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The Compendium*

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Photo by Rudy Light

The eye is always caught by light, but shadows have more to say….

– Gregory Maguire (Mirror-Mirror)

* *Compendium*... "giving the sense and substance of the topic within small compass." In dialing, a compendium is a single instrument incorporating a variety of dial types and ancillary tools.

A Triple Horizontal Dial For California

John Davis (Ipswich, UK)

Introduction

There are not many clients for a horizontal sundial who have consulted an original copy of William Leybourn's 1682 book[1] on dialing before arriving to discuss their dial design. But Dr. Rudy Light, of Redwood Valley, California, had done so and also brought a copy of Leybourn's diagram of "An Horizontall Dial with its Furniture" (reproduced in Waugh[2] and shown in Fig. 1) with him when he visited me in the summer of 2003. When he explained that he wanted a large scientific dial to position outside his house and that he "wasn't afraid of complications", I knew it would be an interesting project.

We started with a list of features which the dial should show. The essentials were:

* a time ring for Pacific Standard Time (or the solar version thereof)
* the equation of time
* declination lines for solstices, equinoxes and several family anniversaries
* the sun's azimuth
* the sun's declination
* the sun's altitude
* sunrise/sunset times
* right ascension of the sun.

An additional list of possible features included:

* local apparent time
* times of noon at various places
* a compass rose
* a moondial
* a nocturnal
* owner's and maker's names
* motto(es)
* subsidiary direct east and direct west dials on the sides of the gnomon.

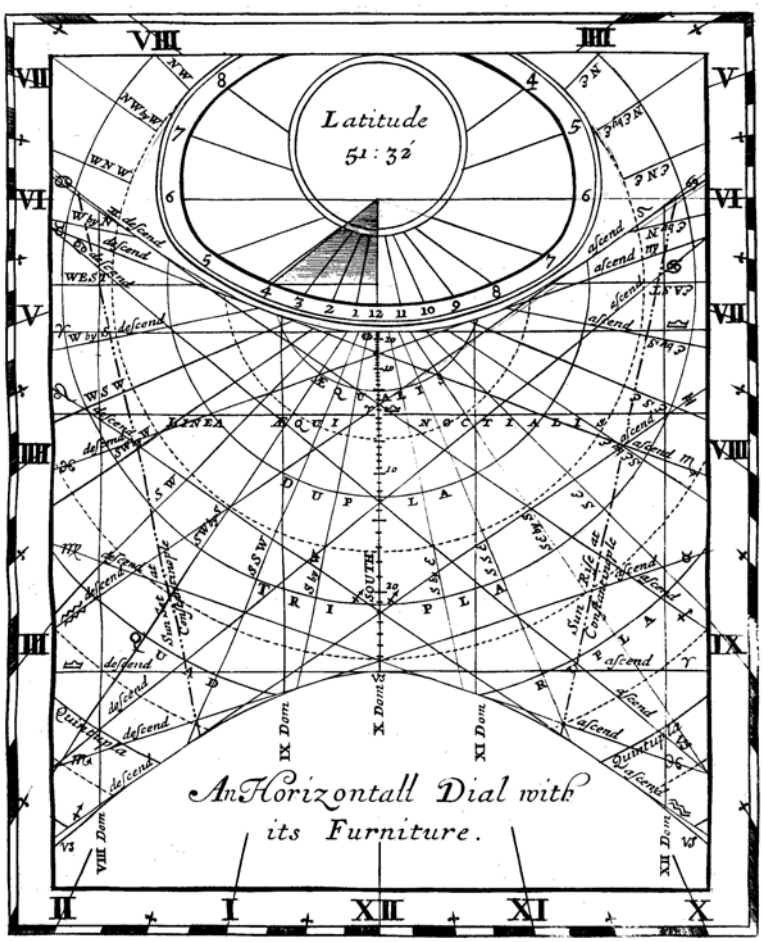

Fig. 1. A 'conventional' horizontal dial with a full set of furniture from Leybourn (ref. 1).

It took numerous iterations of the design before we came up with the instrument shown in Fig. 2 which meets most of the requirements. I do my designs using TurboCad™ software and, such was Rudy's dedication to the project, he also installed a copy of the program so that we could correspond about the fine details of the design. The story of how the design developed and was eventually turned into bronze follows.

