited at the Science Museum was framed.[5] According to Ritchie, this resulted in the voices of the object being ventriloquised, as opposed to letting the material speak for itself. By doing so, Ritchie highlighted the difficulties that Lorraine Daston's famous approach set out in trying to make things talk.[6] The aim of this part of the chapter is to demonstrate the various topics that were discussed in relation to the Transit Circle while it still contributed to observing programmes. Such themes included seeing the instrument as an example of technological advancements in the production of astronomical instruments, the main instrument for the astronomical observations carried out at the Observatory, and as the instrument that contributed to maintaining the maritime power of the British Empire by providing observational data for the *Nautical Almanac*. In addition, it will show that the instrument was seen as an essential part in the process of producing the Greenwich Meridian. By knowing how the instrument was framed, later sections will be able to demonstrate the extent to which approaching the Transit Circle as a museum object resulted in the production of different narratives. Furthermore, this section will provide a glimpse into how users of the instrument interpreted its functions, as opposed to having to rely on accounts written by individuals who never made an observation with it.

The next section will expand upon the last years of the working life of the instrument. It will demonstrate that despite finding systematic errors in the observations (resulting from the design of the instrument) in the 1920s, it continued being used as part of a reduced programme on a daily basis until 1940. Similarly, even after its retirement, the Transit Circle had to be once again 'revived' and restored to working order due to the destruction of the Pulkovo Observatory. This analysis will demonstrate that despite the acknowledged shortcomings of the Transit Circle, it continued to be used by the Observatory and, therefore, its transformation from a scientific

[5] Tom Ritchie, 'Ventriloquised voices: the Science Museum and the Hartree Differential Analyser', *Science Museum Group Journal*, 10 (2018).
[6] Lorrain Daston, *Things that Talk*.

instrument into a museum object did not take place overnight. Building upon the object biographies approach, this part of the chapter will analyse how the lives of scientific instruments come to an end, and the extent to which the term end offers a practical way of analysing this life-stage of the instrument. The works of Samuel Alberti and Lorraine Daston have been widely cited as key contributors to object-focused biographies. While Alberti highlighted the “life” and “afterlife” of objects within museums, Daston helped in developing the framework to retrospectively capture the lives of objects.[7] Within history of science, this approach included scientific analysis of the components of materials too, in order to expand on the tools available for historians.[8] Despite these approaches, Thomas Soderqvist and Adam Bencard argued that lives are always assigned and inscribed to objects as opposed to life being an inherent attribute of any entity. They warn historians that this can easily overstep the useful aspects of the approach and turn things into humans, thereby overlooking the thingness of things: ‘rather than making the world like us (endowing things with the ability to speak), we [should] see ourselves more like the world.’[9] By incorporating such an approach to object biographies, the chapter will demonstrate the limitations of ascribing “lives” to objects, while at the same time highlighting how the biographical approach can still guide the researcher of material objects into new directions. To do this, the chapter will rely on focusing on the changing functions of the object as opposed to on trying to define the definitive end of the Transit Circle.

[7] Alberti, *Objects and the Museum*; Samuel Alberti (ed.), *The Afterlives of Animals* (Charlottesville and London: The University of Virginia Press, 2011); Daston, *Things that Talk*.
[8] Bulstrode, *Riotous assemblages*.
[9] Thomas Soderqvist and Adam Bencard, ‘Do Things Talk?’, in Susanne Lehman-Brauns, Christian Sichau, and Helmuth Trischler (eds.), *The Exhibition as Product and Generator of Scholarship* (Max Planck Institute for the History of Science, 2010), 93-102 (p. 97). [Accessed at https://www.mpiwg-berlin.mpg.de/preprint/exhibition-product-and-generator-scholarship on 11 February 2018]

The final part of the chapter will analyse the various interpretations that the National Maritime Museum (now Royal Museums Greenwich) and its members of staff have given about the Transit Circle. By exploring these interpretations, we are able to gain a better understanding of how the history of the instrument was interpreted in relation to its contribution to nautical and positional astronomy (the historical aim of the Observatory) as well as to its contribution to other practical applications of astronomy. Such an analysis illuminates the variety of narratives within which the Transit Circle was embedded as a museum object: the history of the Greenwich Prime Meridian, the dissemination of Greenwich Time, the wider history of finding longitude, and providing large data sets for fundamental star catalogues. As the section will demonstrate, the different interpretations of the Transit Circle led to the gradual disassociation of the Prime Meridian from the instrument within the public imagination, and resulted in fostering multiple (often contradictory) explanations on how the Prime Meridian was defined.

Connecting these sections together, the concluding remarks will frame the history of the Transit Circle through the question of what could be considered the end of the life of the instrument. Relying on the object biographies approach, it will ask whether or not the downfall of the instrument marked the end of its life. Thereby, it asks the question whether objects can be considered to have a life, or whether the biographical approach simply offers the guiding questions for analysing the history of things and scientific instruments. In addition, it will engage with the question of what can be considered the end of the life of a scientific instrument. Did the halting of operations with the Transit Circle mark the end of its life and perhaps even the end of its history? Or does its function as a museum object on display form part of the history of the scientific instrument? As the section will demonstrate, the multiple times operations were halted and the restarted with the Transit Circle, as well as its currently described state in a "working order" questions the definitions of "object lives" and "end of scientific objects".

2. Narrative frameworks of history the Transit Circle

As the previous chapter showed, the Transit Circle was communicated to both the general public and to special audiences through various mediums. This section focuses on the written descriptions of the instrument that appeared in magazines, newspapers, and other periodicals. By examining what themes were mentioned within these publications, we are able to trace how the interpretation of the instrument changed among the astronomical and public audiences from its first day of operation until the end its life. Such an analysis demonstrates that the end of the instrument coincided with a gradual disassociation between the instrument and its contributions to astronomical work.

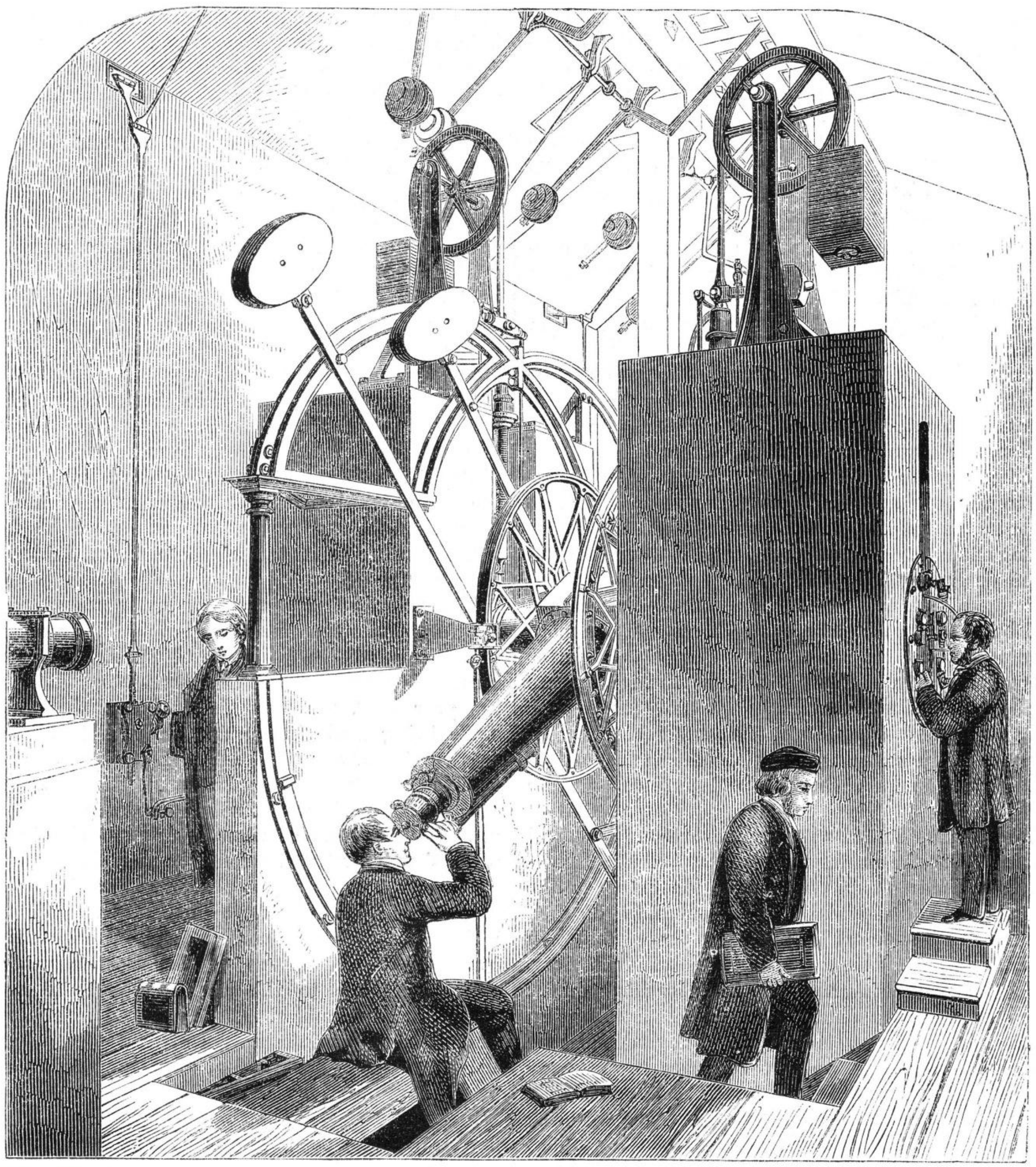
An analysis of British periodicals between 1850 and 1957 (available on Gale and ProQuest historical periodical databases) showed that there were 69 articles that mentioned the Transit Circle.[10] Based on the frequency of its appearance in articles, it can be seen that the first 15-20 years of its life generated the most attention to the instrument. This was due to models of the instrument appearing at meetings of the British Association for the Advancement of Science (in 1850 and 1851), the observations commencing with it in 1851, a model of the instrument exhibited in Paris in 1855, the same model's subsequent display at the South Kensington Museum, and the publication of two histories of the Observatory in 1862 and 1868. During the 1870s, mentions of it were tied to discussions about the 1874 Transit of Venus expeditions. In 1884 the International Meridian Conference at Washington took place, where a resolution was

[10] A list of these articles is given in Appendix I.

passed about the Transit Circle serving as the basis for defining the International Prime Meridian. Unsurprisingly, multiple articles detailing this connection appeared in 1885. The turn of the century saw renewed interest in the instrument. This was due to the Observatory's role in the Carte du Ciel astronomical project, and to the appearance of Walter Maunder's series of articles about the history of the Observatory. However, after the first decade of the twentieth century, a relative silence about the instrument began.

Through the various articles we see that depending on the life-stage of the instrument, different aspects of it were highlighted. Before observations commenced with the instrument, the articles mostly highlighted the technical details of the instrument.[11] The focus on the technical details continued well into the 1860s. For instance, articles about the model of the Transit Circle sent to Paris highlighted almost exclusively its technical features.[12] The first article that deviated from this norm was Edwin Dunkin's description of the Observatory and its history.[13] While providing a detailed technical description of the instrument, he also described the operations carried out with it. By doing so, Dunkin connected the instrument to the practical applications of positional astronomy, such as determining time, defining the Greenwich Meridian, and providing essential astronomical data for navigation. This departure from previous descriptions was highlighted with the illustration that accompanied the text. It used Plate 1 of the official description of the Transit Circle as its basis, but placed several figures surrounding and using the instrument (figure 44). This editing of Plate 1 demonstrated Dunkin's aim to describe the instrument in its working state and as part of the daily operations of the Observatory.

[11] For examples see 'British Association for the Advancement of Science', *Morning Post*, 9 August 1850, p. 3.; 'Scientific Memoranda', *Reading Mercury*, 22 June 1854, p. 7.
[12] For examples see 'Model of the Greenwich Transit Circle', *Illustrated London News*, November 1855, p. 629; 'Palais de l'Industrie', *Norfolk Chronicle*, 19 May 1855, p. 4.
[13] The description was published in two parts. See Edwin Dunkin, 'The Royal Observatory, Greenwich: A Day at the Observatory', *The Leisure Hour*, 9 January 1862, 22-26 and 'The Royal Observatory, Greenwich: A night at the Observatory', *The Leisure Hour*, 23 January 1862, 55-60.



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THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY.

Fig. 44. Illustration of the Transit Circle for Dunkin's article (scan provided by Graham Dolan)

Dunkin's descriptions were representative of how the Transit Circle was discussed in future articles. Articles by James Carpenter and George Forbes explored both the technical features of the instrument and its practical applications within astronomy and everyday life (i.e.

dissemination of time and defining the Greenwich Meridian).[14] Another important feature of these accounts was their incorporation of how the uses of the various instruments related to each other. By doing so, the instruments (including the Transit Circle) did not appear as isolated entities, but rather as collaborators working towards the aims of the Observatory. In this sense, they appeared as an assemblage of instruments. Turning to the visual depictions of the Transit Circle once again, we can see them being reflective of such a change. The illustration accompanying an article about the Observatory in *The Graphic* featured a collage of smaller illustrations showing the various instruments of the Observatory.[15] This decision was representative of how the relationship between the building and the instruments were often thought of during the nineteenth century. Instead of considering an observatory as halls and spaces for astronomical research, they were often seen as mere shelters for the instruments. As David Dewhirst beautifully highlighted, readers of the *Penny Cyclopaedia* wishing to learn about the definition of an observatory were simply instructed to 'see Transit Instrument'.[16] Highlighting such a relationship in visual terms, the illustration in *The Graphic* similarly placed the emphasis on the assemblage of instruments as opposed to on the Observatory as a totality independent from it.

