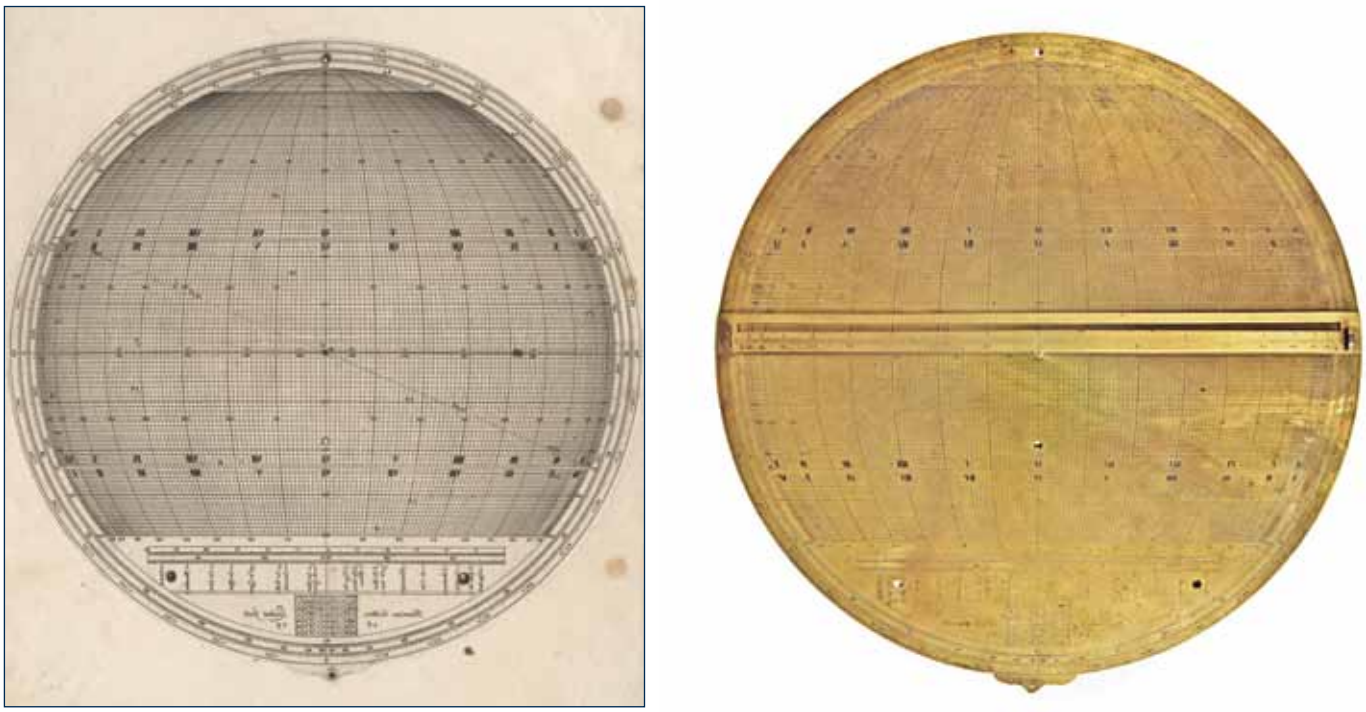
Reverse-Printed Paper Instruments (With a Note on the First Slide Rule)

Boris Jardine

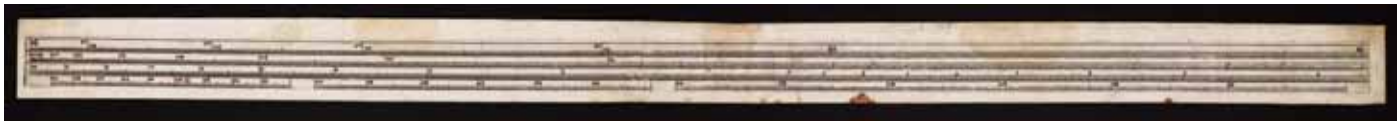
When David Bryden published his exceptionally useful essay 'The Instrument Maker and the Printer: Paper Instruments Made in Seventeenth Century London' (1997), there was one class of print that left him puzzled: 'Another practice to be aware of,' he wrote, 'is the paper instrument that has been made by using a flat engraved brass instrument as a printing plate. [...] Whether this was simply to record a piece of particularly fine or laborious workmanship for future reference in the workshop, and as a sample which could be shown to customers, or some other explanation, remains speculative so long as so few examples are known.'[1] At that point Bryden could list two reverse-printed paper instruments, both held at the Museum of the History of Science, Oxford: a print from the dial-plate of an early-eighteenth century John Rowley horizontal dial (inv. no. 13309); and one from the 'Rojas' projection on a large 1659 astrolabe by Henry Sutton – the latter, remarkably, stored at the MHS alongside the instrument from which it was pulled (Figs 1a & b; inv. nos. 56420 and 51786, respectively).