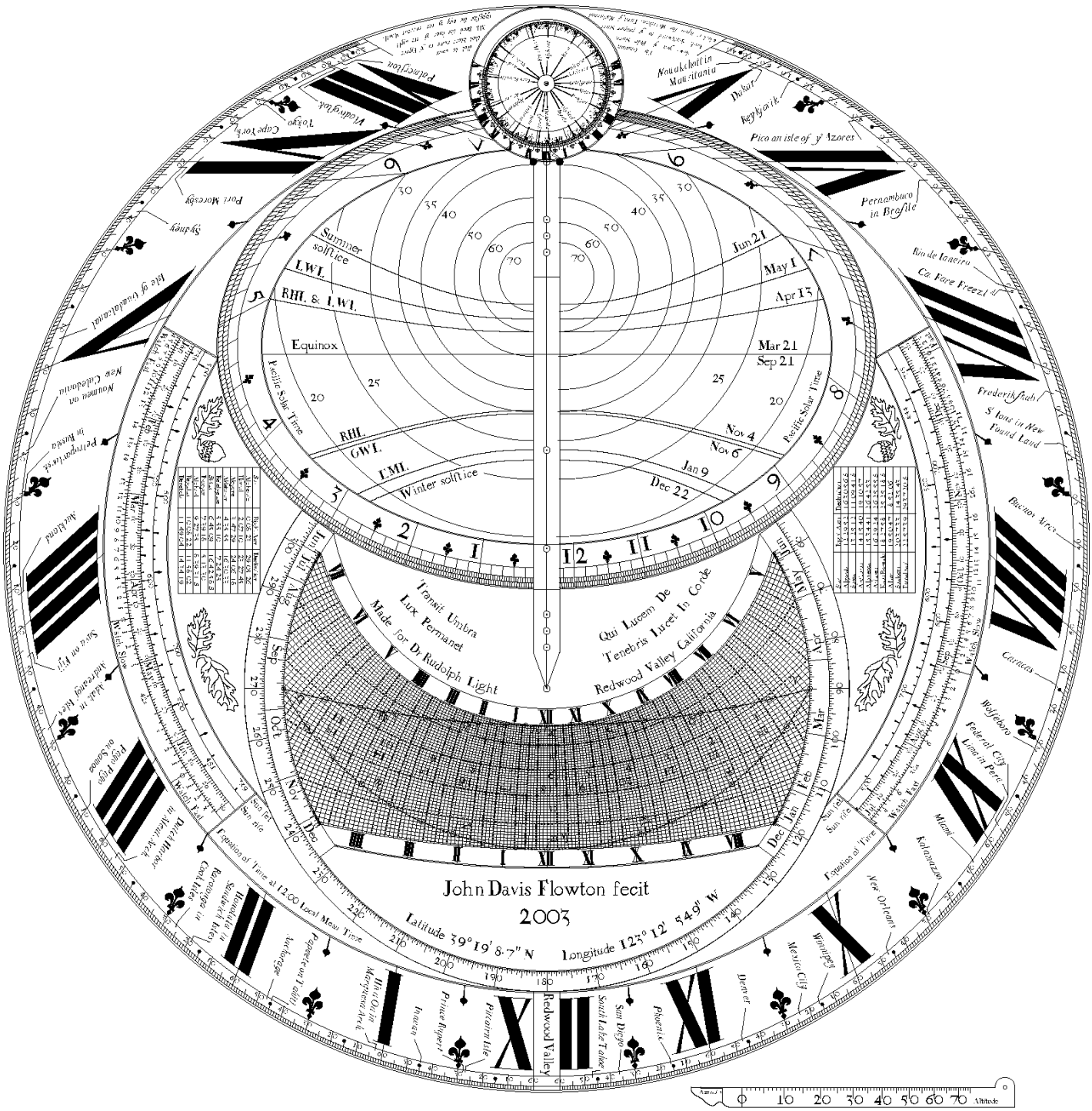

Figure 2a. Drawing of the dialplate of the Redwood Valley dial.

Figure 2b. Drawing of the gnomon of the Redwood Valley dial.