During 1899 a series of articles about the Observatory and its history appeared in *The Leisure Hour*, written by another one of the Observatory's members of staff, Walter Maunder.[17] Similarly to Dunkin's work, the series of articles were subsequently expanded upon and

[14] Carpenter's description was published in three parts with the same titles: 'John Flamsteed and the Greenwich Observatory', *The Gentleman's Magazine*, 1866, February (Part 1), March (Part 2), and April (Part 3). For the description by George Forbes see 'The Royal Observatory, Greenwich', *Good Words,* January 1872.
[15] 'Greenwich Observatory Illustrated', *The Graphic,* 8 August 1885.
[16] Cited in David Dewhirst, 'Meridian Astronomy in the Private and University Observatories of the United Kingdom: Rise and Fall', *Vistas in Astronomy,* 28 (1985), 147-158 (p. 150).
[17] This work by Walter Maunder was published in four parts: 'Greenwich Observatory', *Leisure Hour,* January 1898; 'Greenwich Observatory', *Leisure Hour,* February 1898; 'The Census of the Sky', *Leisure Hour,* July 1898; 'The Bond of the Universe', *Leisure Hour,* September 1898.

published as a book. Maunder's articles in relation to the Transit Circle are interesting for two reasons. First, they were written after the Transit Circle gained fame for defining the Greenwich Prime Meridian. This was mentioned frequently in Maunder's articles and connected to the important role that it played in maintaining the British Empire. By doing so, Maunder argued that Transit Circle was not an astronomical instrument isolated from society, but rather, one of the tools of Empire too. Second, the articles highlighted here by Dunkin, Carpenter, Forbes, and Maunder shared the feature of describing in their works the technical aspects of the Transit Circle, its operations, and the wider applications of its use. By doing so, they approached the Transit Circle as a working scientific instrument. As we will see in the next sections such a framing of the instrument became less prevalent once it was transformed into a museum object, since its operational aspects were no longer considered relevant within the nautical/maritime framing of its history.

3. The gradual downfall of the Transit Circle

A scientific instrument does not turn into a museum object overnight. In the case of the Transit Circle, its long and gradual transformation into a museum object began during the early years of the 20th century, when new technological developments allowed for the construction of instruments that surpassed its accuracy.[18] Similarly, the gradual shift in focus within the wider field of astronomy towards physics brought increased emphasis on photographic and

[18] For a discussion on the development in the design of transit circles see E. G. Martin, 'Transit Circles, Past and Present', *The Observatory*, 69 (1949), 140-142; R. H. Tucker, 'Transit Circles Today', *Quarterly Journal of the Royal Astronomical Society*, 10 (1969), 223-232. For a more broader overview of the development of transit circles in relation to other astronomical instruments see King, *The History of the Telescope*.

spectroscopic apparatuses.[19] While modifications were made to the Transit Circle in order to attempt to keep up with the increased standards (the divided circle was re-graduated, and an impersonal micrometer was made for the eye-end of the telescope), they were not enough to keep it in use in the long run.

Flaws in the design of the Transit Circle began to show by 1921 (after 70 years of use). In that year, ‘following an exceptional dry summer, the east pier started to move downwards’.[20] This proved to be problematic as Airy’s design did not incorporate the physical adjustment for level and azimuth. As a result, from 1921 onward the height of the east bearing had to be raised almost every year until the end of the Transit Circle’s useful life. Another set of major concerns arose in 1926 when systematic errors were detected in the observations made with the instrument.[21] The unreliability of the observations led to transferring the task of making measurements and observations for the Time Service to another instrument (a small reversible transit instrument simply referred to as Transit B).[22] With this move, one of the main tasks was taken away from the Transit Circle. In light of the systematic error and the decaying state of the instrument, in 1931 it was proposed to replace it with a new instrument. While acknowledging the high quality of service that the instrument provided, the proposal also highlighted its ‘nearly worn out’ state, the ‘badly stained’ object glass that did not ‘bear further repolishing’, and that the ‘many divisions of the circle [were] nearly obliterated as the result of constant cleaning’.[23] With this decision, the instrument was destined to transition from the realm of “science” into the “*history*

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[19] For a discussion on the rise of astrophysics during the nineteenth-century see Iwan Rhys Morus, *When Physics Became King* (Chicago & London: The University of Chicago Press, 2005).

[20] Harold Spencer Jones, ‘Greenwich Meridian Observations’, *Astronomical Journal*, 59 (1954), 49-51 (p. 49).

[21] Phillip Gething, ‘The collimation error of the Airy Transit Circle’, *Monthly Notices of the Royal Astronomical Society*, 114 (1954), 415-432 (p. 415).

[22] Ibid.; Frank Dyson, *Annual Report of 1928*, p. 13. It is unknown where this instrument was set up within the Observatory.

[23] *Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich.* (1931), pp. 16-17. This Report can be found at the last section of the *Observations Made at the Royal Observatory, Greenwich in the year 1930* (London: His Majesty’s Stationery Office, 1932).

of science".[24] In 1937, the instrument reached the final days of its regular observing programme, which meant that "no further use [was to] be made of this instrument for fundamental observations".[25] This statement related to the end of its use for future observing programme, but still allowed its continued use until its ongoing programme was finished. With this decision, the end of the regular observing programme with the Transit Circle was announced in the Annual Report of 1938. Somewhat surprisingly, the same Report already announced the future of the instrument as a museum object: 'Even if no further observations are made with this instrument, it will be retained in its present position because of its historical interest.'[26]

The statement in the report emphasised two key elements. First, that the continuation of observations was conditional as opposed to being certain. By doing so, it showed that the termination of the use of the instrument was not due to it being completely broken, but rather because it was no longer considered reliable by the Board of Visitors. Second, that even at the beginning of the 20th century, the historical interest of the instrument was grounded upon its association with the Greenwich Prime Meridian. By highlighting that the instrument 'will be retained in its present position', the Transit Circle appeared not only as a sum of its mechanical and optical parts, but rather, as an assemblage going beyond the boundaries of the instrument itself. At the same time, it also has to be mentioned that the large size and heavy weight of the instrument made it difficult to transport. This was another possible obstacle that the Observatory had to consider at a time when it was actively looking to move to a new site. With this framing, the site where the instrument functioned (on the meridian at the Royal Observatory at

[24] Marchel Duchamp referred to the 'death' of a painting or its transformation from 'art' into 'history of art' after forty or fifty years of its life. The same can be said about scientific instruments when they are relocated into museums. It also raises the questions whether instruments and objects have a life that can end, and what defines the end of an instrument's life. Pierre Cabanne, *Dialogues with Marcel Duchamp* (USA: Da Capo Press, 1987) p. 67.
[25] *Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich.* (1938), pp. 38-39. This Report can be found at the last section of the *Observations Made at the Royal Observatory, Greenwich in the year 1937* (London: His Majesty's Stationery Office, 1951).
[26] Ibid., p. 39

Greenwich), its products (the Prime Meridian), and the instrument itself bear equal importance in the Transit Circle's 'historical interest'. While such an assemblage might be featured less prominently in the use of other instruments, the case of the Transit Circle highlights that approaching the history of a scientific instrument has to take into consideration the site where it was used, the products that it provided, and the multiple (internal and external) parts of the instrument itself. So far, such an approach has most frequently been used in telling histories of scientific instruments when they are taken out from their usual assemblages, contexts, and sites. For example, the problem of finding longitude at sea originates from taking instruments out from their usual assemblages.[27] Similarly, the British Magnetic Survey had to face the challenge of operating instruments at extreme conditions.[28] Finally, the lack of proper tools to repair the instruments highlighted additional connections upon which the use of instruments relied.[29] By contrast, the Transit Circle offers a great example of the analysis of these assemblages within an observatory context due to the supervision that was exercised over its daily use. Furthermore, expanding on the suggestion of Deborah Jean Warner and Simon Schaffer, an approach through assemblages helps in creating a solid theoretical foundation for displaying instruments not only on their own, but by connecting them to their products, to the sites where they operated, and to the additional instruments with which they were used.[30]

[27] For an detailed overview of the problem of longitude see Richard Dunn and Rebekah Higgitt, *Finding Longitude: How Ships, Clocks and Stars helped solve the Longitude Problem*. (Glasgow: Collins, 2014).
[28] Matthew Goodman, 'Proving instruments credible in the early nineteenth century: The British Magnetic Survey and site-specific experimentation', *Notes and Records*, 70 (2016), 251-268.
[29] Schaffer, *The Bombay Case*.
[30] Deborah Jean Warner, 'What Is a Scientific Instrument, When Did It Become One, and Why?', *The British Journal for the History of Science*, 23:1 (1990), 83-93; Simon Schaffer, *Easily Cracked*, p. 707.

Infrequent observations continued to be made with the instrument until terminated on 12 September 1940.[31] It is important to mention that the observations were terminated not because of the ongoing war, but because the observing programme with the Transit Circle ended.[32] However, 1940 did not prove to be the very end of the instrument. The global scale of the war led to the destruction of the Pulkovo Observatory and many of its instruments. This meant that the Pulkovo observing programme, which included positional observations of celestial bodies, had to be abandoned. In addition, it prompted the international astronomical community to begin searching for a replacement instrument that could continue the observing programme. The choice fell on the Transit Circle, and as a result, it was restored to an operational order. The restoration efforts took around a year, and on 26 May 1942 the instrument continued the Pulkovo observing programme from Greenwich by making occasional fundamental observations.[33] This restricted programme of observations continued until 1949. During this time, the mercury pool of the Transit Circle was replaced with a new one, demonstrating the reliance on maintaining the working state of the instrument.[34] Further modifications were made to its assemblage by changing the eye-pieces of the collimating telescopes,[35] placing new mirrors inside the telescope tube,[36] and several other alterations 'to both the level and azimuth of the instrument'.[37] In 1949, the Transit Circle took part in the Photographic Zenith Tube programme, which led to a new increase in the number of observations made with the instrument.[38] Furthermore, additional modifications to the Transit Circle were applied when the mercury arrangements for observations

[31] *Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich.* (1941), p.3. This Report can be found at the last section of the *Observations Made at the Royal Observatory, Greenwich in the year 1940* (London: His Majesty's Stationery Office, 1953).
[32] Ibid.
[33] *Annual Report*, 1942, p. 3
[34] *Annual Report*, 1947.
[35] *Annual Report*, 1942.
[36] *Annual Report*, 1945.
[37] *Annual Report*, 1947.
[38] *Annual Report*, 1949, pp. 10-11

by reflection were adapted from the newly built Reversible Transit Circle. Despite this newly found use for the instrument, the systematic errors and the nearly worn out state of the instrument remained. Emphasising this point, the Annual Report from 1949 stated that the only reason for continuing observations with the Transit Circle was the delay in the installation of the Reversible Transit Circle at the new site of the Observatory at Herstmonceux.[39] Therefore, once the new instrument became operational, the final observation with the Airy Transit Circle was eventually made on 30 March 1954.

The Annual Report of 1954 was the first official document to mention the transfer of the Transit Circle into the hands of the staff of the Maritime Museum. The report noted that the museum staff were 'being instructed in [the instrument's] care and maintenance.'[40] It is important to note that Spencer Jones used the words 'care and maintenance'. While maintenance is associated with the working order of the instruments, care tends to be associated with vulnerability of objects that are easy to break.[41] Therefore, the choice of words in the case already signalled the transitory state of the instrument whereby it was going through the process of turning into a museum object. This was also reflected in other parts of the Report. When describing the formal opening of the Octagon Room by the Maritime Museum, it was mentioned that the 'Airy Transit Circle has been shown to visitors, subject to not being in use for observation at the time.'[42] The display of the instrument to visitors, but only when it was not in use, highlighted the gradual transformation of the Observatory into a museum site as well as the transformation of the Transit Circle from a working instrument to a museum object. Unfortunately, the surviving records do not mention whether showing the instrument was only carried out under the supervision of a

[39] Ibid. p.10
[40] *Annual Report* 1954
[41] For an overview for the differences and similarities between the uses of the terms care and maintenance see Shannon Mattern, 'Maintenance and Care', *Places Journal*, November 2018.
[42] *Annual Report* 1954.

member of staff or whether visitors were allowed into the Transit Circle Room on their own. This was significant, since during the working life of the Transit Circle an assistant or the Astronomer Royal was always present when the instrument was shown to a visitor to the Observatory. The purpose of this was not only to explain the use of the instrument, but also to make sure that the visitor did not unintentionally adjust the instrument. Furthermore, since the instruments of the Observatory were in constant use, the visitor's guide could decide the right time to visit the different rooms, so that the visit did not interfere with the work of the Observatory. However, such visits took place very infrequently. For example, in an article written after the installation of the Great Equatorial, the limited access to the observing rooms and the instrument was attributed to the sanctity of the room.[43] The sanctity of the room was also associated with its solemn silence, which Airy really cherished, especially after the introduction of galvanic recording system in the 1850s. For example, Airy complained to Charles Piazzi Smyth (director of the Royal Observatory, Edinburgh), that the beat of the transit clock was too loud for galvanic observations, 'which we would wish to have in solemn silence.'[44] Therefore, the Annual Report of 1954 demonstrated the gradual removal of this sanctity of space that characterised the instrument and its assemblage throughout its working life. To put it differently, the sanctity of the space was no longer present in the Transit Circle Room (once it was turned into a museum space), thereby allowing visitors to enter the space that once had been restricted for them.