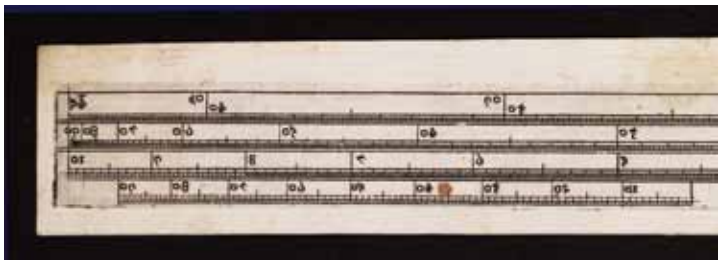
Since 1997 there have been two further contributions to our understanding of the practice of printing directly from flat metal instruments. In 2005 I co-authored a paper with Catherine Eagleton describing a pair of identical reverse-prints, preserved at the British Library and taken from a 1661 Henry Sutton double-horizontal dial.[2] In line with Bryden's original suggestion, we argued that reverse prints of the horizontal projection – both as representations of the heavens and records of impressive technical feats of engraving – would have been of interest, in and of themselves, to the large number of scholars, amateurs and gentlemen pursuing the mathematical arts in seventeenth-century England. The vogue for the horizontal projection and the method of acquiring large paper collections relating to the various branches of the sciences[3] seemed to favour this interpretation – though, like Bryden, we proceeded cautiously and acknowledged the lack of secure evidence, in particular concerning provenance. Subsequently, major progress has been made by John Davis and Michael Lowne, who have catalogued a total of nine prints bearing the horizontal projection (all from double-horizontal sundials).[4] Of these, one is a reverse-print of a double-horizontal dial by Thomas Tuttell and is held at the National Maritime Museum (inv. no. ZAA0649); two are the British Library Sutton prints (Additional MS 4473); and two must be discounted from the present discussion owing to lack of evidence about their nature. The remaining four have allowed Davis and Lowne to draw the strongest conclusion yet about reverse prints, namely that they were an intermediate stage in the production of counter-proof impressions.[5] In this process the reverse print is *itself* printed from, the result being an 'unreversed' image. (For simplicity I will refer to these as 'counter-proof' images.) One print, in the 'Byrom Collection', is a counter-proof of a Sutton double-horizontal dial, dated 1661 (though *not* identical with the British Library impressions). Another set of prints, preserved in the Boyle Papers at the Royal Society, is even more instructive: here three impressions survive, two reversed and one counter-proof, the latter clearly taken from the more heavily inked of the former.[6] The conclusions from this are crucial for understanding reverse printing: first, the reversed image was not simply an end in itself, because a counter-proof could be made that preserved at least the form if not the functionality of the original instrument; second, the tradition of engraving the horizontal projection is intimately connected with the practice of reverse printing.

Last year, in the course of my research into the relationship between printing and the instrument trade in England in the sixteenth and seventeenth centuries, I made two discoveries: a reverse-printed rule by Elias Allen, held at Cambridge University Library, and a reverse-printed nocturnal on a quadrant, unsigned but clearly from the group of instrument makers associated with Allen and his apprentices (Figs 2a, b



Figs 1(a) *Reverse print, and* (b) *the astrolabe from which it was pulled, by Henry Sutton and dated 1659. Museum of the History of Science, Oxford.*





Figs. 2 (a) *Reverse print of a 24-inch rule by Elias Allen, preserved with a letter from William Oughtred to Allen dated 1638.* (b) *With close-up, showing one end of the rule. Cambridge University Library.*

& 4). The first of these, it transpires, is in fact a remnant of the very first slide rule. Finally, and bringing the story up to the present day, my attempt to write up these two minor discoveries in a brief notice for the *Bulletin* has been happily scuppered by communications from Anthony Turner and then David Bryden, who have brought to my attention no fewer than seven(!) further reverse prints, now adding spiral logarithmic scales and yet more horizontal projections to the list. My intention here is to describe the two prints that I have discovered (the rule and the nocturnal), and to give a brief account of the other recently located prints. We now know of some eighteen reverse prints and counter-proofs, and so the conclusions that have been drawn so far can be tested and refined. But this, I hope, is not the end of the story, and here I make two pleas to readers of the *Bulletin*: first, if you know of further instances of reverse printing, or of prints that you believe to be counter-proof, please let the instrument community know by writing to the editor of the *Bulletin*; second, if you are in possession of a flat, engraved, early instrument that you would be willing to have passed through a rolling press, please contact me directly (bj210@cam.ac.uk). Nicholas Smith at the Historical Print Room, Cambridge University Library is, in principle, willing assist me in conducting an experiment into printing from an instrument and counter-proofing that print – but as yet I have been unable to find a suitable instrument from which to print.

Oughtred and Allen

One of the difficulties in accounting for reverse-printed paper instruments has been a lack of secure provenance, compounded by the fact that prints may have been made at any time after the original instrument was finished. The original two MHS examples have no known provenance beyond their acquisition source; both are on what is very likely to be contemporary paper (though the Rowley print has been poorly treated at some point in its life and bears the marks of having been scrunched up). The British Library Sutton prints are more promising – as Eagleton and I described, they have a definite provenance going back to the antiquary and historian of the Royal Society Thomas Birch (1705–1766), and a likely provenance going back to the mathematician John Pell (1611–1685).[7] But, as is unfortunately typical of the papers of early-modern scholars, Pell's papers were not originally catalogued in sufficient detail and were added to and muddled after his death. A folio of very evidently miscellaneous ephemera, such as contains the two Sutton prints, is not a very promising foundation on which to build an argument.