A Double Horizontal Dial?

The starting point was a standard horizontal dial with a polar-pointing gnomon and a nodus, designed to fit on a rectangular dial plate like the Leybourn example. The multitude of lines produced a rather messy-looking design, though. As an alternative, the double horizontal dial[3,4] seemed an attractive proposition as its stereographic projection maps the whole visible half of the celestial sphere, allowing many of the measures of the sun's position to be shown directly. At the time, I was busy researching the large double horizontal dial made in 1685 by Henry Wynne, probably for the 1st Earl Ferrers of Staunton Harold.[5] I had made several double horizontal dials before but never one for America. I showed a drawing of the Wynne dial to Rudy and he was much taken with it, so we decided that his dial should be based on, or include, a double horizontal dial. It is worth mentioning that a replica of the Staunton Harold dial has subsequently been finely crafted by Tony Moss.[6]

I quickly found a snag when laying out the dial. The stereographic projection is read from the shadow of a vertical knife-edge gnomon positioned in the center of the grid. In a double horizontal dial, this vertical gnomon fits underneath the polar-pointing gnomon needed for the standard horizontal dial which is placed around the outside of the dial plate. The difficulty is to get the vertical gnomon tall enough to cast a shadow across the grid in the summer sun. In a conventional English double horizontal dial, this is achieved by putting the vertical gnomon in the center of the dial plate and offsetting the origin of the polar gnomon as far as possible towards the southern edge of the dial plate (an extreme example of this can be seen in the 'Bacon' dial[7]). This tends to result in a rather narrow 'tail' for the upper part of the gnomon and a high percentage of

old double horizontal dials have bent or broken gnomons. In designing a dial for California, at a much more southerly latitude (approximately 39° as opposed to 51.5° for London), the problem is significantly worse than in England both because the polar gnomon is at a shallower angle and because the sun can be much higher in the sky, leading to shorter shadows.

The solution which I adopted was to move the whole of the stereographic grid towards the northern edge of the dial plate, allowing a taller knife-edge to be fitted in underneath the polar gnomon. This resulted in the grid no longer completely dominating the design. The features of the grid largely follow those of a Henry Wynne design. It has declination lines at 1° intervals and hour arcs for every five minutes of time. The 5° and 15° declination lines and the quarter- and half-hour lines have dots on them to make it easier for the eye to follow them – a feature which is easy to describe but time-consuming to do! The two arcs for the ecliptic also have dots on them; a total of 360 spaced for each degree of solar longitude. Every 10th dot is emphasized and the zodiac sigils are placed at 30° intervals. The form of the sigils is that seen on Wynne's hand-engraved dials: I had produced a font of his lettering styles (there are two major ones) so it seemed a nice touch to make this new dial with old-style lettering.

The declination line for the equinoxes, running across the centre of the stereographic grid, is numbered [0] to [12] and then upside down back to [24], showing the right ascension of the sun.

The date scale running around the horizon circle of the grid uses the modern Gregorian calendar, of course, rather than the Julian one on a Wynne dial. We also chose to make it run anti-clockwise, so that the outward-facing names of the months read conventionally from left to right. This is an arrangement that was not adopted on English dials until around 1710, right at the end of Wynne's career. It does make for a more practical dial than Wynne's inward-facing engraving.

An azimuth scale is placed around the outside of the date scale. It runs from 60° in the southwest to 300° in the southeast, with 180° at the north. It might seem that this clockwise arrangement is the wrong way round, but it is designed to show the bearing of the sun directly from the shadow of the knife-edge. Old English dials normally used a 4× 0-90° scale, often with the zeroes at the East and West points, but this is not very convenient today.