[43] The article characterised the work with the instrument (in reference to the illustration, which depicted it) as: 'We may here remark that the sanctity of the observing-room is seldom disturbed by the presence of such visitors as the artist has inserted in the drawing: they are introduced merely to relieve the monotony of the picture, and to give an idea of the general proportions of the instrument.' 'The Equatorial in Greenwich Observatory', *Illustrated London News*, 24 August 1861, p. 205.

[44] Airy to C. P. Smyth, 1854 October 4, RGO 6/144 113.

4. The Airy Transit Circle as a Museum Object

With the amalgamation of the Observatory into the National Maritime Museum, the Transit Circle became part of a set of instruments that were thought of in terms of museum objects. As it was mentioned above, the difference between an instrument in a working order and an instrument as a museum object can be characterised by the sanctity of the space within which it was exhibited. While the Transit Circle was still used, visiting it was a rare occurrence. By contrast, from 1960 onward, with the opening of the Flamsteed House as part of the Museum, visitors were also allowed to marvel and walk past the instrument. After the last observation was made with the instrument in 1954, the Museum took over its supervision. As a result, from 1955 onward, the instrument began to appear in the publications of the Museum and its curatorial staff.

1954 also marked the transfer of operations of the Royal Greenwich Observatory from the Old Observatory situated at Greenwich Park to a new location at Herstmonceux, Sussex. The fate of the Old Observatory along with the future of the instruments that it housed (including the Transit Circle) became an important question. By the mid-20th century, the Observatory lost some of its architectural appeal as parts of the building undergoing significant decay due to lack of use and proper maintenance.[45] Despite this, there was no doubt about the historical value of the site. In light of this, the possibility of converting the buildings into a museum was raised at the Ministry of Works, which department was in charge of its upkeep.[46] Two museums were considered for taking over the buildings: the Science Museum and the recently opened National Maritime Museum. Both museums were able to make good cases for taking charge of the Observatory.

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[45] Kevin Littlewood, and Beverley Butler, *Of Ships and Stars: Maritime Heritage and the Founding of the National Maritime Museum, Greenwich* (London and New Brunswick, NJ: Athlone Press, 1998), p. 145.
[46] Ibid., p. 146.

The Science Museum was the leading institution in relation to displays of scientific and technological achievements of the British nation, while the National Maritime Museum focused on the history of British naval power over the centuries that incorporated displays about its scientific and technological basis. By the 1940s the Science Museum had already had an extensive collection of astronomical instruments. On the other hand, the historical connection of the Observatory to the 'Quest for Longitude' brought forth the site's contribution to the development of navigation techniques, which made it a perfect fit for the Maritime Museum. Finally, the Old Observatory was located on the top of the hill at Greenwich Park, which brought it into close geographical connection with the Maritime Museum (its buildings being on the opposite side of Greenwich Park). By contrast, the Science Museum occupied a building in west London. In light of these details, the director of the Maritime Museum, Frank Carr, began an active effort for the annexation of the Observatory.[47] He framed its history as an Observatory devoting all of its attention to supporting the development of navigational techniques, thereby placing emphasis on the nautical and practical applications of astronomy. However, such an emphasis diminished the contributions of the Observatory to the theoretical side of positional astronomy. Carr's efforts were ultimately successful as the Ministry of Works agreed to the incorporation of the Observatory into the National Maritime Museum.

An analysis of the descriptions of the Transit Circle in publications by the Maritime Museum highlights how the history of the instrument was gradually reframed within the narratives of the Museum's exhibitions and the maritime connections highlighted by Carr. As Littlewood and Butler demonstrated in their history of the Museum, the institution faced the difficult task of incorporating the Observatory's collection into the aims of the Museum. The first version of the proposed new display linked the history of the Observatory to its contributions to positional

[47] Ibid. pp. 147-148.

astronomy.[48] Through positional astronomy, the Museum would have had the possibility of placing the emphasis on the production process and the theoretical underpinnings of the field. In addition, it would have opened up need to analyse the contribution of instruments as well as the hidden technicians in astronomical labour. However, this first version was later rejected, and rewritten with the use of the term nautical astronomy.[49] The use of 'Nautical Astronomy' allowed for making closer connections between the Observatory's history and the collection of the National Maritime Museum. It was a historically accurate selection, since the foundation of the Observatory was directly connected to a key concern of nautical astronomy, i.e. the quest for longitude. In addition, the Observatory was funded by the Admiralty and the production of the *Nautical Almanac* took place for decades at the Observatory.[50] However, nautical astronomy shifts the emphasis of the historical analysis of the Observatory from the production processes and the astronomical labour to their direct products and applications. As a result, the processes relied on within positional astronomy as well as the astronomical labour taking place on a daily basis at the site were black-boxed and given less attention by the Museum's interpretation of the Observatory's history. By analysing how the Transit Circle was described and interpreted in the publications of the Museum, we can illustrate this black-boxing of the astronomical processes including the use of the instrument.

[48] The following was the first suggestion for the new scope of the Museum: 'To collect, preserve, exhibit, and study objects and material (particularly those of historical interest) connected with (a) British seafaring and shipbuilding, and (b) positional astronomy; and to make available information on these matters, and their significance, to students and the public.' Cited in Littlewood and Butler, *Of Ships and Stars*, p. 183.

[49] The following was the amended Statement of the Objectives: 'To promote and maintain interest in Seafaring and Shipbuilding, past and present, particularly British, and in Nautical Astronomy. To collect, preserve, study, exhibit, and make available to all who are interested, any objects which will explain the story or assist the students.' Cited in Ibid.

[50] Even after its production was transferred to the Nautical Almanac Office, the Greenwich Observations served as the basis for it.

Coinciding with the grand opening of the Flamsteed House as a museum in 1960, a guide for the Observatory was written by Philip Laurie.[51] Discussing the ongoing renovations taking place, Laurie considered '[t]he rebuilding of the Circle Room and the erection of the famous Airy Transit Circle in 1851 among [the Observatory's] greatest achievements.'[52] In addition, it connected the instrument with Longitude Zero: '[w]ith nearly seven hundred thousand observations to its credit, the Transit Circle performed its duties for more than a century and still stands defining the Prime Meridian.'[53] This narrative tradition of connecting the instrument with Longitude Zero has continued to dominate the displays and the exhibitions on site even today.[54] Three years after the opening of the Flamsteed House, the renovation of the Meridian Building was officially approved in the spring of 1963.[55] During the renovations, many of the instruments were removed from the Meridian Building. An extensive set of photographs survives from this period of 3-4 years that shows the transformation of the Meridian Building into a museum.[56] The images taken of the instrument during the renovations show parts of it being covered as a protection.[57] In light of this, and with the lack of sources denoting the removal of the instrument, it is safe to assume that the Transit Circle remained on site during the work. Keeping the instrument at the site even during the renovations reflected the close connection between its materiality and the Greenwich Meridian that the instrument defined. The current display of meridian instruments at the Royal Museums Greenwich reflects this same proximity. Every time

[51] Philip S. Laurie, *The Royal Observatory* (London: M. Harland & Son, 1960).
[52] Ibid. p. 16.
[53] Ibid.
[54] Besides Longitude Zero, it is worth noting that Laurie proposed an estimate for the total number of observation made with the Transit Circle. His estimate of 700,000 observations was relatively close to the actual number of observations. Gilbert Satterthwaite undertook the tedious task of attempting to harmonise the reported number of observations (as published in the Greenwich Observations and the Annual Reports), and counted 679,380 transits observed and 632,040 zenith distances determined over the course of the instrument's history. See: Satterthwaite, *The History of the Airy Transit Circle*, p. 57.
[55] Littlewood and Butler, *Of Ships and Stars*.
[56] Available at the Curatorial Office of Royal Museums Greenwich.
[57] Reference to photograph. The possibility that the instrument has never left the site of the Observatory was also mentioned in Richard Ormond, *The Old Royal Observatory: The Story of Astronomy & Time* (1992) p. 27.

a new transit instrument was introduced at the Observatory, the Greenwich Meridian was moved to be defined by the new instrument. The Museum's display marks the location of previous instruments, and in consequence, highlights the gradual shift in the position of Greenwich Meridian over the years.

Later publications by the National Maritime Museum continued connecting the Transit Circle with nautical astronomy and the story of longitude. The description of the Observatory in a publication from 1963 was the first museum-produced document to mention the Washington Meridian Conference of 1884 at which the Transit Circle was recommended as the instrument to define the Prime Meridian.[58] Furthermore, the text provided suggestions on how the visitors could interact with the Prime Meridian: 'The meridian is marked across the courtyard so that visitors can indulge in the conceit of being photographed standing with a foot in each hemisphere.'[59] This custom has since become a defining feature of tourist visits to the site. While the mark of the meridian across the courtyard passes through the Transit Circle, photographs taken by tourists tend to be made with the London cityscape in the background, with the sculpture *Prime Meridian Marker* by Christina Garzia, or showing only the feet of the visitors. This type of disassociation of the meridian line from the materiality that defined it continues to contribute to the separation of the instrument (including the processes, which used to go into the construction/re-determination of the line) and the line as two distinct entities as opposed to nurturing a view that reflects their historically symbiotic relationship. In consequence of this disassociation, the line is depicted by the majority of tourist photographs as an entity on its own, which portrayal shows it as independent from the defining processes of the instrument.

[58] *National Maritime Museum – Old Royal Observatory: Flamsteed House* (4 March 1963), in the collection of the Caird Library marked D.D.3. and EDU/25/6/64, p. 1.
[59] Ibid.

Frank Carr's *Maritime Greenwich* was published in 1965, which continued to describe the now established topics: the 1884 Washington conference, and the large number of observations (which Carr noted as 650,000).[60] In contrast to the previous publication of the Museum, Carr offered a very simplistic interpretation of the Washington conference. As opposed to highlighting the clashes due to 'each delegation patriotically [urging] the meridian of its own capital',[61] Carr retold the event as a meeting where 'the universal acceptance of Greenwich for the world's zero of longitude' took place.[62] Furthermore, he candidly added that it was 'probably the only occasion in history when all the nations of the world have agreed on anything'.[63] Since Carr's book, several works have called attention to the lengthy negotiation processes during the meridian conferences, as well as to the slow adoption of the Greenwich Meridian as longitude zero.[64] In addition to the previously mentioned points, Carr offered an interesting connection of the materiality of the Transit Circle with longitude zero. As opposed to using the wording of the 1884 definition for a recommended meridian, Carr stated that the 'prime meridian has been the centre wire in the Airy transit circle'.[65] This type of exclusive focus on the materiality of the longitude idealised the Transit Circle (and the central wire) as a perfect instrument that was aligned exactly with the meridian, and as a result never deviated from its fixed position. As was demonstrated through the chapters on the maintenance and repair of the Transit Circle, the instrument was never in a fixed state. Instead, the Observatory staff, being aware of the changes of the instrument, frequently measured the errors they caused, and applied those measurements

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60 Frank Carr, *Maritime Greenwich (Pride of Britain)* (London: Pitkin Guides, 1965), p. 14.
61 *National Maritime Museum – Old Royal Observatory: Flamsteed House*, p. 1.
62 Carr, *Maritime Greenwich.*
63 Ibid.
64 See Howse, *Greenwich Time*, p. 127-143; Ian R. Bartky, *Selling the true time: nineteenth-century timekeeping in American* (Stanford, California: Stanford University Press, 2000), pp. 147-151; Ian R. Bartky, *One time fits all: the campaigns for global uniformity* (Stanford, California; Stanford University Press, 2007), pp. 38-47 & 82-99; Withers, *ZeroDegrees*.
65 Carr, *Maritime Greenwich*, p. 14.

during the final calculations. In consequence, the central wire of the instrument did not mark the Greenwich Prime Meridian. If that had been the case, then Longitude Zero was nothing but a spider-thread that was frequently replaced by the instrument makers and occasionally got destroyed by incompetent observers. As a result, instead of considering the central wire being as an end in itself (longitude zero), it has to be considered as a means to an end (to gain initial measurements in order to determine longitude through calculations).