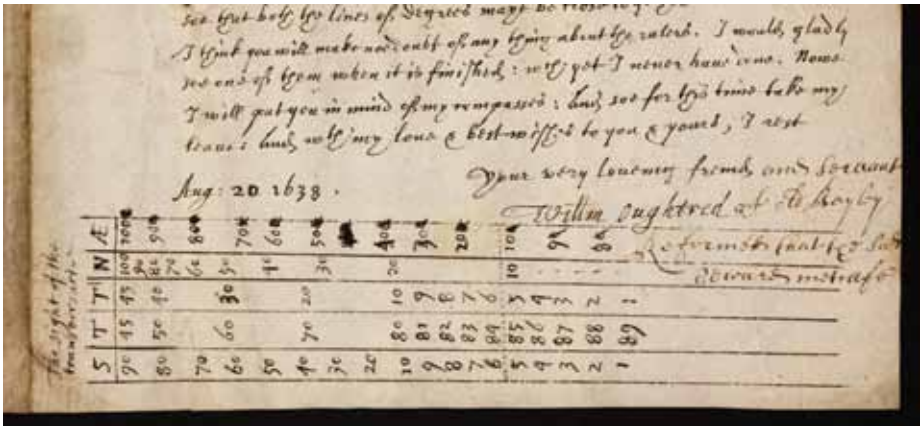


Fig. 3 *Portion of the letter from William Oughtred to Elias Allen, showing a sketch of the 'transversarie'. Cambridge University Library.*

Hence the discovery of an Elias Allen rule (see Figs. 2a, b), reverse printed and surviving alongside a letter from William Oughtred to Allen and dated 20 August 1638, is a real blessing (Cambridge University Library MS Add.9597/13/5/215). The letter has long been known, and has in fact twice been edited and printed, first by Rigaud in his *Correspondence of Scientific Men of the Seventeenth Century*, and then in a short notice in the *Journal of the Oughtred Society*.[8] However, its full significance has not yet been acknowledged. In the letter Oughtred describes the construction of an instrument consisting of two rules carrying numerous scales, and following very closely the description in Oughtred's 1633 'Declaration of the Two Rulers for Calculation'.[9] This of course is one of the two publications in which Oughtred first describes the straight slide rule, in its primitive form simply two transposed scales of Edmund Gunter's 'line of numbers'.[10] Accompanying the letter is what Rigaud dismissed as an uninteresting 'impression of a copper plate'; the authors of the *Oughtred Society* do not comment on the print, describing it merely as a 'drawing'.[11] It is in fact a remnant of the earliest known (straight) slide rule. That it is a reverse print and neither a copperplate nor a drawing is crucial to this point: the print directly records the instrument. What's more, we may fairly say that this is the first *ever* such instrument, as Oughtred specifically notes in the letter: 'I would gladly see one of [the rules] when it is finished: wch yet I never have done.'[12]

A fuller description of this letter and its importance is in preparation. For now it is worth pausing briefly to consider the historical moment. Soon after the invention of logarithms and their publication by Napier in 1614, Edmund Gunter had devised a rule that gave a physical means of using them, known as the Gunter Scale. Then around 1630 the more portable and self-contained 'circles of proportion' and the much longer but equally convenient spiral logarithmic scale were developed – we have surviving examples of these in variant forms by

Allen, Thomas Browne, Richard Delamain and others, and of course the dispute over their invention is one of the best known controversies of the period.[13] In 1633 Oughtred published his 'two rulers' – a versatile instrument which could be used like a cross-staff for observational astronomy, like a Gunter's Scale for trigonometry and, crucially, like a modern slide rule for multiplication and division. For some reason, by August 1638 Oughtred was still yet to see his instrument made, and at this point it seems that Allen requested instructions for making the rule. Oughtred's letter begins 'I have here sent you directions (as you requested me being at Twickenham) about the making of the two rulers, part whereof I have noted in the sheet you left with me, wch I have here inclosed, and part I will here deliver.'

After making the instrument, or part of it, to Oughtred's specifications, Allen then *either* gave Oughtred the finished rule and kept a reverse print for himself *or* returned Oughtred's letter to him with the reverse print enclosed.

As for the rule itself, following Oughtred's description in the 'Declaration' and the description and sketch in the letter, which may be by Allen (Fig. 3), the 24-inch reverse print carries scales of equal parts ([0]–60; [0]–60; [0]–90), sines ([0]–90), tangents ([0]–45 on one side, 45–89 on the other), and a line of numbers ([0]–9, 1–10).[14] These constitute the scales of what Oughtred called the 'transversarie'; a set of similar scales were supplemented by others on a longer 'staff', the pair then being used either like a modern slide rule or, set up at right angles like a cross-staff. To my knowledge no example of this instrument survives other than in this partial, reversed print – a record of an instrument long since lost.

Of course, the print is reversed and represents only one of two parts of the instrument – yet it clearly could have answered Oughtred's desire, expressed in the letter, to 'gladly see one of them'. As I have suggested, there are two possible explanations for the existence of the print alongside the letter. Either Allen kept the letter and print back as a record of the instrument, or he returned both to Oughtred as a means of communicating his work. Each of these possibilities is tantalizing: either we have a reverse print used as a record for the workshop, or as a means of communication in and of itself. The provenance, such as it is known, is not decisive. The letter is part of the Macclesfield Collection housed at Cambridge University Library. The earlier papers all came into the collection via John Collins[15], and amongst those there are very many of Oughtred's manuscripts – yet the letters amongst these naturally are almost all addressed *to* Oughtred, and of course there are plenty of other letters not relating to Oughtred from other mathematicians (though none obviously came via instrument makers). Collins probably started his collection after 1649, when he began teaching mathematics in London, in which case the letter would have been at least a decade old when it came into his hands, perhaps much older if it came later via Oughtred, who died in 1660. From the documents themselves we might favour the route via Oughtred – after all, the letter mentions other enclosures which are no longer present and which have been replaced by the reverse print: Oughtred wrote requesting to see of one of the rules – the letter survives with what is evidently one of the rules. But we must also consider the nature of the instrument trade in this period, and the role played by artisans in the circulation of paper. Allen's shop in particular became a 'clearing-house' for letters, descriptions of inventions, advertisements, paper instruments and books.[16] So we have circumstantial evidence either way, and two fascinating possibilities: via Oughtred, the reverse print standing in for the instrument; via Allen the letter and print being preserved in one of the great working repositories of early-modern practical mathematics.

