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The Astronomical Skeleton Clock

Creating a Dream

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In January 2010, the readers of the *HJ* were introduced to the 'Astronomical Skeleton Clock', perhaps one of the most ambitious horological construction projects ever undertaken. The covers of the issue showed **Figures 1 and 2**: respectively, the project mock-up made of wood and the rear view, showing what had, by then, been completed in metal. At that time, the task had been underway for just under three years, and what was completed had already become an impressive endeavor. After an additional nine years of construction, the clock is now complete — produced by the firm Buchanan of Chelmsford, to my own design specifications.¹

Born of a happy convergence of artist and artisan, exuberant creativity and exquisite craftsmanship, this clock is a work of art in which mechanics, visual fantasy and fun converge.

The Philosophy Behind the Design

I wanted to create, for lack of a better term, my 'dream clock'. It had to incorporate four main principles: scale, complexity, motion and, of course, beauty. The combination is employed to maximise visual impact. This is reflected in the design of the remontoire and strike flies. The use of 90° triple-set bevel wheels for maintaining power systems in place of a flat sun-and-planet arrangement, the dual remontoire and counter-rotating escapement systems, Janvier slant-wheel variable differentials and the strike train's operation are altered from convention to make maximum use of their special fly governors. In the orrery there are operating moons for Jupiter and Saturn and eccentric orbits for all planets that require them. All celestial bodies are made from semi-precious stones and pearls and allegorical animals, mostly birds, are used. Even the rate at which the compound pendulums oscillate was carefully chosen to give a hypnotic effect: a longer period of two-second, rather than the standard one-second, beat (each pendulum takes four seconds to complete a full period).

What I wanted to represent in the astronomical parts of the clock was a depiction of the world around us at various scales, and the ability to demonstrate how the things we see with our own eyes look, both from near and farther into space. When the celestial train is demonstrated, one will see the interaction of the sky as it would be if one were standing on the ground, with the stars and sun moving across it in the planisphere, this includes the Sun and Moon rising and setting in their separate dials as well as the change in the length of the day and night as the seasons change throughout the year. One can also see when all these things happen contemporaneously as well as in the past and future, as governed by the third-order, reversible, 400-year perpetual calendar. Moving a bit into space, it is also possible to see the inner planets and the Earth and Moon

system around the Sun through the tellurion. One can also see how this system affects the way we observe the stars and Sun in the planisphere, and the Sun and Moon's rising and setting dials. Finally, at a further magnitude of distance, we see the entire solar system (at least as it was known to Philippe Mathäus Hahn in the late eighteenth century, upon which data this orrery is based). This looks back into the tellurion, planisphere and finally the Sun-Moon dials. At this scale, we see how small our place is in His creation!

The base frame is robust, consisting of straight lines and angles representing the foundation of the piece, and is the only area where one will see a straight-lined assembly. Built upon it is a series of modular frames made to look like trees complete with branches that bear red fruit (red chatons). Between the trees is a dense forest composed of curvilinear sub-frames, wheels, levers, cams and nearly every mechanical contrivance demonstrated in horology... and what is a forest without animals? Birds inhabit the escapement, strike detents and hammer-pulls. Strike snails look like a slice of a nautilus shell and above this forest is the firmament as represented by the orrery with the Sun, planets and representation of the Zodiac. A small world is alive within.

All of the wheelwork between the three main train frames is made of pink bronze to contrast with the brass surrounding frames. Scattered throughout are over 800 red spots; about half are synthetic ruby jewel bearings, many of which are held in chatons. The rest are hybrid ceramic ball bearings (ceramic balls in steel races) which are covered with a red plastic dome to match those held in chatons. All detents are jewelled. Every screw is polished and blued to a bright electric blue colour, resulting in several thousand more blue dots. All of the bright steel parts are made from stainless steel, with the arbors that turn in jewel bearings having tool steel pivots. Semi-precious stones and pearls are used for planets and moons in the orrery and tellurion and additional colour comes from the use of custom-made enamel dial work. The overall finish approaches watch work and is the best one will find in a clock. Total wheel count exceeds 500 and 8000 parts overall. Given the complexity of this machine, we tried to make it as reliable as possible.