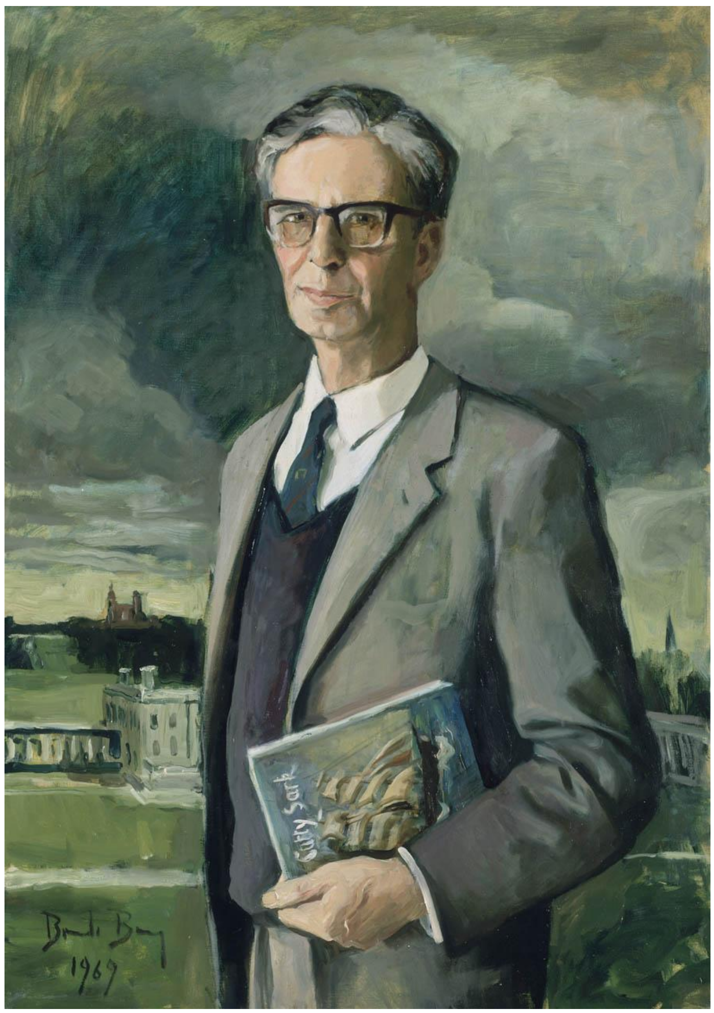

Fig. 45. Portrait of Frank Carr (1969, RMG, Object ID: BHC2600)

The Meridian Building was finally opened as a museum on 19 July 1967. At the opening ceremony of the building, Richard Woolley (the Astronomer Royal at the time; figure 46) made a speech detailing the history of positional astronomy in relation to Greenwich and the Observatory's contributions to later developments in astronomy.[66] Surprisingly, Woolley's account of Airy's contributions lacked the emphasis on nautical astronomy and the 1884 Meridian conference in Washington. Instead, Woolley connected the use of the instrument to the 'principal interest of Victorian astronomers and mathematicians' which was 'the extension of observation and theory to enable Newton's law of gravitation to account for the motions of the objects in the solar system'.[67] By doing so, Woolley's speech demonstrated that the narrative around the Transit Circle as told by the publications of the National Maritime Museum was at the time embedded completely in the context of nautical astronomy as opposed to other advances made within the field of astronomy at the time.

The narrative framing of the Transit Circle by the Museum was not surprising given that the Observatory was established with the aim of finding longitude and aiding nautical astronomy. Furthermore, given that the Museum was focused on maritime history, it was also in the Museum's interest to nurture a narrative that connects the Observatory to the Museum's exhibits. However, Woolley's approach placed celestial mechanics and positional astronomy as a basis for nautical astronomy. Positional astronomy contributed to celestial mechanics through devising coordinate systems that allow for the measurement and comparison of observations.[68] Woolley's focus on this branch of astronomy underpinning nautical astronomy was an echoing of Newcomb's statement who argued that the contribution of the Observatory to astronomy was through a specific 'treatment of the positions and motions of the heavenly bodies […]' for the

[66] A transcript of Woolley's speech can be found in the Caird Library, *Opening of Meridian Building at Greenwich, 19th July 1967*, call number: 069(26:421)7:520.1.
[67] Ibid. p. 4.
[68] George Williams Collins, *The Foundations of Celestial Mechanics* (Tucson, AZ: Pachart Publishing House, 2004), pp. 15 & 20.

practical application of nautical astronomy.[69] We see here a problem similar to that of the relationship between the Line (a product) and the Transit Circle (part of the production). The Museum's publications through an emphasis on nautical astronomy highlighted one of the products of positional astronomy, while Woolley's approach focused on the astronomical labour with the Transit Circle that contributed to other branches of astronomy too besides nautical astronomy.

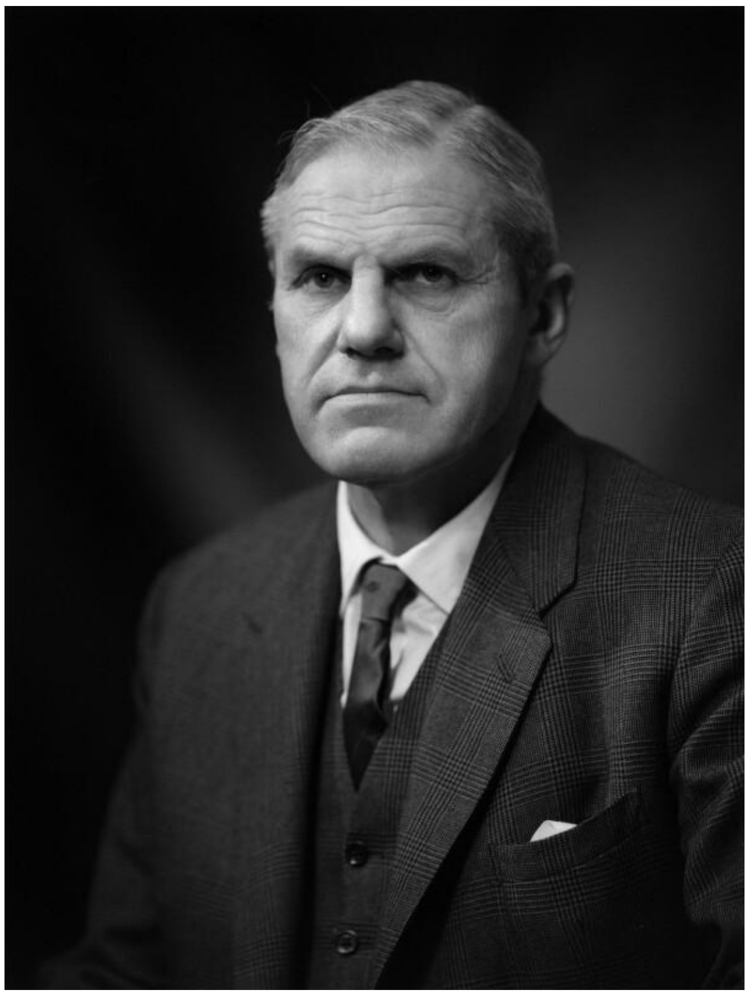

Fig. 46. Photograph of Sir Richard van der Riet Woolley (1965, NPG, x172076)

[69] Simon Newcomb, 'Astronomical Observatories' in *The North American Review* 133:297 (1881), 196-203 (p. 198).

The next guide by the Museum (*The Old Royal Observatory*) continued the emphasis on nautical astronomy and the Prime Meridian but also began incorporating the theme of nineteenth-century research into gravity.[70] This was carried out through connecting the work of the Transit Circle to how Flamsteed's observations contributed theory of universal gravity. This was a significant addition to the narrative because it showed that while the Observatory was officially devoted to nautical astronomy, celestial mechanics was also one of its important research areas. Despite the presence of this historical basis for connecting the Transit Circle to celestial mechanics, its association with the Prime Meridian continued to overshadow such considerations. The guidebook, similarly to Carr's publication from 1965, continued with defining the Prime Meridian as an object marked by the instrument itself. However, as opposed to the use of the centre wire, the guide defined Longitude Zero as the 'longitudinal centre line of this instrument'.[71] In addition, as with previous examples, the choice of the Greenwich Meridian for Longitude Zero was referenced as the outcome of an international agreement in 1884. While this guide did not depict the agreement as a glorified unanimous agreement as Carr's book did, it still overlooked mentioning any opposition to choosing the Observatory as the basis for the Prime Meridian.

During 1969 the *Notes for visitors* was also published by the Museum. The *Notes* did not give a detailed account of the Transit Circle, but mentioned that until 1850, the Greenwich Meridian was defined by other instruments placed in another room, which with the installation of the Transit Circle had moved. In addition to this, the notes also mentioned the 1884 Washington Conference selecting the meridian through the Transit Circle as the Prime Meridian of the world,

[70] *The Old Royal Observatory: A brief guide* (National Maritime Museum, 1969).
[71] *The Old Royal Observatory: A brief guide* (1969) p. 12.

and line being marked across the courtyard of the Observatory.[72] With these brief mentions, the *Notes* demonstrated that the Transit Circle continued being presented within the framing of longitude, and continued highlighting the close proximity between the materiality of the instrument and the Prime Meridian.

Only one year later another history of the Old Royal Observatory and an early pamphlet version of Derek Howse's popular *The Story of Greenwich Time* were published. The *Introduction* to the Observatory informed the reader that by 1970 most of the historical instruments previously used in the Meridian building were re-installed at their original positions.[73] When the book provided a more detailed description of the Transit Circle, it repeated one of the mistakes of previous publications by declaring the decision of the 1884 Washington conference to be a universal agreement. In relation to Longitude Zero, the publication defined it in a vague manner as 'the meridian of the centre-line of Airy's transit circle'.[74] While it is possible to interpret the intended meaning of the definition as the centre-line of the instrument being the meridian, it is important to highlight that lines do not have meridians. Instead, lines can be, rest on, be parallel to, or dissect a meridian. Despite this shortcoming, 'the centre-line of the Airy's transit circle' remains an accurate definition as it allows for such a centre-line not to be connected to a fixed physical point, but rather, to a theoretical product that can be redefined. As a further addition to the description of the Prime Meridian, the *Introduction* also connected the Line to being the basis of the International Time Zone system. Surprisingly, since transforming the Observatory into a museum, this is the first occasion that the International Time Zone system was referenced in relation to the Transit Circle in any of the publications by the Museum. This was a major milestone in the communication and the interpretation of the instrument, as it allowed a historical

[72] *National Maritime Museum : Notes for Visitors* (National Maritime Museum, 1969), p. 11.
[73] *The Old Royal Observatory: An Introduction* (National Maritime Museum, 1970) p. 5.
[74] Ibid. p. 6.

discussion more focused on the concept of time, than on the concept of space. As we will see, in publications from 1970 onward both Greenwich Time and Greenwich "space" were referenced in relation to the Transit Circle. Lastly, the *Introduction* repeated the description as a caption to a photograph of the instrument, with additional information on the shifting of the meridian line eastward with the installation of the Transit Circle.[75] By mentioning the historically shifting nature of the line, the book helped to demonstrate the close relations between the materiality of the instrument and the meridian, as well as the constructed nature of the line, through the ability of the Observatory to "move the meridian" with subsequent instruments.

Howse's *The Story of the Greenwich Time* provided the reader a glimpse into the history of the Observatory from its earliest times to the latest developments of the era. As the title also suggested, the pamphlet focused more on the history and the procedures of the measurement of time, as opposed to the finding of longitude. In consequence, the Prime Meridian was only mentioned with reference to the Greenwich Mean Time and the International Time Zone System. Yet, the specific definition of Longitude Zero given by the article has been the most accurate out of all the publications to date: 'a meridian passing through the centre of Airy's Transit Circle'.[76] This definition allowed for the changing nature of the instrument, but still did not consider that the smaller changes in the physical centre of the instrument did not shift the meridian itself. Similarly to Woolley, Howse also attempted to open the possibility of a narrative outside the confines of nautical astronomy by referring to the two aims of the Observatory as 'perfecting navigation and astronomy'.[77] However, with the focus of the article being on time, the theoretical (and non-navigational) contributions of the Observatory to astronomy remained unexplored. At

[75] Ibid. p. 8.
[76] Derek Howse, 'The Story of Greenwich Time', *Journal of the British Astronomical Association*, 80 (1970), 208-211 (p. 208).
[77] Ibid.

the same time, the discussion on Greenwich Time allowed the history of the Observatory to go beyond the limits of nautical astronomy and to explore astronomy's applications in other aspects of everyday life. Surprisingly, these two publications from 1970 were the first ones that connected the Transit Circle to time measurement and its dissemination. They were the starting point of an approach that has defined the interpretation of the instrument for the past 50 years.