With a stereographic projection, the sun's altitude is measured from the origin of the grid to the point where the knife-edge shadow crosses the declination line for today's date. The scale is non-linear, ranging from 0° on the horizon circle (sunrise and sunset) to 90° (zenith) at the center. It would be possible to show the altitude by a set of unequally-spaced concentric circles engraved over the grid but they would look confusing. Although one or two early 17th century drawings show these circles, I am not aware of any real dial with them. Instead, a straight ruler-like scale was usually engraved elswhere on the dial so that the sun's height could be measured with the aid of a pair of dividers. On some dials, provision is made for this by cutting away the foot of the knife-edge, allowing easy access to the origin of the grid. An alternative would be to provide a separate rule or alidade, pivoted about the origin and capable of being rotated to the shadow position. It is thought that some old dials had such a device although none is now extant. We decided to have a pair of alidades, mirror images of each other. The reason for having a second alidade is that the thickness of the brass casts a shadow and this can lie exactly where the measurement is being taken. With a pair of alidades, one of them can be chosen so that its fiducial edge is facing the sun. A slight extension to the length of the alidades also allows them to provide a reading on the azimuth scale.

A Third Dial

Moving the stereographic grid towards the north of the dialplate left an empty space to the south of the center. No self-respecting 17th century English mathematical instrument maker would leave

valuable brass un-engraved so we too sought a good use for the space. Our choice was for another dial face and thus we arrived at the triple horizontal dial of the title. This third face was given an elliptical chapter ring, both because it filled the space rather efficiently and because the different shape seemed to add something to the aesthetics. It also nicely matches the elliptical inner ring of the Leybourn design. The third dial uses the same polar-pointing gnomon as the main dial on the periphery of the plate. So that it does not simply duplicate that dial, it is delineated with the longitude offset of Redwood Valley from the standard parallel 120°W, amounting to 12.8 minutes. Labelled "Pacific Solar Time" (rather than Pacific Standard Time), it is divided to single minutes. To avoid the spacing getting too small, this is arranged in two rings, the inner one showing the even numbers of minutes and the outer, the odd ones. This feature was used on the Thomas Heath dial at Erddig, in Wales and then adopted by George Adams Jr. in the 18th century.

The elliptical dial also has a set of declination lines, necessitating a nodus on the gnomon. This is not a standard feature of a traditional double horizontal line. The declination lines are for the solstices and equinoxes and also for five family anniversaries, discreetly labelled with initials. The nodus (actually a pair of noduses, separated by the thickness of the gnomon – see below) also allowed a set of lines for the altitude of the sun to be added. These are pairs of semi-circles, separated by the gnomon thickness. In Leybourn's design, the altitude lines are for *Equalis, Dupla, Tripla* etc., depending on the length of the shadow of a vertical gnomon of unit height. But we opted for the more modern approach of altitude in 5° and 10° steps.

I normally draw the outline of the gnomon on the dial plate in very narrow lines, together with the centers of any bolt or dowel holes. These etch to provide a good center-mark for later drilling, ensuring proper alignment. At the 'toe' of the gnomon, the two origins of the horizontal dial delineation are marked by 2 mm diameter black circles. When finally assembled, the tip of the gnomon should cover exactly a quarter of each circle. On old English dials, these spots are often actual holes drilled right through the dial plate though they have usually become filled with corrosion products over the centuries. It is believed that these holes were used to locate some form of rotating ruler while the dial was being delineated but the process does not seem to have been documented.

The Outer Dial

The main horizontal dial around the periphery of the plate is very traditional. The large Roman numerals face outwards and are skewed along the hour-lines. The division to individual minutes (numbered in 10s) is on the very perimeter of the dial so that they can have maximum spacing. The half-hours are marked by fleur-de-lys though the style chosen was not the intricate design of Wynne but that of Thomas Wright who worked a generation after him. The dial naturally reads Local Apparent Time (solar time) and this point is stressed by having the location, Redwood Valley, engraved in the noon gap. Showing the times of noon at various places around the globe is another feature which Wynne frequently used (and may have actually introduced). He had a number of formats for doing this including a series of separate chapter rings but the one which we adopted is copied from the Staunton Harold dial. The names of the places are engraved in small letters in the main chapter ring with one, or sometimes two, place(s) in each half-hour space. A short line to the minute ring gives the exact time of noon, by Redwood Valley LAT, of the place. The choice of place names mixed traditional locations such as ***S^t. Iohns in New Found Land*** and ***Pico an Isle of ye Azores*** as used by Wynne and others such as ***Kalamazoo*** (surely not seen on a dial before?) and ***Wolfeboro*** to which Rudy had a personal connection. The font used was again Wynne's, including his use of the long-s as in ***Frederikſhab***.