Intriguingly, there is a small collection of other early-seventeenth century material amongst the Macclesfield letters pertaining to the construction of divided scales and rules for practical mathematics.[17] We might tentatively suggest that the real focus of attention here should be not on Allen or Oughtred, but on Collins and his interest in gathering up material relating to the development of mathematical instruments in the half-century or so before he came to London. In line with this speculation about Collins it would seem likely that the significance of the letter was once known – it effectively constituted, after all, a prototype of a newly invented instrument, and one that was part of a family of instruments beset by confusion and conflict over priority.

As I noted, until now there have been no secure dates for reverse prints. As we have no reason to doubt that the print is contemporary with the letter we can say that the first reverse print known dates from 1638 or soon after. Elias Allen appears, then, to have begun the tradition (we will see that this word is apt) of reverse printing. This is hardly surprising given his close ties to London publishers. For instance, Allen produced the prints of instruments that accompanied Edmund Gunter's books, and would have been tutored in the preparation of such illustrations by his master Charles Whitwell, who engraved maps, as well as the plates for William Barlow's *Navigator's Supply* (1597).

A Nocturnal by Walter Hayes?

The second of the batch of newly discovered reverse prints is a planispheric nocturnal on the reverse of a quadrant, showing six constellations (see Fig. 4).[18] This is a standard component of one of the most common instruments of the period – yet the engraving is confident and fluid, a far remove from many of the crudely engraved examples found on seventeenth-century quadrants. My first thought, that

Fig. 4 *Reverse print of a nocturnal on a quadrant, possibly by Walter Hayes. Private collection.*

Fig. 5 *Quadrant by Walter Hayes, undated. Museum of the History of Science, Oxford.*

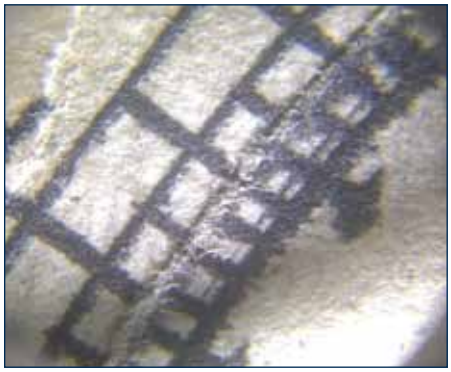


Fig. 6 *Magnified portion of the reverse-printed nocturnal, showing the 'join' between the disc and the hour scale. On the original instrument these would have been around a millimetre distant from one another, and yet there is no distortion to the printing of the hour-scale, nor is there any ink build-up around the disc, as can be clearly seen (Fig. 4) around the central rivet.*

here was another example of the work of Elias Allen, is almost certainly incorrect. Although there are Allen nocturnals with the relatively uncommon constellation of Auriga, Allen appears always to have cross-hatched in his shading, and yet there is no cross-hatching here at all. Close examination reveals too many other stylistic differences to pursue the suggestion. A far better fit is with a quadrant by Walter Hayes, preserved at the MHS, Oxford, the nocturnal of which not only carries Auriga but has the ram associated with the figure represented inside his body (inv. no. 36399). Stylistic similarities are in evidence throughout the design – though there are some minor differences, in particular in the placing of stars in relation to the figures (Fig. 5).

Unusually, the differences between the print and the Oxford quadrant are less notable than those between known Hayes nocturnals, some of which show a markedly cruder engraving and a different manner of arranging the constellations. Perhaps we are here seeing a progression of Hayes' engraving, from earlier, cruder nocturnals to the Oxford example and then to the example from which the reverse print comes. If this was the height of his achievement in depicting the heavens it would make sense for him to have printed from it in order to keep a record. A point that must be remembered when thinking about reverse printing is that instrument makers, scholars, amateurs and practitioners would not have had access to instruments after they were sold, unless they were on friendly terms with the purchaser. In our age of large museum collections, well illustrated publications and online databases it is impossible for us to recover the sheer scarcity of instruments as they existed in the early-modern period. Even the shops that we imagine as jewel houses of brass and must have been relatively barren, as instrument makers would not have been able to afford to keep the shelves stocked with unpurchased pieces.[19] Needless to say, the nocturnal could also have been the basis of a counter-proof, which would then have been pasted onto wood or brass and used as a perfectly functioning instrument.

In addition to the stylistic connection, there are other reasons that Hayes is a good candidate for the nocturnal's maker. He had been apprenticed to John Allen, the latter apprenticed to Elias Allen, and, as Hester Higton points out, Hayes effectively took over Elias Allen's position in the mathematical community after the latter's death in 1653[20]: both had busy workshops; both were active in the Clockmakers' and Grocers' Companies; both were highly skilled engravers; both had shops that served as meeting points for the community; both produced the plates for instruments in textbooks – indeed in Gunter's works Hayes' name was simply reworked onto the original plates by Elias Allen.[21] To find a reverse-printed instrument by Hayes – the same practice pioneered by Allen – would therefore hardly be surprising.