The next publication about the Observatory was an edited guide by Colin A. Ronan.[78] It attempted to tell briefly the history of the 300 years of astronomy which was carried out at the Observatory. The section that first mentioned the Transit Circle was titled *Time* and was authored by Humphry M. Smith (former Head of Time Department). However, this mention included only a single photograph of the instrument with the caption 'observer using Airy's transit circle which, from 1851 to 1933, was used for time and position measurements.'[79] By highlighting the functions of the instrument as 'time and position measurements', Smith continued the line of narrative that takes the Transit Circle beyond the limits of nautical astronomy. This approach was also emphasised by the chapter titled *Observing the Universe*, authored by Philip S. Laurie. While the description of the Transit Circle was connected to zero longitude (without giving any definition of what zero longitude is or how it is defined), it also elaborated a little on the design of the instrument: '[the Transit Circle] combined the functions of a transit telescope for time and a circle for position'.[80] This interpretation meant that Laurie, similarly to Smith, continued connecting the research carried out with the Transit Circle to observational/positional astronomy as opposed to exclusively to navigation. In addition, this was the first instance when the design of the Transit Circle was described in publications by the

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[78] Colin A. Ronan (ed.), *Greenwich Observatory: 300 years of astronomy* (London: Times Books,1975).
[79] Ibid. p. 25.
[80] Ibid. p. 31.

Museum as a combination of two other types of astronomical instrument. This signalled a gradual turn towards approaching the Transit Circle through its materiality and as a scientific instrument with its history, as opposed to just being a "museum object" marking the Prime Meridian. Furthermore, Laurie characterised the Transit Circle as a telescope that was 'approaching the end of its useful life' by 1933.[81] The choice of 1933 as the end of the 'useful life' was given no justification by Laurie, but it can be argued to coincide with the beginning of the construction of the Cooke Reversible Transit Circle (the instrument that was going to replace the operations of the Airy Transit Circle at Herstmonceux) which was proposed to the Board of Visitors by the Astronomer Royal in 1931. Despite this, as it was demonstrated at the beginning of the chapter, the Transit Circle continued to be used on a frequent basis at least until 1940, and then revived as a working instrument during World War II. On the other hand, the characterisation of the time-period from 1851 to 1933 as the instrument's 'useful life' brings into question the differences between keeping the instrument in working order as a museum object, and the usefulness of the telescope during its active/useful life. The difference between the two states being the change in the function of the Transit Circle from an instrument used for measurement of time and positions, to an object that marks its own history. If a museum object and a working instrument have different functions, then it can be argued that the Transit Circle continues to be a 'useful instrument' by fulfilling its assigned role as a museum object instead of its previous function as a working astronomical instrument.

[81] Ibid. p. 33.

Derek Howse expanded on his earlier journal article on Greenwich Time in the form of a book published in 1980.[82] The book provided an overview of the history of the quest for longitude and the various ways in which time was measured since ancient times. In addition, the appendices of the book provided valuable information on the various methods with which longitude was determined, as well as the method of time measurement and dissemination at the Observatory. The significance of the Transit Circle in Howse's account of the history of the Observatory was already established in the preface. Here, he quoted from the document produced at the 1884 Washington Meridian Conference that recommended the Transit Circle to define the Prime Meridian: 'II. That the Conference proposes … the adoption of the meridian passing through the centre of the transit instrument at the Observatory of Greenwich as the initial meridian for longitude.'[83] Despite this, the eager readers of the book had to wait until they were halfway through it, in order to find reference to the Transit Circle again. When describing the procedure of measuring and distributing time across Britain (as starting from the Observatory), Howse highlighted the first step in the process as '*find the time* by astronomical observations of the so-called 'clock stars', using the transit circle […]'.[84] Therefore, Howse established the use of the Transit Circle specifically as the basis and the first step in the production of time, and upon which measurements the rest of the time distribution process mattered. The instrument was next mentioned in connection to another apparatus called the chronograph, which Airy installed in 1852 in order to 'automatically [record] seconds impulses (later, two-seconds impulses) from the Sidereal Standard Clock on the same paper chart as the precise times of astronomical observation on transit circle'.[85] With this passage and the previous description of the procedure of time

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[82] Howse, *Greenwich Time*.
[83] Quoted in *Ibid.*, p. xiv
[84] The 'transit circle' in this context referred in specific to the Airy Transit Circle. Ibid. pp. 92-94.
[85] Ibid. p. 100

dissemination combined, Howse helped the reader to imagine the Transit Circle not as an isolated instrument but, rather, as a part of a larger assemblage of instruments used in order to produce and disseminate time across Britain. The depiction of the Transit Circle as an assemblage of various instruments (in the production line of time measurement and dissemination) was once again a new approach in which it was depicted for the first time. While the Transit Circle had been previously mentioned in relation to other meridian instruments (due to the "moving" of the meridian), Howse was the first to mention the set of instruments that were connected to it during its use. The other instance when the Transit Circle resurfaces in the book was in relation to the retriangulation of Great Britain in the 1950s and 1960s, as the basis for new maps. During the project, it was found that the Transit Circle was not located exactly on the meridian, but a very short distance away from it. After thorough examinations of the calculations, the officials concluded that the previous triangulation of the region had not taken into account the moving of the Greenwich Meridian from one room to another in the Meridian Building after the installation of the Transit Circle in 1850.[86] In relation to the 1884 Washington Meridian Conference, Howse provided one of the first accounts of what led up to convening the conference, as well as the tedious negotiations that occurred during the conference regarding where to place the Prime Meridian. By doing so, it showed that the Greenwich Meridian was not chosen for the Prime Meridian on a unanimous decision. Finally, Howse gave a longer description of the Transit Circle in the appendices to his book. While previous accounts referred to the useful life of the instrument to span from 1851 to 1933, Howse argued that the downfall of the instrument began in 1927, when smaller reversible transit circles were introduced at other locations for the accurate determination of time. With the introduction of reversible transit circles, astronomers were able to eliminate the collimation error of the non-reversible

[86] Ibid. pp. 170-171.

counterparts of the instrument. However, taking away time measurements did not mean the complete end to the useful life of the Transit Circle as position measurements remained to be carried out with it.[87] To sum up, Howse's account of the Transit Circle was able to bring together the narrative of both nautical astronomy and non-navigational applications of positional astronomy, and interpreted it not as an isolated instrument, but one that was used in conjunction with several others around the Observatory.

Two years after Howse's book, Greenhill's guide to the National Maritime Museum was published. While the Transit Circle was only mentioned very briefly, it was enough to connect it to the Prime Meridian as well as the to line providing 'the basis for time kept the world over'.[88] In addition, it also provided the fourth different definition for the longitude zero: defined by the instrument's 'optical axis'.[89] Lastly, the label underneath the image of the Transit Circle made another interesting mistake by referring to the year of the instrument's installation as 1852. While it is possible to understand a dispute between the years 1850 and 1851 (since the instrument had already been set up for observations by the end of 1850, and the first observation was delayed due to bad weather until 4 January 1851), there was no reasoning provided by the text why 1852 was selected as the year of the Transit Circle.

It took more than ten years for the Transit Circle to appear in another publication by the Museum. However, this time it appeared in a major role by being featured on the cover of the publication. This cover for Lippincott's *The story of time and space* showed a collage of images that included a photograph of the meridian building with the wall shutters open and showing the

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[87] Ibid. p. 202.
[88] Basil Greenhill (ed.), *The National Maritime Museum* (London: Philip Wilson Publishers Ltd and Summerfield Press Ltd., 1982), p. 110.
[89] Ibid.

Transit Circle.[90] The work introduced the instrument within the larger narratives of quest for longitude and standardisation of time. Emphasising the important contribution of the instrument to these stories, the book's introduction began with the statement that all time and space is measured relative to Longitude Zero (000 00' 00"), which is defined by the crosshairs of the great Transit Circle telescope in the Meridian Building of the Observatory.[91] The use of the term crosshairs is even more interesting here, since it suggests a target marker, as opposed to being part of a measurement process.

As can be seen, this statement continued the mistaken association of the crosshair with the Line. In addition, it removed the reference to Airy from the name of the instrument and used the simple label of great Transit Circle. This is somewhat surprising, as the 'great' label was used for the Equatorial telescope installed in 1860, but not for Transit Circle. The book returned to discuss the Transit Circle towards the end of the publication, where it provided a different definition for how the instrument defined the Line: 'the meridian passing through the principal transit instrument at the Observatory at Greenwich was to be this 'initial meridian.''[92] Once again, we observe that the instrument was seen as marking the meridian as opposed to contributing to the process of determining it. At the same time, the book began to embrace thinking about the Transit Circle as an assemblage and as a nineteenth-century technological marvel by providing a description of the purpose and use of the micrometers in the western pier.

The next guide to be published by the Museum incorporated even lengthier descriptions of the Transit Circle. As expected, it made the first reference to the instrument in relation to its connection to the Prime Meridian: 'the principal transit circle has been used to define the Prime

[90] Kristen Lippincott, *The story of time and space: the Old Royal Observatory at Greenwich, past, present and future* (Addax Publishing, 1994).
[91] Ibid. p. 2.
[92] Ibid. p 27.

Meridian.'[93] With the use of this definition, the book was able to highlight the contribution of the instrument in the process of defining the meridian as opposed to physically marking it. Later parts of the guide provided one of the most detailed descriptions of the history of the instrument connecting it to previous meridian instruments, the moving of the meridian with successive instruments, the contribution of engineers and instrument makers, and mentioning the Transit Circle to be Airy's own design.[94] In addition, it continued portraying the instrument as an assemblage by highlighting the changing method of observations with the introduction of the chronograph in 1854. The need to mention the instrument makers continued in the next publication of the Museum. At the same time, the inclusion also reflected the expertise of one of its authors, Gloria Clifton, in the history of instrument makers. While the Transit Circle only featured in this book through an image and a short caption underneath the photograph, the caption was one of the most accurate ones found among the Museum publications, mentioning the installation, use, and practical contribution of the instrument.[95]

Besides these works, it is also worth mentioning two other undated publications by the Museum. The first one mentioned here is *The Old Royal Observatory: The Story of Astronomy & Time* with an introduction by Richard Louis Ormond.[96] The interesting contribution of this book was its mention of the observation by reflection method, and the statement that since its installation in 1851 it has never left the Observatory. The former helped in contributing to building a narrative outside the nautical framing of the instrument, while the latter highlighted once again the close

[93] *The Old Royal Observatory Greenwich: guide to the collections* (London: National Maritime Museum, 1998), p. 7.
[94] Ibid. pp. 91-93.
[95] Gloria Clifton and Nigel Rigby, *Treasures of the National Maritime Museum* (London: National Maritime Museum, 2004), p. 22.
[96] *The Old Royal Observatory: The Story of Astronomy & Time* (Centurion Press, [undated]).

connection that the instrument and the space it occupied shared.[97] The second publication requiring our attention was Derek Howse's *Guide to the Old Royal Observatory Greenwich*.[98] This pamphlet offered the second longest description of the instrument in any publications by the Museum. It referred to the instrument both as Airy's Transit Circle and as the Great Transit Telescope.[99] It provided a description of the various methods of observations, and the various parts of both the internal and external assemblage of the instrument. It also connected it to previous instruments, and called Airy's project to construct the instrument an 'exercise in massive precision engineering.'[100] In addition, it included the often-overlooked fact that the lifting machinery at the top with its counterweights holds up the instrument, so that only 10% of its total weight rests on the trunnions to avoid the gradual wear of the pivots. By highlighting these features of the instrument, it contributed to the development of a narrative frame that considered the Transit Circle as a technological artefact that embodied new methods developed by engineers and instrument makers at the time.

5. A framing of its history through positional astronomy

The middle of the chapter demonstrated that both the Science Museum and the National Maritime Museum were interested in incorporating the Observatory with its historical instruments into their assets. This chapter also argues that the two museums would have offered different interpretations of the Transit Circle. While the previous sections explored how the National Maritime Museum exhibited it, it is worth imagining how the Science Museum could

[97] Ibid. pp. 26-27.
[98] Derek Howse, *Guide to the Old Royal Observatory Greenwich* (National Maritime Museum, 1973).
[99] Ibid. pp. 2 & 7
[100] Ibid. p. 7.

have differed in displaying and interpreting the instrument's history. I argue that while nautical astronomy would have remained a significant interpretation of the Transit Circle, the Science Museum would have had the possibility to explore positional astronomy in more depth within the context of the objects already found in its existing collection.

So what would a framing through positional astronomy would look like? I suggest that it would bring forth the contribution of Transit Circle to the production of star catalogues, and it would emphasise its production process. Satterthwaite identified 12 different catalogues published between 1854 and 1954 to which the Transit Circle contributed. Going beyond the catalogues, the Transit Circle helped in the 'determination of the solar parallax from astrometric observations of the minor planet Eros at its close approach to Earth in 1931'[101] Similarly, the published observations on the Sun, Moon and inner planets served as the basis for demonstrating the possible irregularities in the rotation of the Earth. By highlighting the production processes for these observations, the framing would call attention to Airy's implementation of Besselian analysis into the reduction of the observations.