The Nocturnal

Yet another feature copied from Wynne was the inclusion of a nocturnal. This is in the form of two concentric discs placed immediately to the south of the gnomon. The outer disc, designed to be fixed, is calibrated anticlockwise VII-XII-V hours, sub-divided to 5-minutes, on a 15° per hour basis. There is a small secondary mark at 12:13 labelled PST for Pacific Standard Time (the main nocturnal scale indicates local mean time). The inner disc carries a calendar scale and, superimposed on it, the names of 19 stars prominent in the Californian sky. These are positioned so that their right ascensions correspond to the dates with 12:00 at the first point of Aries. Instructions for using the nocturnal are engraved, in a slightly paraphrased version of Wynne's original script, on the dial:

> *The Gnomon shows you ye Pole Starr.*
> *Look southward to ye proper Starr which is upon the Meridian.*
> *Turn ye Nocturnal dial to point that Starr name to ye figure XII.*
> *Read the hour of the night opposite the day of the current month.*

The full list of right ascensions and declinations of the chosen stars, epoch 2000.0, are shown in two rectangular tables to the east and west of the elliptical dial.

Other Scales and Furniture

The other features which complete the scientific part of the dial are the arc segments containing the equation of time and sunrise/sunset data. I normally use equation of time data averaged over the next 50 years for engraving on dials, aiming at a continued accuracy over the life of the dial (or its owner!). For this dial, though, Rudy wanted to keep all of the design features for a particular year, in this case the millennium of 2000. Tabulated data is easy to obtain but most almanacs show the EoT for 0 hours UT each day. This is ideal for an astronomer but less convenient for a Californian sundial, likely to be observed around noon local time. So the data were interpolated to give appropriate values for 12:00 local mean time each day. The common English EoT display, showing a continuous date scale and the number of minutes "Watch Slow" or "Watch Fast" against it, requires a further calculation to work out the decimal day number when the EoT is an integer number of minutes. The decimal dates for half-minute EoT values (and 15-second intervals in some places) were also calculated. One further figure occurs at the maxima and minima, where the two adjacent numbers on the minutes scale are the same. Here, the extra number of seconds at the absolute max/min were calculated and inserted with a small 's' to indicate seconds. Thus, for example, on November 2.8, the EoT is shown as 16m 26s (Watch slow). All this was second nature to an 18th century mathematical instrument maker in London – no wonder they served a seven-year apprenticeship.

The same date scale also serves for the sunrise and sunset scales. The solar times of local sunrise/sunset were first calculated on a daily basis, assuming no refraction, using the standard equations. These were then converted to local mean time. These were finally used to calculate theoretical dates when the sunrise/sunset would fall at a desired time, in five-minute steps, for the scale. The result is a highly non-linear scale, completed at each end with the extreme sunrise/set times for the solstices.

The final dial furniture comprises the names of the maker and owner, the latitude and longitude, and some decorative oak leaves and acorns. We also decided to have two mottoes. Mottoes on double horizontal dials are rare but not unknown – one used by Henry Wynne was *Nulla Dies Sine Linea* or 'No day without a line' – an injunction not to be idle particularly appropriate for the many-lined double horizontal design.[8] With a surname like 'Light', the temptation was to use something along the lines of 'Lumen in umbra, Lumen ab intus' (*light in shadows, light from within*) but this was resisted as too immodest. Rudy finally chose "Transit Umbra, Lux Permanet" (*the shadows*

pass, light remains)[9] and "Qui Lucem de Tenebris Lucet in Corde" (*he who [sends] light from darkness shines in his heart*).[10]

Fig. 3. The pierced and engraved gnomon of the dial (actually a modern replica) by Thomas Tompion in Kew Gardens, the inspiration for the gnomon on the Redwood Valley dial.