With a few exceptions, this clock will run oil-free. Oil is the number one cause of failure in clocks from drying out, spreading or attracting contaminants turning it into a grinding paste. It was Abraham-Louis Breguet who said, 'Give me the perfect oil and I will give you the perfect watch.' Of course, not using oil obviates this problem. To avoid oil, we use Harrison's grasshopper escapement, specially designed anti-friction wheels for the pendulum supports, dry jewelled bearings with arbors that are lightly loaded and turn once an

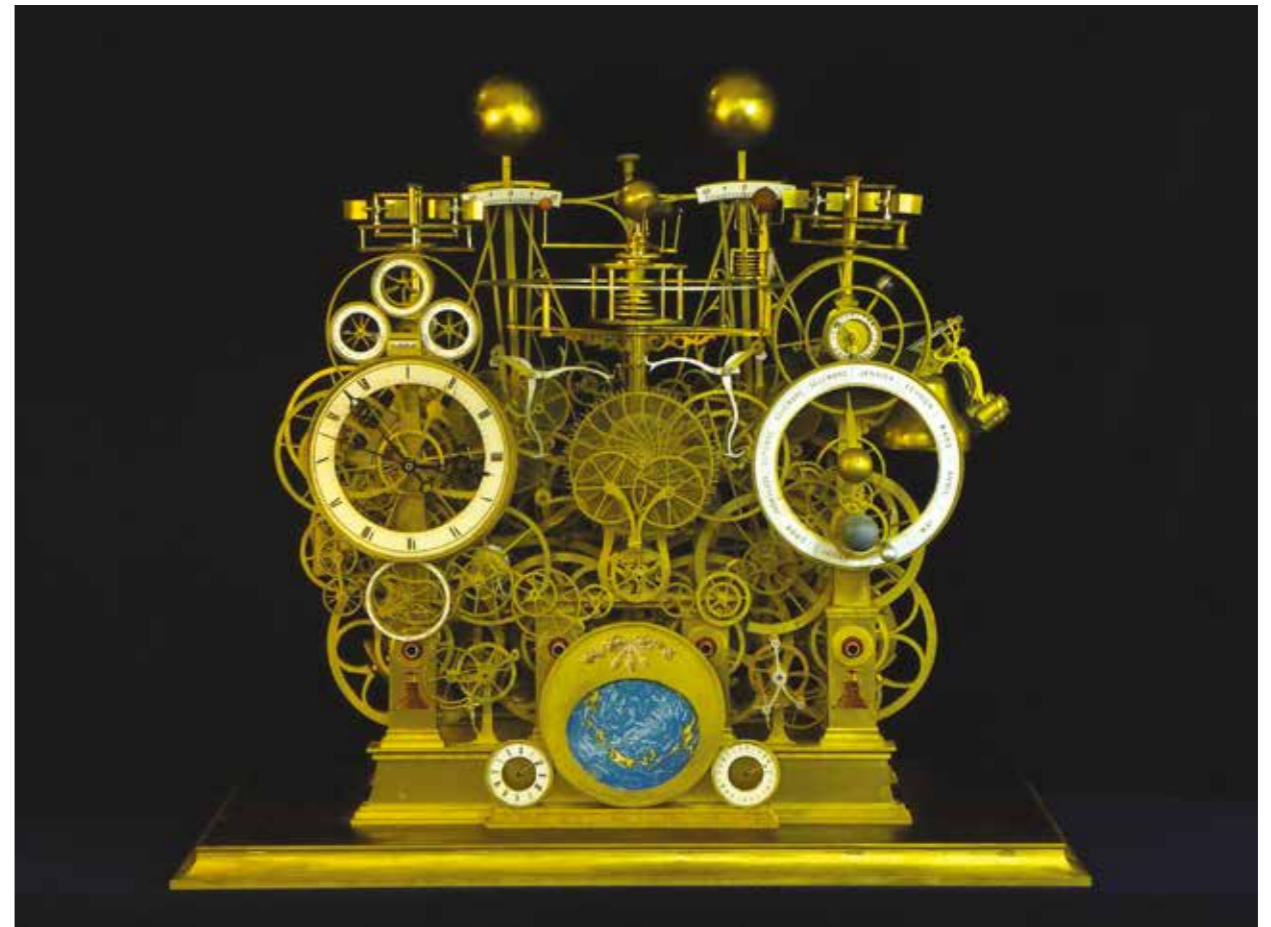


Figure 1. Project mock-up made of wood, 2009.