Through the production processes, it would have had the possibility to show the constructed nature of time and space, and therefore to link it to the discoveries about the relative nature of time, and to "moving" the meridians. For instance, Karl Pearson demonstrated that time is 'a relative order of sense-impressions, and there is no such thing as absolute time' by using a *clocks-Royal Observatory-stars* sequence.[102] By using this sequence, he argued that there is always a fixed reference point from which time is derived. However, the fixity (or regularity) of that point is always only conceptual to aid our understanding, as opposed to reflecting reality. As he put it: 'Absolute intervals of time are the conceptual means by which we describe the

[101] Satterthwaite, *The History of the Airy Transit Circle*, p. 59.
[102] Karl Pearson. *The Grammar of Science* (London: Adam and Charles Black, 1900), p. 186-192.

sequence of our sense-impressions, the frame into which we fit the successive stages of the sequences, but in the world of sense-impression itself they have no existence.'[103] Within this framing, the Transit Circle emerges as a crucial instrument within the sequence of time regulation. It was not only the instrument that guided the process of deriving Greenwich Time, but also the artefact that transformed and inscribed into it its own errors and precisions. In this way, the histories of time as well as its relativity become the history of the Transit Circle too.

Besides the relativity of time, the framing can also incorporate the "moving" of meridians, and highlight the competing systems that have been derived during the 20th century. In research published in 2015, scientists called attention to GPS identifying zero longitude 102 metres to the east of the currently marked meridian line inside the premises of the Observatory.[104] As the researchers pointed it out, this was due the differences between the astronomical (1884) and geodetic (1984) methods being the basis/standards for determining geographical positions. While the history of longitude connected the meridian to the material instrumentation, this framing of the history connects the history of "the Line" to the methods and standards used by scientific communities. In this light, the Greenwich Prime Meridian is disassociated from the Transit Circle, and Longitude Zero takes on an almost independent existence. At the same time, by comparing the materiality of the instrument with the conceptuality of the theoretical methods, the Transit Circle emerges as a materialisation of the nineteenth-century practice as opposed to an instrument on its own. Such a change in approach allows us to open up the black box of methods and standards to observe whether it is empty or not.

[103] Ibid. 189.
[104] Stephen Malys, John H. Seago, Nikolais K. Pavlis, P. Kenneth Seidelmann, and George H. Kaplan, 2015. 'Why the Greenwich meridian moved', *Journal of Geodesy,* 89:12 (2015), pp. 1263-1272.

Finally, a framing through positional astronomy would call attention to Airy's organisational methods as responses to challenges caused by managing big data within astronomy. Star catalogues and published observations were presented in the form of tables. Such a mode of presentation allowed for the management of large astronomical data.[105] Taking the Greenwich Observations as an example, the names of celestial bodies, their positions, and the factors that contributed to the errors of the finals results were presented in a clear and simple way. Through this framing, Airy's criticisms of the Greenwich Observations (while he was still at Cambridge Observatory) appear as criticisms of how big astronomical data should be managed within positional astronomy. Therefore, once appointed as Astronomer Royal, the implementation of factory techniques appears as a response to manage big astronomical data on a daily basis. Division of labour, astronomical instruments in the likeness of heavy machinery, standardised skeleton forms, and close supervision of the business of the Observatory all served the purpose of ordering the individuals, the instruments and the numbers that they produced.

6. Object biographies and object lives

This chapter examined the history of the Transit Circle through the lens of object biography. It applied a biographical approach to understanding the life of the instrument by considering three of its life-stages: its downfall, its transformation into a museum, and its afterlife as narrated by the Museum publications. By comparing the narrative frameworks within which the instrument was placed during its "working life" and its "afterlife", it demonstrated a

[105] Arthur L. Norberg, 'Table Making in Astronomy', in Martin Campbell-Kelly, Mary Croaken, Raymond Flood, and Eleanor Robson (eds.) *The History of Mathematical Tables: From Sumer to Spreadsheets* (Oxford and New York: Oxford University Press, 2003), 177-208.

shift in how the instrument was interpreted. While during its working life the instrument's technical aspects, methods of observation, and practical applications were all discussed, within the museum context the focus remained mostly on the practical by-products of the observations made with it. However, towards the end of the 20th century, the narrative frameworks that dominated discussions throughout its life began to re-emerge. The chapter argued that the shift in these narrative frameworks was indicative of the different life-stages of instrument: it was transferred from the realm of science into the realm of history of science.

A major consequence of this narrative shift was the reconsideration of the relationship between the Transit Circle and the meridian that it defined. The chapter argued that focusing the attention on the product of the instrument (the Prime Meridian) as opposed to on the product itself transformed the relationship between the materiality of the Transit Circle and Longitude Zero by hiding instrument in the Meridian Line's history. As demonstrated through the varying definitions of the Prime Meridian with reference to the Transit Circle in publications by the National Maritime Museum, the narrative shift also resulted in obscuring that the instrument was used to help in defining the local meridian as opposed to marking it. By doing so, such a narrative further separated the everyday operations of the instrument during its working life from the history of the Meridian Line.

The chapter argued that one of the reasons for such a change in the narrative framework was the influence of the aims of the National Maritime Museum established after the incorporation of Observatory into its organisation. With an emphasis on nautical astronomy instead of positional astronomy, it guided the display towards the application of astronomical research as opposed to towards analysing the process of astronomical labour. At the same time, it can also be argued that the Museum simply preserved through its exhibitions and publications the black-boxed nature of an international standard. As a result, instead of opening up discussions through its exhibitions on the process of how the Prime Meridian was determined repeatedly with the use of the Transit Circle, it thought about the instrument that had to be guarded and preserved similarly to the classical units of standard in physical forms (e.g. the standard yard, the standard metre, or the standard kilogram).

This chapter applied the biographical approach to the analysis of the Transit Circle by breaking its life down into life stages. As it was highlighted in the Introduction of this dissertation, a similar approach has been used by Staudenmaier who divided up the histories of the technological artefacts into three stages. This chapter focused on what can be characterised as the end of a scientific instrument. It was defined as an end, since the operations with the Transit Circle no longer continued. This resulted in the Transit Circle losing its function as a working instrument used for regular observations. However, as the chapter highlighted, the end of the Transit Circle did not happen overnight. It was first brought back to use due to the destruction of the Pulkovo Observatory, and then even after its final official observation, occasional observations continued being made with it. Through these examples, the chapter showed that a scientific instrument can have more than one end to its life, and that the ends of scientific instruments have to be understood as gradual processes as opposed to events that take place from one moment to another.

Meanwhile, the chapter also paid attention to the "afterlife" of the instrument as a museum object. However, rather than being a dead object (as Alberti's taxidermy animals), the Transit Circle remained in a limbo state whereby its capacity to be restored into a properly functioning instrument remained.[106] This is reflected in the current description of the instrument as being in a "working order". This dual state of the instrument (both dead and alive at the same time) raises two important questions within object biographies. First, it highlights the limits of a biographical approach, since the approach does not feature a life-stage where the object is in such a dual state. As a result, it highlights a major criticism of the object biographies approach that it can only guide the researcher as opposed to being able to explain through the approach the states of transformation. On the other hand, the Transit Circle being turned into a museum object can also be thought of as the continuation of the life of the instrument as opposed to marking the end of its life. Through this interpretation, the life of the Transit Circle did not end, but rather, its function was merely transformed from that of a working scientific instrument into a museum object aimed at informing people about past practices within the field of astronomy.

7. Conclusion

The Airy Transit Circle as a museum object questions how the identity of an artefact is shaped. It highlights how the National Maritime Museum interpreted its history within the framework of nautical astronomy, which led to overlooking other aspects of the instrument's history. The story showed us that artefacts are always assigned an identity as opposed to an artefact's identity being something that originates from their core materiality. By assigning an identity, a different interpretation of its history is projected into the Transit Circle's materiality. The aim of this chapter was to analyse these projections of identity into the materiality of the instrument throughout three distinct periods of its life: its working life, its downfall, and its

[106] Alberti, *The Afterlives of Animals*, pp. 1-17.

function as a museum object. These three distinct life-stages were characterised with three distinct identities that gave rise to different narrative framings of the instrument. Throughout its working life, it was seen as a technological marvel, a contributor to both astronomical research and navigation. During its downfall, the narrative shifted to that of an outdated instrument, which was no longer able to attain the precision required by its users. Finally, as a museum object, it was assigned an identity that matched the needs of the Museum that displayed it. This way, the Transit Circle both changed and remained the same instrument was installed at the Observatory in 1850.

Discussions about the transformation of the instrument raised crucial questions that the object biographies approach engages with: how do the lives of objects end and how do their afterlives shaper their histories? The analysis of the downfall of the Transit Circle showed that the lives of scientific instruments as objects do not come to an abrupt end. Instead, objects can similarly undergo a long and gradual end to their lives. In special cases, as with the Transit Circle, they can even be resurrected after they had been pronounced dead. In this sense, the lives of objects can come to multiple ends. Meanwhile, the way in which the instrument is still described to be in a "working order", shows one of the limitations of the object biographies approach, since it has trouble classifying the afterlives of instruments that are no longer operating, yet are still with us. To avoid this problem, the chapter shifted the attention to the function of the instrument. This term helped make sense of the instrument's life by considering the end of its operations as a scientific instrument and its transformation into a museum object as a change in its assigned function. By doing so, the term also highlighted the extent to which the life of objects are always subject to the social context within which they are placed, while at the same time react to it through their materiality.

While the first half of the chapter aimed at demonstrating the multiple narrative frameworks, the second half of the chapter traced how the almost exclusive framing of the instrument within nautical astronomy was developed after it became a museum object. While such a framing was in line with the aims of the National Maritime Museum, the chapter also demonstrated the existence and the gradual emergence of other narrative frameworks too (Woolley's speech at the opening of the meridian building, and Howse's book on Greenwich Time). An analysis of the publications of the Museum further demonstrated how the framing of the instrument within nautical astronomy was maintained by the institution. This analysis also called attention to Frank Carr's *Maritime Greenwich*, which book popularised two common misconceptions related to the instrument's history: the 1884 International Meridian Conference passing resolutions unanimously, and the central wire of the Transit Circle marking the Prime Meridian.

Since this dissertation focused on the materiality of the Transit Circle, Carr's statement on the relation between the Prime Meridian and the Transit Circle was considered more extensively in this chapter. It showed that such an interpretation overlooked how the Transit Circle was just one of the components in the long production process of defining the meridian. This conceptual shift from *defining* the meridian to *marking* the meridian was shown to be an example of how astronomical (and scientific) activities are disseminated in a black-boxed form, and how it can lead to drawing mistaken relations between instruments and their products. At the same time, simplifying the production process of defining the meridian contributed to stabilising it as an international standard and in the wider standardisation process. By not opening such a black-box, the Museum continued the historical oversight implemented into maintaining the Prime Meridian as an international standard. The various (and often contradictory) definitions offered by the publications of the Museum were examples of this, since they demonstrated the lack of engagement with the processes the produced that Prime Meridian (see table below). This further contributed to the decoupling of the Transit Circle from the Line itself in their representation.

1963	*National Maritime Museum – Old Royal Observatory: Flamsteed House*	'…the Airy Transit-Circle, the centre-line through which still determines by international agreement the meridian of Greenwich - the Prime Meridian of the world.'
1965	Frank Carr – *Maritime Greenwich*	'…the prime meridian has been the centre wire in the Airy transit circle…'
1966	*The Restoration of the Old Royal Observatory, Greenwich, with a provisional list of instruments and clocks*	'It contains the Airy Transit Circle (still in working order) which, by international agreement, defines the Prime Meridian of the world…'
1969	*The Old Royal Observatory: A brief guide*	'The longitudinal centre line of this instrument defines the Prime Meridian of the world (Longitude Zero)…'
1969	*National Maritime Museum*	'…the meridian through Airy's Transit Circle which was selected as the Prime Meridian…'
1970	*National Maritime Museum, The Old Royal Observatory: An Introduction*	'The Greenwich Meridian (Longitude Zero) - The meridian of the centre-line of Airy's transit circle…'
1970	Derek Howse - *The Story of Greenwich Time*	'…a meridian passing through the centre of Airy's Transit Circle…'
1982	Greenhill – *The National Maritime Museum*	'…Airy's new transit circle whose optical axis define the world's prime meridian…'
1998	*The Old Royal Observatory Greenwich:*	'…the principal transit circle has been used to define the prime meridian…'

	Guide to the Collections	
2004	Clifton and Rigby – *The Treasures of the National Maritime Museum*	‘Since 1884 the meridian passing through the Airy Transit Circle has been internationally recognised as Longitude 0…’
2005	Roy Clare – *A Guide to the Royal Observatory Greenwich: The Story of Time and Space*	‘…Longitude Zero (000 00’ 00”) which is defined by the crosshairs of the great Transit Circle…’
Undated	*The Old Royal Observatory: The Story of Astronomy & Time*	‘The Airy Transit Circle which defined the Greenwich Meridian since 1851…”
Undated	*The Old Royal Observatory at Greenwich*	‘Looking through the eyepiece of such a telescope will show stars or other sky objects crossing the centre of the field of view, which is of course the Meridian.’
Undated	*It’s about time (Media Information)*	‘The cross-hairs in the eye-piece of the Transit Circle precisely defined longitude 0 for the world.’

Chapter 7 : Was the Airy Transit Circle an awry instrument?