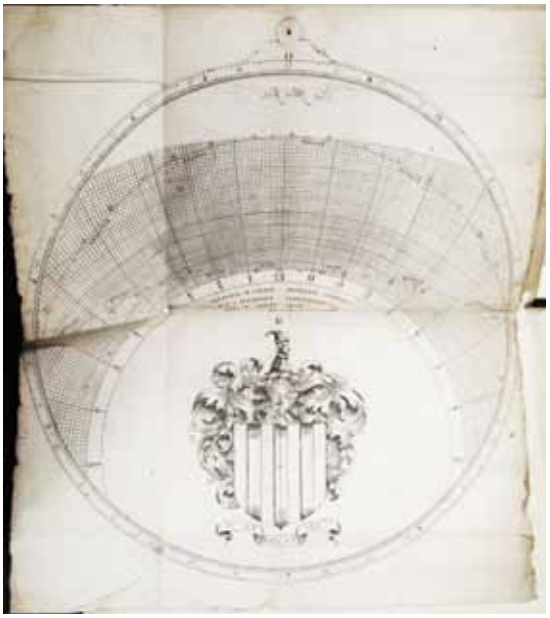
One oddity of the nocturnal is that, while it is easy to see the protruding central rivet and the knob used for rotating it, there is no excess ink between the nocturnal disc and the contiguous hour-scale. Close examination reveals slight abrasion surrounding the nocturnal, suggesting that in spite of the absence of excess ink it *has* made a deeper impression on the paper, though that is now flattened (Fig. 6).

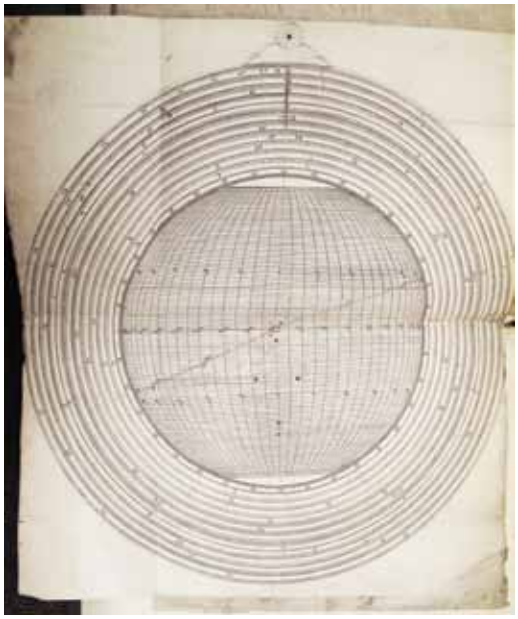
This minor mystery, I think, points to something important about reverse prints: immense care was taken over their production, such that in this case it seems as though two impressions were taken: one with just the underlying quadrant plate in order to capture the hour lines, and one with just the nocturnal disc, so placed in the press that it imprinted into the blank space surrounded by the hour lines. This is the only explanation that I can think of for the fact that a nocturnal ordinarily protruding a full millimetre or so from the base plate has not left any residue of ink or affected the printing of the engraved hour-scale contiguous with its edge.[22] Whether it was Hayes or someone working with him or in his tradition, the production of this seemingly ephemeral item required the utmost skill and most likely a number of failed attempts.

Marsh's Library and the Newdegate Collection

I now come to the magnificent array of reverse prints kindly brought to my attention by Anthony Turner and David Bryden. From the former I learned of a pair of prints held at Marsh's Library, Dublin, which form a record, front and back, of the horizontal instrument, circles of proportion and universal projection by Elias Allen at St John's College, Oxford (Figs 7 a & b; classmark: Z.2.1.12/5).

I am yet to study these 'in person' so hesi-





Figs 7 (a) and (b) *Two separate sheets carrying reverse prints of a horizontal instrument and circles of proportion by Elias Allen – the instrument itself is held at St John's College, Oxford. Marsh's Library, Dublin.*

tate to draw too many conclusions – suffice it to say that these prints are important for a number of reasons. First, they are the only known examples of a reverse-printed horizontal instrument (as opposed to the more often printed double-horizontal dial). Second, the instrument they record is early, having been donated to St John's College by George Barkham in 1635. These may, therefore, be the earliest reverse prints. Their provenance is not known, but may well go back to the founding collection of Narcissus Marsh, clergyman and erstwhile natural philosopher.[23] There are a small number of other astronomical prints amongst the manuscript collection, and Marsh had studied at and became proproctor of Oxford, and was loosely connected to the world of the mathematical practitioners through his appointment as chaplain to Seth Ward.[24] But beyond these bare facts it is hard to speculate about the history and purpose of the prints.