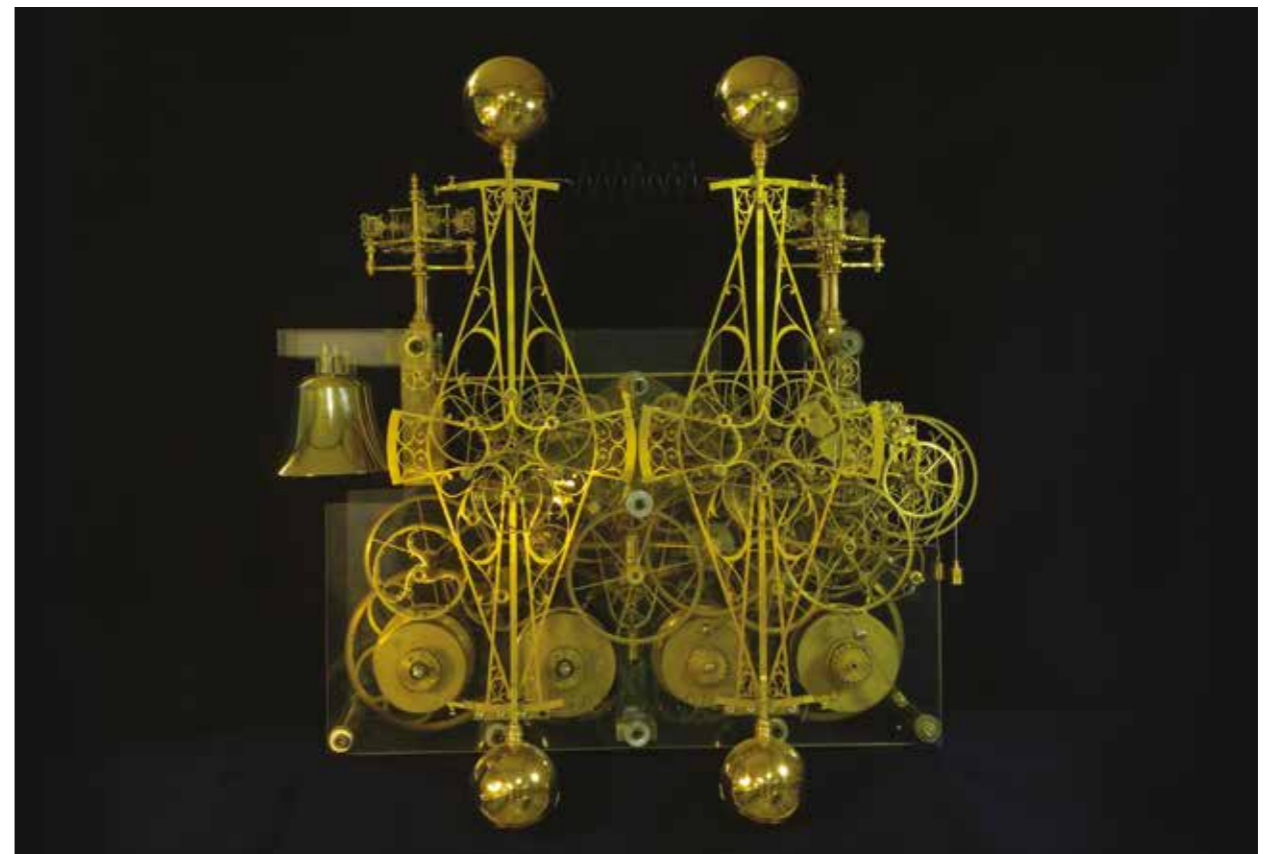


Figure 2. Rear view of metal components as completed by 2009.