The Gnomon

The general shape of a double horizontal gnomon is largely fixed by the geometry of the dial plate. When shown the first design, with plain slab sides in the form of a solid triangle, Rudy's wife commented, quite correctly, that it looked rather 'clunky'. On his double horizontal dials, Wynne generally covered the triangular sides with engraved coats of arms or calendrical tables but this would not have broken up the much larger triangle for our dial. On his visit to England, Rudy had visited Kew Gardens where he had seen the (replica) dial by Thomas Tompion with its elegantly pierced gnomon (Fig. 3) and so we decided that we needed some decorative piercing, enhanced by engraved lines. Rudy has a long-standing passion for oak woodland conservation and has planted thousands of oak trees on his ranch so, instead of the traditional vine or acanthus leaves, details from the local Californian black oak tree (*Querus kelloggii*) were to be included. Additionally, a local species of garden spider (*Argiope trifasciata*) was added, seen in dorsal view on the east side of the gnomon and in ventral view on the west. A smaller spider is engraved near the tip of the gnomon. As I have no artistic abilities, Rudy had a local artist draw the required design and this fact is recorded by an engraving on west side of the base of the gnomon reading "Karen Soberanis delineavit".

The choice of a nodus type for a horizontal dial is always full of compromises between visibility for all postitions of the sun, non-ambiguous readings and aesthetics. This is especially the case when the gnomon is quite thick. In the past, I have used V-cuts, 'W' forms and short cylindrical cross-pieces (Fig. 4). In general, the cut-out forms have the disadvantage of disappearing at noon and consuming a significant length of the style edge when the sun is low, whereas any form of addition to the style edge leads to difficulty in deciding which part of the shadow is the intended position. After some experiments, I found that putting a hole through the gnomon, just behind the style edge so that it broke through and produced a narrow slit, worked well at all times other than noon and it was also very neat. If a reading is needed at noon, a short rod can be temporarily laid across the slit. I did the experiments using a circular hole but there is no need for it to be this shape. On the actual dial, we made the hole in the shape of an acorn and had its cup engraved as part of a decorative leaf-and-acorn border running up the side of the gnomon (see Fig 4(e)).

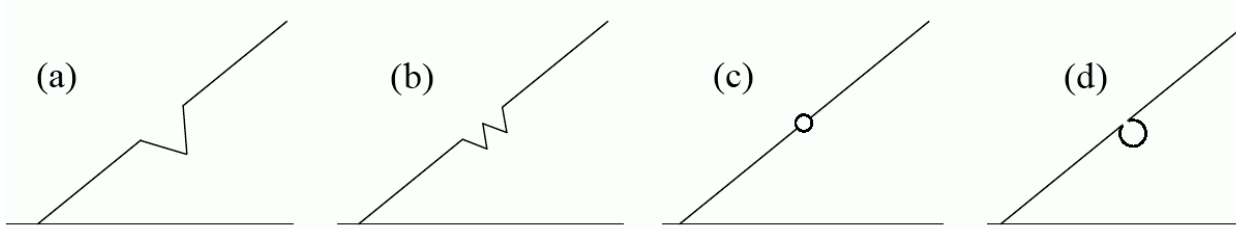

Fig. 4. Diagram of various nodus types for a horizontal dial. (a) V-cut, (b) 'W' form, (c) cross-cylinder, (d) through-hole.

Fig. 4(e) Photograph shows the form actually implemented.

Making the Dial

By the time the dial design was finalised, it had grown from its initial diameter of 24" to be 27" (686 mm). The dial plate was to be 5/16" (8.3 mm) thick and the gnomon was a substantial 5/8" (16 mm). Although originally specified as brass, this had now been changed to phosphor-bronze (PB102). The old adage of "you will appreciate the quality long after you've forgotten the cost" was used to justify this Rolls-Royce material. Certainly, although 17th and 18th century English dials were made of alloys which were essentially brasses, many of them contain a low percentage of tin which is thought to have accounted for their surviving several centuries of weathering, at least at locations which avoided the worst of the acid rain during the Industrial Revolution.[11] As well as cost, the other implication of the change from brass to bronze was one of availability. Brass is readily available in high-quality cold-rolled sheets but for bronze the larger sizes are produced by hot-rolling, resulting in an inferior surface finish. This was to lead to added difficulties during manufacture.