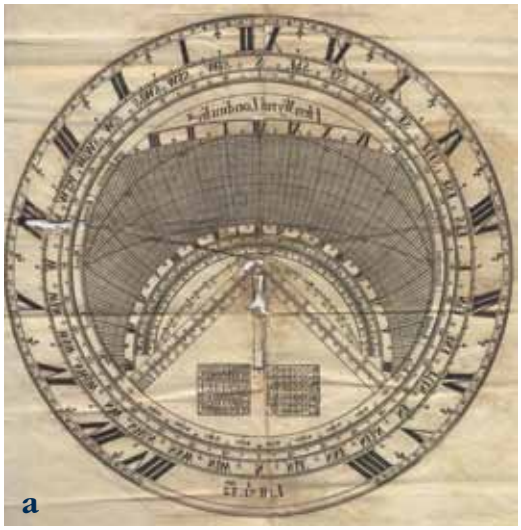
More, perhaps, can be said about a fascinating group identified by David Bryden at the Warwickshire County Record Office, amongst the Newdegate of Arbury Papers (classmark CR136). These consist of: a reverse-printed double-horizontal dial by Henry Wynne, dateable to *c.* 1685 based on the perpetual calendar; a sheet with two reverse-prints of a 1674 double-horizontal dial by Henry Wynne, one on each side of the paper; and sheet with two reverse-prints of a 1663 Henry Sutton spiral logarithmic scale, again with one on each side of the paper (Figs 8 a–e).[25]

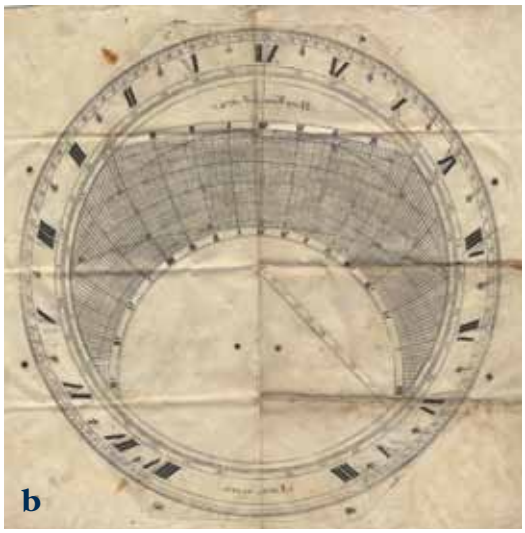
At this stage of research it is unclear which of several Restoration members of the Newdegate family originally acquired these prints. But, what may be of greater interest, they are part of a sizeable collection of material mainly relating to the Oxford instrument maker and specialist in paper instruments John Prujean.[26] The exact nature of the collection is uncertain – perhaps it was a working one, Prujean having either gathered up material from other instrument makers (a common practice by the end of the seventeenth century), or printed from instruments himself (he had, after all, been apprenticed to Elias Allen in 1646 and would likely have been familiar with the practice). Uncertainty over the role of Prujean, however, is superseded by the strong evidence that the reverse prints offer for the practice of counter-proofing. As noted, two of the sheets in the Newdegate collection have been printed recto and verso – in each case with a faint and imperfect impression on one side and a very strong impression on the other.[27] Recalling Davis' and Lowne's argument that reverse printing was an intermediate stage before counter-proofs were made, and by comparison with the very strongly inked John Marke reverse print and its counter-proof in the Boyle Papers, it seems almost certain that here we have further examples of reverse prints that were only a stage in a more elaborate process. The first run resulted in a faintly inked impression; the second in a heavily inked impress which was then run through the press to make a counter-proof. As Davis has pointed out, it is hardly surprising that the reverse prints survive but not the counter-proofs: the latter would, after all, have been perfectly functional as (in this case) a horizontal projection and a spiral slide rule, and would therefore have been worn down through use – the low survival rate of paper instruments in general attest to their status as workmanlike tools, not to be prized or kept.[28]