During the nineteenth century, the Royal Observatory, Greenwich, was the main astronomical institution contributing to positional astronomy. The Greenwich Observations were distributed to observatories around the world, and served as the basis for astronomers to calculate the movements of celestial bodies. From the same observations arose the determination of Greenwich Time and the Greenwich Meridian. Behind these products stood the monotonous, painstaking, and repetitive astronomical labour that involved the organisation of a large number of people, instruments, and tasks. The Airy Transit Circle was the instrument with which the observations and measurements of celestial bodies were made in these long processes. As such, it played a significant part in the production of time and space until the last observations were made with it in 1954. Despite the fact that it no longer forms part of the production of these standards, its historical status as the instrument that defined the Prime Meridian has left its role in the astronomical labour black-boxed. This dissertation opened up this black box to demonstrate the interactions with the Transit Circle and how such interactions were shaped by Airy's oversight of the Observatory.

The instrument was considered a significant addition to nineteenth-century astronomy on several grounds. First and foremost, it was considered a technological marvel for embodying new techniques. Many of its large parts (including the telescope tube, the pivots, and the lifting machinery) were manufactured with the chilled iron method, which had not previously been used for the making of astronomical instruments. This new method allowed for more uniform wear of its moving parts, which was an essential requirement for precision instruments. The use of an 8-

inch object glass increased the size of the instrument too. This made it the largest transit circle, with the largest optical power, of its time. The larger optical power allowed for making observations of fainter celestial bodies too, which increased the scope of astronomical objects that the Observatory was able to measure, while at the same time made the observations of already visible ones more reliable. The reputation of the instrument as a technological marvel was not limited to the British Empire. Displaying models of it at the Exposition Universelle of 1855 in Paris showed that such contributions were internationally acknowledged. Second, the Transit Circle was designed with the ability to measure its instrumental errors with more ease and precision that with previous meridian instruments. This reflected Airy's attitude towards the management of astronomical instruments as well as his oversight of astronomical labour that incorporated a factory mentality. The combination of the design of the Transit Circle with the organisational context made the astronomical data published in the Greenwich Observations more reliable and easier to be checked by other astronomers. These tables of astronomical datasets served as the basis for calculating the positions of celestial bodies. Finally, the observations made with the Transit Circle also contributed to the everyday life of people. It determined the Greenwich Meridian, which played an important role in the production of maps and charts. Through this work, the instrument played a central role in organising the space that governed the British Empire. Similarly, the observations with the Transit Circle served as the first step in determining Greenwich Time, which was later distributed around Britain. In this light, the ticking of the clocks that were adjusted to Greenwich Time were the sonic manifestations of astronomical labour within which the Transit Circle played crucial part. In brief, the instrument was a key component in the production of time and space both internationally and within the British Empire.

The Transit Circle was a product and component of Airy's management and oversight of the Observatory. Its materiality embodied industrial manufacturing techniques with the precision of optical instrument makers. By incorporating aspects of industrial machines, it reflected the factory mentality that Airy implemented into his organisation of astronomical labour. In this light, Airy altered both the organisation and the instrumentation of the Observatory to embody a factory mentality. The instructions prescribed for the Transit Circle's use and the ability to compare the measurements made by different observers turned it into a technology of discipline. This way, it expanded Airy's surveillance of the work of the astronomical labourers. This dissertation showed that it was also a precision instrument that required regular maintenance as well as measurement of its errors. Through these moments of breakdown, the Transit Circle appeared in a more fragile and constantly changing state, which turned it into a technological artefact that, similarly to human observers, required disciplining to work according to the standards prescribed by Airy. Therefore, Airy's oversight of the instrumentation of the Observatory was grounded on a belief that both instruments and members of staff easily committed errors, which required the constant disciplining of both human and non-human entities. However, superintendence did not eliminate instrumental and human error. Instead, it made error visible and "accountable" during the final calculations of producing astronomical data.

The story of the object glass of the Transit Circle demonstrated Airy's oversight in relation to every project and every individual who became associated with the business of the Observatory. When Airy contacted opticians, the ability to exercise personal oversight of the project based on his own terms appeared as a key component in selecting the final supplier. Therefore, it demonstrated how his personal preferences shaped and were embodied in the materiality of the instrumentation of the Observatory. In this light, the Transit Circle was embedded within the social and political spheres. Similarly, its material form reflected the decisions made by individuals involved in its construction. The reluctance of Merz to test the object glass according to Airy's wishes led to significant delays in the negotiations. Combined with Airy's previous negative experience in negotiations with the instrument maker, it led to a temporary deterioration of trust. This example provided an early sign to what Myles Jackson identified as the gradual diminishing of the quality of the services offered by Merz, which formed part of the reason for losing his monopoly over the production of object glasses.[1] By contrast, Simms was willing to prioritise Airy's request over other projects (even if it meant using an object glass destined for another instrument) in order to comply with the Astronomer Royal's desire for economy, efficiency, and oversight. The comparison of how the two instrument makers reacted to Airy demonstrated that instrument makers that maintained close connections with him were aware of the important role that exercising personal oversight played in Airy's decision making process.

The presence of multiple suppliers also demonstrated that there was no single best object glass and instrument maker at the time. Instead, the selection of the final object glass was based on Airy's individual preferences. As a result, the communication and relationship between Airy and the instrument makers became an important factor in determining who would be chosen as the supplier. The letters surviving between them provided insights into how the instrument makers managed their connections, and the extent to which they were willing to give in to the demands of their client. However, the relationships between Airy and the three instrument makers were also determined by past experiences through previous orders. For example, Merz was considered

[1] Jackson, *Spectrum of Belief*.

troublesome by Airy, while Simms has proved his ability several times during previous projects and offered Airy more oversight of the process.

Airy's preference for Simms's object glass was not developed in isolation. Instead, his close friends and allies provided advice and support prior to and throughout the negotiations. Sheepshanks advised him to stir up competition between the three opticians. In addition, he also tried to convince Airy about purchasing the object glass from Merz, given the optician's reputation and the high quality of his previous products. Sheepshanks was not alone with such an advice. John Herschel similarly advised Airy to trust Merz and to order the object glass from him. The presence of Herschel and Sheepshanks showed that Airy's oversight did not mean control and decision making in isolation. Instead, his oversight was actively shaped by the people around him. The effect of other people on his decision making manifested itself most clearly in keeping open the option of orders from Merz and Lerebours until the purchase of the object glass from Simms.

The history of the large and graduated parts of the Transit Circle demonstrated the contribution of engineers to the project. It was through the work of Ransome & May on the telescope tube, the lifting apparatus, and the pivots that the final instrument embodied the chilled-iron technique used for the manufacturing of agricultural and industrial machinery. Through the application of this method, the final form of the Transit Circle embodied the characteristics of both astronomical precision instruments and industrial machines. This combination of features reflected the transformation of the Observatory into a factory that went beyond the reorganisation of rules and astronomical labour. It also involved the re-instrumentation of the Observatory for aiding the production of astronomical observations at a larger scale. In this light, the Transit Circle became a machine of astronomy that embodied industrial principles for mass producing astronomical observations.

The construction of the divided circle highlighted the competing definitions of accuracy employed by different networks of nineteenth-century science and technology. The appearance of Joseph Whitworth in the story foreshadowed the debates of the Standards Commission during the second half of the nineteenth century. It showed that Airy preferred the use of line measurement methods for making precision instruments instead of relying on end measurement techniques. This was reflective of his thinking at the time about the mathematical tools of the astronomers increasing the accuracy and precision of astronomical instruments made by instrument makers. This reliance on line measurement allowed Airy to exercise oversight of the management of the final instrument. His design for an apparatus to measure the ellipticity of the pivots as well as the re-measurement of their ellipticity after installation similarly demonstrated the perceived hierarchy between men of science and instrument makers. Within this hierarchy, the physical tools of instrument makers and engineers were considered less precise than the mathematics and the calculations used by men of science.

The choice of Ransome & May was based on more than their use of chilled-iron technique. Airy maintained several close connections to the firm. His friendship with George Ransome through his uncle, George Biddell, created the historical grounding for their trust. In addition, the employment of his cousin, Arthur George Biddell, and his friendship with Charles May allowed him to receive information on the construction process quickly and at almost any time. Through this direct access to the business of the firm, he was able to request reports on the developments of the construction process and to exercise personal oversight at every step of the project. The letters exchanged between Airy and May also portray Airy in a different light than his popular image as an unimaginative despot.[2] Instead, his interactions with May highlighted his playfulness exhibited only among his private circle of friends and family. As a result, this dissertation provided a more complete account of the organisation of astronomical labour at the Observatory by taking into account Airy's despotic persona as the Astronomer Royal, as well as his informal interactions exhibited in his letters to personal friends.

Finally, by analysing how the different parts of the Transit Circle were constructed, we saw that each part had a different history to tell: the object glass told us about the competition between opticians around Europe, the divided circle told us about the competing definitions of accuracy, while the pivots told us about the cooperation between elite instrument makers and engineers. Through these stories, the Transit Circle appeared not as a single instrument, but as an artefact that brought together these various stories. In this sense, the histories of the different parts of the instrument assembled the larger history of the Transit Circle. At the same time, the materiality of the different parts were also interdependent and interwoven: the object glass determined the size of the large parts of the instrument, the final errors of the pivots exerted a constant effect on the observations, while the delays in finishing the divided circle led to halting the installation at the Observatory. In brief, the proper functioning of the instrument relied on the harmonic interaction between its constituent parts, and the Transit Circle appeared as an assemblage of these parts. Approaching an instrument as an assemblage helped in highlighting how the individuals from different networks interacted with each other, as well as how and why other members were rejected from being involved in the construction project. This approach helped in reconsidering the Transit Circle as not only as the product of individuals who were involved in its construction, but also those individuals who were excluded from it (e.g. Merz, Lerebours, Whitworth).

[2] Maunder, *The Royal Observatory Greenwich*, p. 117.

Thinking about the Transit Circle as an assemblage of interacting components highlights the breakdown of the assemblage as a crucial question of inquiry. This approach considers investigating maintenance and repair practices relating to scientific instruments as a fundamental starting point. This is due to breakdowns highlighting the individuals and tools that otherwise go unmentioned in their descriptions. In this sense, the assemblage approach highlights both the invisible technicians and the invisible tools (and techniques) that contributed to the operations of an instrument.[3] In the case of the Transit Circle, such practices highlighted the invisible technicians of the Observatory and the instrument makers who carried out such tasks. The carpenter of the Observatory, John Green, and the workmen of the Troughton & Simms and Ransome & May played a key role in carrying out the actual repair and maintenance of the instrument. At the same time, maintenance practices and smaller repairs highlighted that small-scale adjustments of the Transit Circle were mostly carried out by the Observatory staff. For instance, Airy and his staff improvised with a piece of paper to raise one of the pivots, and created contrivances to guard against the heat of gas burners. Airy was keen to exercise oversight of these practices too. The division of labour implemented by him led to allocating the different astronomical assistants to be in charge of different instruments. For instance, observing with the Transit Circle was not a task that every member of the Observatory staff was allowed to perform. Instead, they had to be trained. Without the proper training, the instrument was easily damaged or adjusted in a wrong way. The destruction of the spider threads in the eye-piece during the training of an observer demonstrated the ease with which the instrument could be damaged.[4]

[3] Russell & Vinsel, *After Innovation*, p. 4.
[4] See entry for 6 February 1863 in *Astronomer Royal Journal 1862-1876*, RGO 6/26. For a note referencing the incident see RGO 6/171 14.

Through the lenses of maintenance and repair, the Transit Circle appeared as a constantly changing instrument.[5] It reacted to the changes in the temperature, to the movement of the ground, and to ways in which different people interacted with it. Maintenance was another way of attempting to exercise control over it, since maintenance regulated its changing features. Therefore, maintenance practices highlighted that instruments were thought of as active entities that required constant attention and care, as opposed to examples of self-regulation. Meanwhile, the constantly changing nature of the Transit Circle also raises the question about the extent to which it remained the same instrument over time. The instrument that was installed in 1850 lacked its connection to a chronograph, had an unpierced central cube, had a different eyepiece, and was used with different collimators. Approaching the Transit Circle as an assemblage becomes useful in this case, because it brings forth these transformations of the instrument through the focus on the interaction between the different components and parts.

A key feature of the Transit Circle was the ability to measure its errors precisely. However, the measured errors were not always fixed by altering the materiality of the instrument. Instead, these errors were accounted for during the final reductions of the observations. This method of maintenance relied on the use of calculations and mathematics. As such, mathematics appeared as a tool used during astronomical labour to maintain the instrument. Calculative maintenance focused on repairing the immaterial form of the instrument as opposed to its materiality. This was reflective of the imposed and perceived hierarchy between men of science and instrument makers, within which mathematics as a tool compensated for the material limits of precision achieved by instrument makers. At the same time, it also highlighted that the material and immaterial forms of instruments are inseparable from each other, and that a change in one

[5] Baker, *Precision*, p. 15.

implies a change in the other. This separation created another technique of oversight whereby the precision of the instruments could be regulated and verified through their material and immaterial forms at the same time.

Approaching the history of an instrument through its instrumental errors framed its everyday operations in a more active light. Instead of the errors appearing as ever-present impediments of an instrument, they appear as features of its personality.[6] In addition, through the constant maintenance and use of the instruments, they emerge as companions of its users as opposed to mere soulless machines.[7] An analysis of the Transit Circle through this approach shows that the disciplining of observers and astronomical labourers did not reduce them to machines that worked perfectly according to the prescribed instructions, because such a machine or instrument did not exist. Instead, both humans and instruments were disciplined because people exercising oversight of them were aware of the differences caused by their inherent personalities.