Normally, I do all my own photo-etching but the size of this dial put it beyond the capacity of my facilities. With the kind assistance of Tony Moss, this work was contracted out to the same company in the Newcastle area (several hundred miles from my home) that had produced the Henry Wynne replica. This meant that the photomasks, which for in-house (literally!) use I can produce as black-on-clear plots using an inkjet printer, had to be commercially produced as large clear-on-black plots. It took some time to find a company who could do this to the required quality, working from my TurboCad files of the design. The file sizes, after converting to the appropriate printer-driver, ran to several Gigabytes and each print took several hours.

The next difficulty to overcome was that the slab of bronze for the gnomon was discovered to be bowed, being several millimetres out over its length. In-house attempts to flatten it using a 3--ton hydraulic jack only succeeded in lifting the roof of my garage – phosphor bronze has a lot of spring! Luckily, Tony's engineering connections had much larger presses and were able to reduce the bow to a fraction of a mm, though it still took much work with a belt sander (thanks, Tony!) to achieve an acceptable surface finish.

The gnomon required both etching (on two sides) for the oakleaf-and-spider pattern and also waterjet cutting of the piercing and outline shape. There was much discussion over the best order for these procedures. If the etching and filling of the lines was done first, the waterjet cutting would have to be aligned to these patterns and there was a chance of surface damage to them from side-spray. But if the cutting was done first, the intricate cut edges would have been almost impossible to protect from the etching so this method was not feasible. In the event, the company of Aquajet did a fine job of aligning the heavy slab of engraved bronze in their machine and very little remedial work to the fill of the etched lines was required. Once again, conversion of the CAD design into suitable form to drive the waterjet machine produced very large file sizes (spiders are not a normal engineering requirement) and an overnight run. The machine had to be run very slowly to keep the sharp angles

intact and the cuts perpendicular through the thickness of the bronze.

Fig. 5. Milling style edge on the waterjet-cut gnomon.

The two large pieces of bronze were then shipped back to my workshop for cutting and finishing. The quality of the waterjet cutting for the gnomon was such that the interior piercing required very little cleaning up with files and other hand-tools. However, the approximate 1° draw on the cut meant that the outside profile did need machining to square-up the edges and this had been allowed for in sizing the outline. In principle, this was a straightforward milling machine operation but the length of the style edge meant that I had to make two passes on my rather small milling machine (Fig. 5). Tony Moss has described[6] the process of machining the knife-edge of a double horizontal gnomon and this was more-or-less the procedure which I followed, though it stretched my milling machine to the limit (see Fig. 6).

Fig. 6. Milling top of the knife edge where it intersects the polar gnomon. Note the stay supporting the gnomon tail.

The circular dial plate was roughly cut from the square sheet by bandsaw and then mounted on a rotary table on the milling maching (Fig. 7). A low-voltage motor rotated it slowly like a merry-go-round while the edges were gradually machined to the finished profile.

With the nocturnal and alidades having been completed in-house months earlier, all that now remained was to mate the gnomon to the dial plate. This was achieved with a combination of dowel pins for alignment and stability and M6 stainless steel allen bolts for the fixings. As this was a private dial destined for relatively benign conditions, extreme precautions against vandalism were not deemed necessary. Flush-fitting brass fixings were supplied to attach the dial to the pedestal so that, as on many old dials, the only visible signs after weathering will be three pairs of tiny holes.

After some rapid photographs of the completed

Fig. 7. Machining the edge of the dial plate, mounted on a motor-driven rotary table.

dial in the rather weak February sunshine (not quite Californian) shown in Figs. 8 and 9, it was packed up into two purpose-made wooden crates for shipping across the Atlantic. A square package with the dial plate weighed 30.5 kg (77 lbs) which made the delivery driver groan rather but the other package with the gnomon and the accessories was 'only' 9.5 kg (21 lbs) – the piercing had left a good fraction of the original bronze slab in my scrap bin. There was a mild panic three days later when the carrier's truck delivered a single package to Redwood Valley but, to much relief, the other one turned up the following day. The dial is currently on a temporary pedestal awaiting its final purpose-designed one.

I think we met our original design brief fairly well with all the 'essential' requirements met and many of the possible extras included. The only significant omission was the moondial and these are never terribly practical anyway. I hope Henry Wynne would approve of our updating of his design.