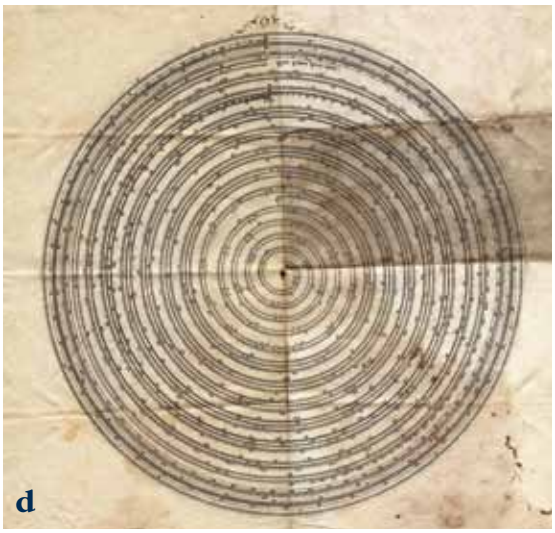
Conclusion

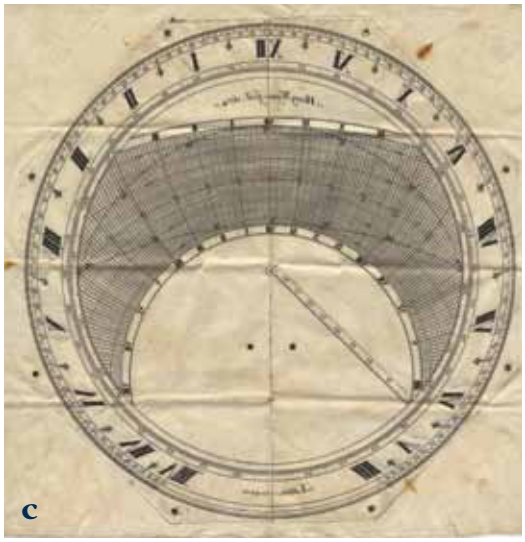
We are now in possession of sixteen reversed impressions, made directly from instruments, on thirteen sheets (three being printed on both sides). In addition we have two counter-proofs (Sutton's in the Byrom Collection; Marke's in the Boyle Papers).The instruments used for printing are known for in two or three cases (Sutton's astrolabe at the MHS, Oxford; Allen's horizontal instrument and circles of proportion at St John's College, Oxford; Sutton's spiral rule at the Science Museum).[29] This makes a total of eighteen relevant prints, of which twelve are of instruments bearing the horizontal projection; four carry logarithmic scales either in circular, spiral or linear form; two carry universal projections; one is a horizontal dial; and one shows the nocturnal on a quadrant.[30] All of the printed instruments are English, and moreover – if we accept the attribution of the nocturnal to Walter Hayes – they are all bar one connected with the craft lineages of Elias Allen and Henry Sutton.[31] It would be fascinating to learn of reverse prints from other eras or other countries – but perhaps, like knowledge of the construction of the horizontal projection, knowledge of (or a taste for) reverse printing was limited to a small group of practitioners and their customers.

One of the early speculations that seems increasingly likely is that the reverse prints were made at more or less the same time as the instruments with which they are associated.The only concrete evidence we have is the 1638 Oughtred-Allen letter and its accompanying print; certainly nothing in the provenance or on the prints themselves suggests a later origin. (As yet, regrettably,









Figs 8 Five *reverse prints preserved in the Newdegate of Arbury Papers:* (a) *a double-horizontal dial by Henry Wynne, undated but* c. *1685; another double-horizontal dial by Henry Wynne, dated 1674 and printed once on each side of the paper:* (b) *FRONT and* (c) *BACK; a spiral logarithmic scale by Henry Sutton, dated 1663 and also printed once on each side of the paper:* (d) *FRONT and* (e) *BACK. Warwickshire County Record Office, CR136/d1/74, 77, 78.*

not a single watermark has been found.)

But what of the *purpose* of reverse printing? Information on provenance is intriguing but inconclusive here. The nocturnal and Allen's logarithmic rule may have been records – the latter may alternatively have been printed and sent as an act of communication with Oughtred. We now have a number of heavily inked reverse prints, suggesting that counter-proofing was, as Davis argues, a common practice – perhaps the main purpose of reverse printing. This would fit with what we know of the rich trade in paper instruments, evidence of which is only fragmentary today.[32] But two facts suggest that counter-proofing was not the *sole* purpose of reverse printing: first, there is the relatively high survival rate of reverse to counter-proof prints; second, the presence of many reverse prints that are not heavily inked. Experiments will be required in order to establish just how the counter-proofing process works for reverse-printed instruments (i.e. how heavily inked the first pull must be, how many counter-proofs can be made), but it seems likely to me that, especially for the horizontal projection, the reverse print was sometimes made without a further counter-proof being done. True, the relative survival rates could be accounted for precisely by the fact that the reverse prints are less useful than the counterpoofs and therefore more likely to survive. Yet reverse prints clearly had a value all of their own – here we must balance solid inferences from only a handful of counter-proofs against speculation based on a much larger body of reverse-printed evidence. Though eventually neglected in unruly archives, reverse prints were apparently once of interest to men like John Collins, John Pell, Narcissus Marsh, Robert Boyle, and one of the learned Newdegates. Were counter-proofs so useful that they couldn't be saved? This seems unlikely, and so I think we have to see the evidence in the round: reverse prints were valued and collected; they were also counter-proofed; and they were kept as records and passed around as a means of communication.

There are a number of ways of going beyond the question of whether or not these prints could have been of *practical* use to their owners. For instance, as was suggested by Bryden, they may have been acquired as examples of fine workmanship. The links to Oughtred, Pell and Collins – scholars who were interested in practical mathematics – are suggestive here. Jim Bennett has argued, further, that we should think of constructions like the horizontal projection in aesthetic terms.[33] The fascination with the horizontal projection, in combination with the difficulty of making it, may have led to a

case of supply outstripping demand – witness the episode recorded in Pepys diary, when for two days running Pepys allows Dean Honiwood a glimpse of his newly acquired double-horizontal dial, and Honiwood 'dotes mightily upon it', to the extent that Pepys resolves 'to give him one, and that shall be it.'[34] Certainly in other national contexts precision and fine manufacture were valued above functionality, as Bruce Moran has shown.[35] Here we might recall Edmund Stone's comment that Henry Sutton made 'the finest divided Instruments in the World', and that 'the Regularity and Exactness of the vast Number of Circles drawn upon them is highly delightful to behold'.[36] That these words were published long after Sutton's death is germane to an account not only of the production of reverse prints but also their survival.

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1. David J. Bryden, The Instrument Maker and the Printer: Paper Instruments Made in Seventeenth Century London', *Bulletin*, No. 55 (1997), pp. 3–15, quotation p. 6.

2. Catherine Eagleton and Boris Jardine, 'Collections and Projections: Henry Sutton's Paper Instruments', *Journal for the History of Collections*, **17** (2005), pp. 1–13.

3. See for example, Richard Yeo, *Notebooks, English Virtuosi, and Early Modern Science* (Chicago, 2014), ch. 3.

4. John R. Davis and Michael Lowne, *The Double Horizontal Dial and Associated Instruments*, British Sundial Society Monograph (London, 2010).

5. *Ibid.*, p. 83.