Calculative maintenance was not used exclusively at Greenwich. Instead, it emerged as a technique during the first half of the nineteenth century, and was gradually implemented for the large-scale reduction of positional observations, and for the management of astronomical instruments. Chapter 4 demonstrated Airy's use of calculative maintenance as early as his directorship of the Cambridge Observatory, and traced how his astronomical practices were influenced by the Besselian method. This was important for showing that the components of Airy's factory mentality implemented at Greenwich were not developed in isolation, and that it did not arise solely from the work and circumstances of the Observatory. Instead, Airy was influenced by the practices of the international astronomical community. His ability to implement these practices into the treatment of astronomical instrument at Cambridge helped in

[6] Schickore, *Ever-Present Impediments*.
[7] Tresch, *The Romantic Machine*.

establishing his reputation and solidified him as a possible candidate for the position of Astronomer Royal. In addition, it provided grounding for developing the technique for its application to the management of future instruments such as the Transit Circle.

Calculative maintenance provided the theoretical grounding for this dissertation to expand the management of instruments to their immaterial states. The immateriality of scientific instruments encompassed their mathematical representations as well as the "image" of the instruments communicated to different audiences. The latter served the purpose of maintaining their reputation and trust in the data produced with them. This was also the case in the operations with the Transit Circle. Similarly to the general business of the Observatory, Airy oversaw how the Transit Circle was depicted and portrayed to different audiences. The case studies showed how he engaged in the management of the instrument's image and how it formed part of his close surveillance of the operations of the Observatory.

Airy's interactions with the artist Benjamin Sly showed how he was involved even in the production of illustrations for the official descriptions of the Transit Circle. Their exchange of letters highlighted how Airy policed the work of the artist in order to present the illustration of the instrument according to his own wishes and with very close attention to the details.[8] At the same time, Sly's regular delay in submitting the drawings to Airy demonstrated that close oversight of work was not enough to ensure that the work was going to be carried out in time. Similarly to the story of the object glass, the case study demonstrated that Airy selected the people working on projects for the Observatory partly because of having more control and oversight of their work in progress.

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[8] Daston and Galison, *The image of objectivity*.

Occasionally Airy also had to defend the reputation of the instrument. Criticisms of the instrument demonstrated that its reputation was in a similar state of flux as its materiality, gradually changing over time. The constant changes and the close connection between the materiality and the image of the Transit Circle were the reasons why this dissertation categorised the management of the instrument's image, reputation, and status as a type of maintenance. The attack by the *Morning Chronicle* showed how the Transit Circle was embedded in the historical reputation of the Observatory. By doing so, it was an example of how the materiality and the status of the instrument were interlinked. The case was also a useful example to highlight that Airy considered it part of his job to defend the reputation of the Observatory along with its instrumentation from public and political attacks. This reasserted his role as an astronomical officer of the government and as a scientific public servant.[9] However, his decision to respond to the attacks in what he considered the scientific press showed that he considered the reputation of the Observatory to be a matter of a specific community as opposed to the general public. In addition, this switch of battleground for the attack allowed him to present his rebuttal in a periodical to which he regularly contributed and one that had supported him in the past. His strategy framed the reputation of the Observatory and its instrumentation to be a public matter, but related astronomy as opposed to politics.

The Marthiad episode highlighted a critical piece aimed directly at the Transit Circle. It showed how Airy's oversight relied on the help of his friends (De Morgan and De la Rue) within the scientific community in order to halt the publication of a damaging article. Through this story, his oversight of the Observatory did not appear as the isolated actions of a single individual, but rather as the operations of a larger network of individuals that Airy was able to use when needed.

[9] Chapman, *Science and the Public Good*.

Being the Astronomer Royal was beneficial for this, as the role placed him in a public position of power in the heart of nineteenth-century scientific networks.

The history of the models of the Transit Circle made for the Exposition Universelle 1855 in Paris explored further how the image of the instrument was managed within various networks. Similarly to the Marthiad episode, Airy faced challenges in presenting an image of the Transit Circle according to his own preferences. In this case, he had to negotiate with various other groups (Royal Society, the Board of Trade, instrument makers, organisers of the exhibition etc.) about what the final models should be, and what kind of message they should convey to the audiences. Through these competing meanings attached to the models, the dissertation showed flexible definition of models in different networks.[10] The different meanings were connected to their materialities too, as the different compositions of the models would have presented different images of the instrument. For instance, the final set of models of the Transit Circle and its parts was not reflective of Airy's initial plans and motives to represent the re-instrumentation of the Observatory. At the same time, the case study showed that despite Airy maintaining close relations with members of the various groups involved in the negotiations, he had to make major changes to the final models. Despite these changes, he still managed to exert some influence and oversight of the production of the final models. For example, the presentation of the Transit Circle through separate smaller models as well as a replica of the full instrument demonstrated his aim to present it as a technological marvel.

The Transit Circle rose to further prominence during the late nineteenth century when it was chosen as the basis for the international Prime Meridian. Regular observation work continued with it, and even increased in numbers according to the data published in the Greenwich

[10] Chadarevian and Hopwood, *Models: The Third Dimension of Science*.

Observations. Comparing the ways in which the Transit Circle was managed under the various Astronomers Royal would provide further insights into changes in astronomical labour, interpretations of instrumental errors, and the management of the Observatory. Such an analysis would also demonstrate the long-term changes in the network of instrument makers, tradesmen, observatories, and institutions that the Observatory interacted with in relation to the management of the Transit Circle. Unfortunately, this was beyond the aims and scope of this dissertation. However, following the history of the instrument during the later stages of its life shows us how its materiality changed. For instance, rather than being considered a reliable instrument, by the 1930s its errors were considered to be systematic caused by shortcomings in its original design. This prompted the Observatory to call for the Transit Circle's replacement with a new instrument. Such a long-term change in its reliability questions whether an instrument should be considered the same entity throughout its entire life. In this light, the assemblage of the Transit Circle in 1851 was different from the one in 1954, and the two instruments have to be assessed as two completely different entities.

If instruments (and their assemblage) change quite drastically over time, then is it possible to say that such instruments have lives? As Soderqvist pointed out, attributing life to objects will always have to tackle the philosophical problem of defining life.[11] Despite this, Alberti argued that a biographical approach can still be used as a guiding framework for the history of objects.[12] By acknowledging life as an analytical tool as opposed to an attribute, the changes in the materiality of the objects as well as their interactions with other entities can be brought forth. This dissertation made use of Alberti's argument to show how the Transit Circle underwent several life stages as opposed to becoming out of order overnight. First, it showed that even after

[11] Soderqvist and Bencard, 'Do Things Talk?', p. 97.
[12] Alberti, 'Objects and the Museum', pp. 560-562.

systematic errors were detected in operations, it continued being used. Therefore, the presence of errors did not lead to abandoning the use of instruments for scientific research. Second, it showed that instruments can have several ends and afterlives. The main example to this was the recommencement of observations with the Transit Circle after the destruction of the Pulkovo Observatory. It demonstrated that instruments can also come to the end of their lives because their accuracy had been superseded, or because they were no longer considered reliable in comparison to other instruments. As a result, such instruments can be considered retired from their operations as opposed to reaching the end of their lives.

Within such an analytical framework for object biographies, the main questions are shifted to the periods of transition from one life stage to another. This dissertation looked at how the Transit Circle was transformed from the working scientific instrument into an object on display at a museum setting. First, it showed how oversight of the instrument was shifted from the hands of the Observatory into the hands of the National Maritime Museum. This resulted in the principal aims and mission of the Museum having to be rewritten in order to accommodate the new collection and site. In this new context, oversight was transferred to a new network of individuals (curators, conservation specialists, and executives of the Museum). Within the museum context the assemblage of the Transit Circle was modified further in order to match the requirements of the new setting. However, as we have seen, the materiality, organisational context, and images of the Transit Circle were interlinked. This meant that the image of the instrument underwent a similar change in the museum. Most importantly, within this new museum narrative of the history of the instrument, the use of the chilled-iron method and its unusually large size (in relation to other transit circles) were given less emphasis. In addition, very few of its descriptions produced since the 1950s mentioned its place within the processes that produced astronomical data. Instead, the narratives focused on the everyday applications of the work with the Transit Circle in the form of Greenwich Time and Greenwich Meridian. This resulted in black-boxing astronomical practices and the role of instruments within the histories of production of time and space. This narrative change has been manifested since the 1950s through the inconsistency in Museum publications about how the instrument defined the Meridian Line, and the gradual appearance of the Line as a distinct entity in public imagination.

The dissertation showed the Transit Circle as an active participant of the history of the Observatory that both shaped and was shaped by the individuals, instruments, and organisational context that surrounded it. Even though all of the individuals interacted with the same instrument, they perceived it differently, which affected their actions towards it. For Charles May, it was a machine that had to be made according to Airy's preferences. For William Simms, it was another instrument that required an object glass, other optical parts, and regular repair. For its maintainers, such as John Green and the workmen of instrument makers, it brought about regular problems that they were assigned to fix. For astronomical assistants of the Observatory, it was almost like a mechanical companion in their daily jobs. For the computers adjusting its errors through calculations, it was an object out of their physical reach, but still within their field of interaction through simple arithmetic. As this dissertation attempted, a history of the Transit Circle has to incorporate all of these different voices in order to present a more complete account of its life.

Appendix 1

<u>List of articles in periodicals about the Transit Circle (in chronological order):</u>

'Scientific Memoranda', *Reading Mercury,* 15 June 1850, p. 4

'British Association for the Advancement of Science', 9 August 1850, p. 3

'Arts and Sciences', *Literary Gazette,* 24 August 1850

'Meeting of the British Association, at Ipswich, and visit of his Royal Highness Prince Albert', *Ipswich Journal*, 5 July 1851, p. 3

'Twenty-First Meeting of the British Association for the Advancement of Science', *Athenaeum,* 5 July 1851

'British Association for the Advancement of Science', *Bury and Norwich Post,* 9 July 1851

'Twenty-First Meeting of the British Association for the Advancement of Science', *Athenaeum*, 12 July 1851

'Scientific Memoranda', *Reading Mercury,* 12 July 1851, p. 4

'Greenwich Observatory', *Ohio Observer,* 31 December 1851, p. 4.

'Report on the Observatory Syndicate (Cambridge)', *Morning Post*, 24 June 1853, p. 6

'Proceedings of Societies', *Literary Gazette,* September 1854

'Scientific Memoranda', *Reading Mercury,* 15 April 1854, p. 7

[R. G.], 'Annual Visitation of the Royal Observatory, Greenwich', *Inverness Courier,* 22 June 1854, p. 6

'Our Weekly Gossip', *Athenaeum,* 10 February 1855

'Literary Selection – The French Exhibition', *Lancaster Gazetter,* 24 February 1855, p. 2

'Palais de l'Industrie', *Norfolk Chronicle,* 19 May 1855, p. 4

'The Opening of the Paris Exhibition', *Illustrated London News,* 9 June 1855, p. 583

'Model of the Greenwich Transit Circle', *Illustrated London News*, 24 November 1855, p. 629

'The late John Henry Belville, Esq.', *Daily News,* 17 July 1856, p. 4.

Airy, George Biddell, 'Science and the Government', *Athenaeum,* 30 Aug 1856

’The Cape Observatory’, *Illustrated London News*, 21 March 1857, p. 271

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‘Scientific Miscellany’, *Manchester Times*, 27 January 1867, p. 7

‘The Astronomer Royal’, *Illustrated London News*, 4 January 1868, pp. 3-5

Forbes, George, ‘The Royal Observatory, Greenwich’, *Good Words*, January 1872

‘The Transit Room at the Royal Observatory (excerpt from Good Words)’, *Leeds Mercury*, 14 November 1872, p. 6

‘Greenwich Observatory’, *Morning Post*, 8 June 1874, p. 4

‘Greenwich Astronomical Observatory’, 11 December 1874, p. 4

‘The Royal Observatory, Greenwich: a Glance at it’, *The Builder*, 19 December 1874, p. 1043

‘Greenwich Observatory’, *Birmingham Daily Post*, 19 December 1874, p. 8

‘A Universal Meridian, and Chronological changes’, *The Friendly Companion and Illustrated Instructor*, 1 January 1885, p. 20

‘Greenwich Time All Over the World’, *Leisure Hour*, January 1885

‘Greenwich Observatory Illustrated’, *Graphic*, 8 August 1885

‘A Private View of the Eclipse’, *Pall Mall Gazette*, 30 January 1888

‘Royal Institution of Cornwall’, *Royal Cornwall Gazette*, 4 June 1891, p. 7

‘Personal Paragraphs’, *Freemason’s Journal (Dublin)*, 12 July 1895, p. 6

‘The Imaginary Line’, *Galveston Daily News*, 3 July 1896, p. 8

‘Greenwich Observatory En Fete’, *Daily News*, 7 June 1897, p. 6

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