Acknowledgements

It is a pleasure to thank Dr Rudy Light both for commissioning the dial and his substantial input to the design; Tony Moss for much advice and practical help with the machining (not to mention divulging commercial secrets); Michael Lowne for astronomical input, and Karen Soberanis for her artistic drawings.

Fig. 8. The completed dial before shipping. Note the nocturnal to the south of the gnomon.

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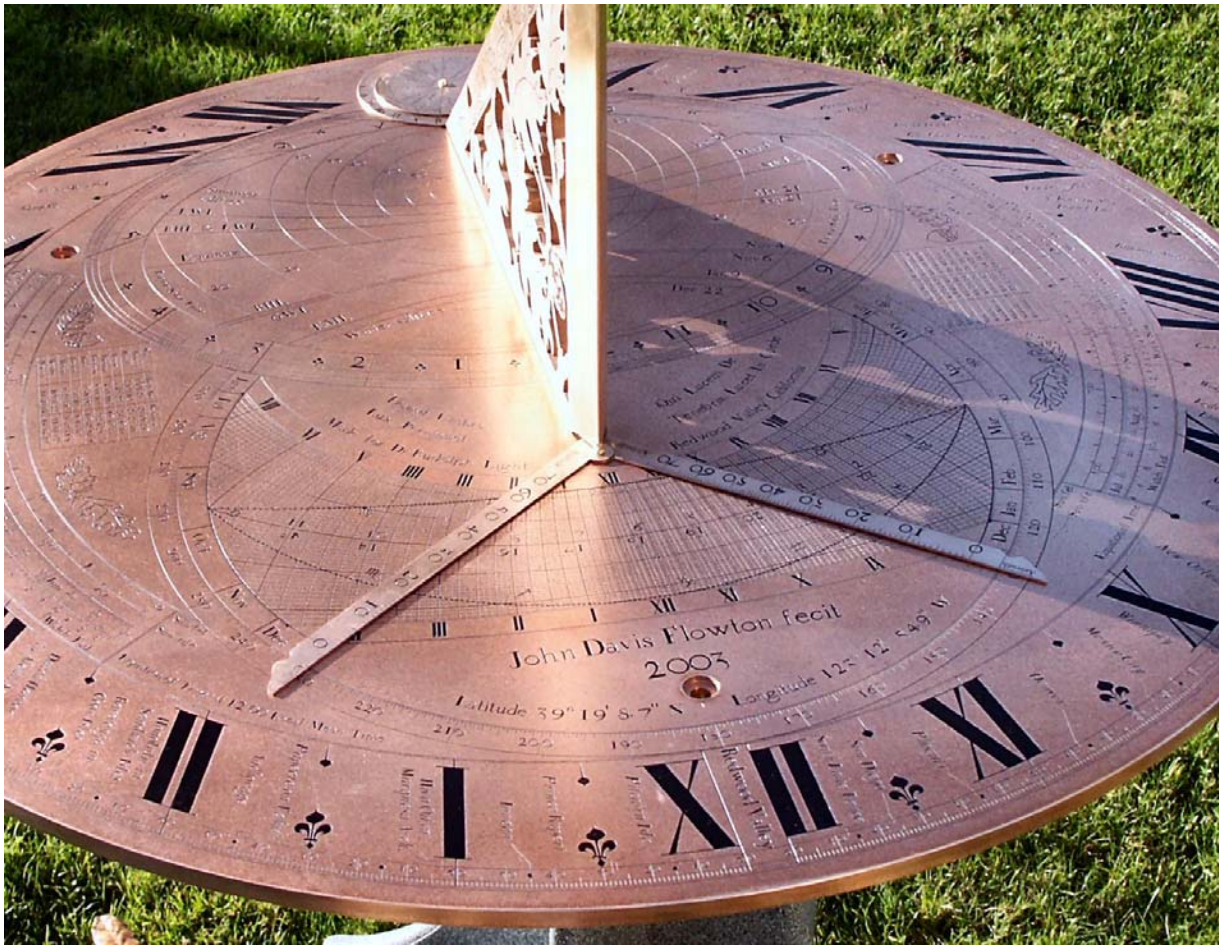

Fig. 9. The dial from the north, with the two alidades pivoted underneath the knife-edge.