6. John R. Davis, 'John Marke's Double Horizontal Dials', *BSS Bulletin*, **20** (2008), pp. 117–18.

7. Eagleton and Jardine (2005), pp. 8ff.

8. Stephen P. Rigaud, *Correspondence of Scientific Men of the Seventeenth Century, Including Letters of Barrow, Flamsteed, Wallis, and Newton, Printed from the Originals in the Collection of the Right Honourable the Earl of Macclesfield*, 2 vols (1841), vol. I, pp. 30–2; Peter Hopp and Bob Otnes, 'A Letter of 1638 from William Oughtred to Elias Allen', *Journal of the Oughtred Society*, **17** (2008), pp. 28–32.

9. In *An Addition unto the Use of the Instrument Called the Circles of Proportion* (London, 1633), pp. 33ff.

10. The other is entitled *The New Artificial Gauging Line or Rod* (London, 1633). Neither of the two 1633 publications is illustrated. For an account of these works see Florian Cajori, *William Oughtred: A Great Seventeenth-Century Teacher of Mathematics* (Chicago, 1916), pp. 50ff.

11. The authors of that paper, however, were working from photocopies of the documents.

12. Cambridge University Library, MS Add.9597/13/5/215r. Underlining added.

13. Anthony J. Turner, 'William Oughtred, Richard Delamain and the Horizontal Instrument in Seventeenth Century England', *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, **6** (1981), pp. 99–125; David J. Bryden, 'A Patchery and Confusion of Disjointed Stuffe: Richard Delamain's *Grammelogia* of 1631/3', *Trans. Camb. Bibl. Soc.*, **6** (1974), pp. 158–166.

14. In fact, the line of numbers extends beyond 2 but does not even get halfway to 1 before it is cut off. This is something of a mystery, as Oughtred specifically mentions the first term of the line of numbers on the transversarie in his 1633 'Declaration' (p. 65). Possibly Allen made an error, or possibly the design had changed in the intervening years – Oughtred does after all mention a separate sheet of instructions, now lost. Certainly it is possible to *use* two transposed lines of numbers even if one of them is incomplete: calculations require that only one first term be employed, and the fractions between 1 and 2 can still be multiplied as both are present in the second cycle of logarithms.

15. Paul Quarrie, 'The Scientific Library of the Earls of Macclesfield', *Notes and Records of the Royal Society*, **20** (2006), pp. 5–24, see p. 6.

16. See Frances Willmoth, *Sir Jonas Moore: Practical Mathematics and Restoration Science* (Woodbridge, 1993), p. 47; Hester Higton, *Elias Allen and the Role of Instruments in Shaping the Mathematical Culture of Seventeenth-Century England*, unpublished PhD dissertation, University of Cambridge (1996), p. 71.

17. See in particular Cambridge University Library, MS Add.9597/13/5/44, 'A copy of Bedwell's ruler and instructions on how to use it, enclosed with the letter from Henry Briggs to Ralph Clarke'.

18. This is the only reverse print in private hands; it was offered by Christie's as Lot 3 in their online sale 'Seven Centuries of Science' (15–29 October 2015).

19. Evidence for this, from advertisements for instrument makers, is collected and analysed in David J. Bryden, 'Evidence from Advertising for Mathematical Instrument Making in London, 1556–1714', *Annals of Science*, **49** (1992), pp. 301–336. By the middle of the seventeenth century there was occasionally 'off the shelf' stock to be found; certain makers favoured (and types of instrument suited) this model, yet, as Bryden puts it (p. 328) these were 'the exception rather than the rule'.

20. Higton (1996), pp. 85–6.

21. See Bryden (1992), pp. 315–7.

22. I am grateful to James Hyslop at Christie's for his assistance in this part of my research, and for supplying Figs 3 and 7.

23. Muriel McCarthy, 'Narcissus Marsh & His Library', *History Ireland*, **4** (1996), pp. 17–22.

24. See the *ODNB* entry by Muriel McCarthy.

25. Bryden believes (personal communication) that the Sutton spiral rules were printed from an instrument held at the Science Museum, London (inv. no. 1964-73). I have yet to examine the Science Museum instrument in this connection.

26. On Prujean see David J. Bryden, 'Made in Oxford: John Prujean's 1701 Catalogue of Mathematical Instruments', *Oxoniensa*, **58** (1993), pp. 263–85.

27. The other print has been so heavily printed to have spoiled the reverse of the sheet, perhaps explaining why the latter was never used.

28. John R. Davis, personal communication.

29. See note 25.

30. There are more instrument types than prints because the Allen prints at Marsh's Library are compendious, with two projections and the 'circles of proportion'.

31. John Rowley was apprenticed to Joseph Howe, whose background is not known.

32. See Bryden (1997), *passim*.

33. Jim Bennett, 'Direct and reverse engraving: Can we link the working communities in the past and connect the scholarly today?', XXVII Symposium of the Scientific Instrument Commission, 16–21 September 2008, Museum of Science, University of Lisbon Portugal.

34. Pepys' Diary, entries for Wednesday 3rd and Thursday 4th June, 1663.

35. Bruce T. Moran, 'Princes, Machines and the Valuation of Precision in the 16th Century', *Sudhoffs Archiv*, **61** (1977), pp. 209–228.

36. Nicholas Bion, *The Construction and Principal Uses of Mathematical Instruments* (2nd edition, London, 1758), unnumbered page entitled 'advertisement' inserted between pp. 264 and 265.

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