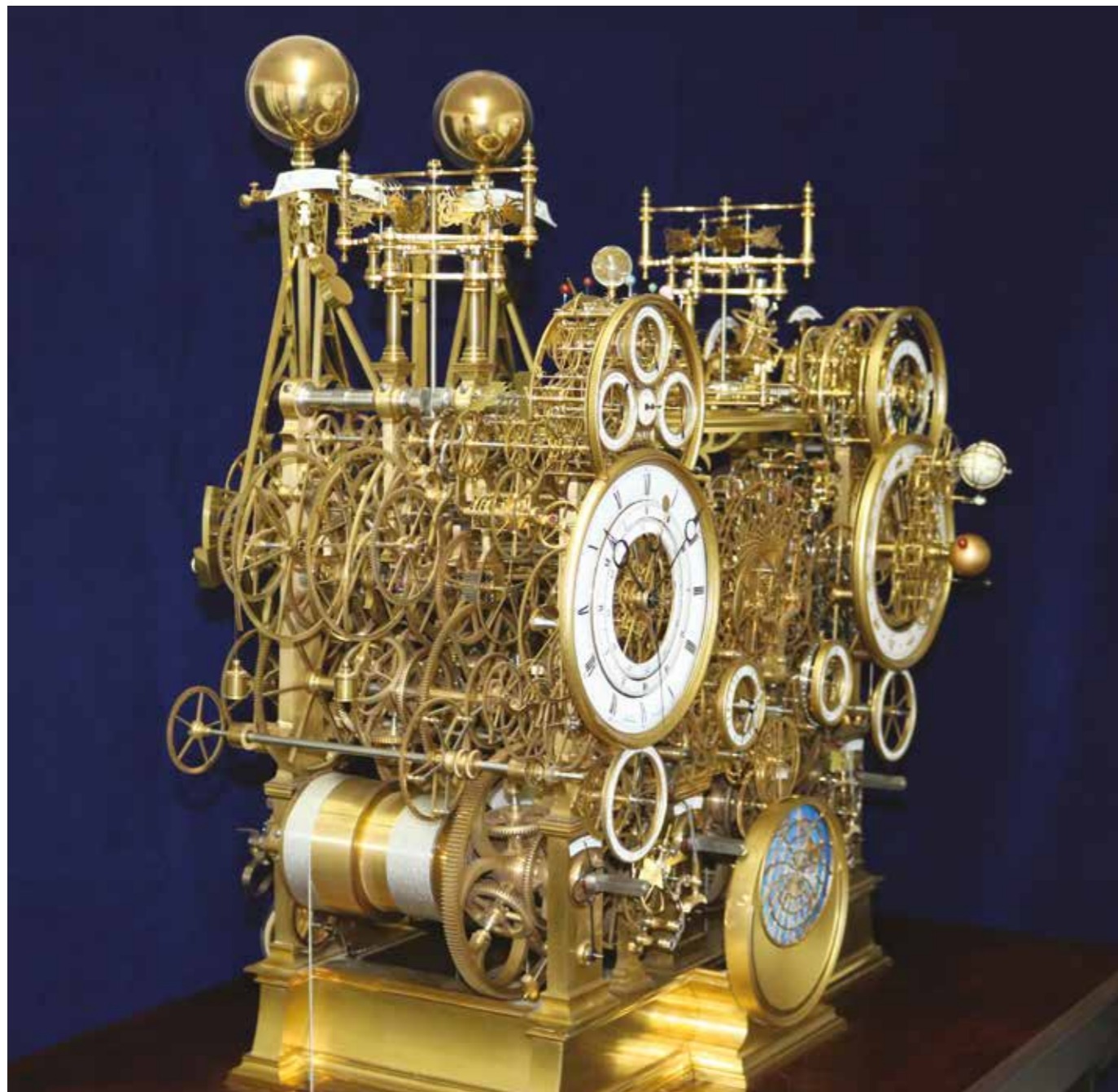


Figure 5. Left three-quarter, astronomical skeleton clock.

hour or less, with the remaining running in hybrid ceramic bearings — all these components will function without the need for oil. The entire machine is modular. All of the dial complications can be removed without the need of tools, like a quick-release bicycle wheel. Furthermore, the four trains — time, celestial, quarter and hour — are contained within three modules designed between curvilinear-form pillars mounted upon the flat-bed base. While I will not pretend removing these modules from the base is simple, it is still far easier than one would expect if the clock were designed with conventional frames.

There are 71 complications read off the main dial work as well as several smaller subsidiary dials located within the body of the machine. (See the end of this article for a list.) From the front, it looks like there are not enough dials to convey that much information. This is intentional. I wanted to reduce the

dial work to a minimum so as to bring the mechanics to the fore. Other makers try to maximise the number of dials to show off the number of complications, but in my view, the results look like the analogue cockpit of an earlier-generation airliner.

Figure 3 (See Front Cover) is the front elevation of the clock. Notice that the clock frame is a near perfect square. Mirrored symmetry and a narrow base give it a slimmer, less bulky look than a machine of this complexity might otherwise have. This is reinforced by the main dial layout forming a V-shape and is the result of careful planning and component placement. The escapement is in the centre, within the central celestial train, and driven remotely from the going train on the left. (For the purposes of this article, I will henceforth use the expression ‘time train’ rather than going train, because it does so much more than simply ‘go’.) Notice how closely



Figure 6. Right three-quarter, astronomical skeleton clock.

the original mockup was followed, **Figure 1**, first completed by Buchanan in March 2009 despite the fact that many changes and challenges were encountered along the way. It must be noted that at that time there were few overall design drawings and none were even sketched out, let alone detailed for any of the dial complications, for the vast majority of the mechanism. As hard as it may be to believe, this machine was designed and built as we went along.

The enamel dial work provides the main readout of the complications and consists of the upper left cluster, the 400-year perpetual and reversible calendar. Below that are the mean solar, sidereal and equation of time. Further below is the equation setting dial. The upper right depicts the information for the Sun and Moon, with 18 complications that can be read off this one dial. Below that is the tellurion with inner planets, Sun/Moon horizon and solar and lunar eclipse times and

location predictions. Underneath that is the strike-setting dial indicator for *grande* and *petite sonnerie*, with silence and quarter pull repeat near the four o’clock position of the tellurion dial. The orrery crowns the movement at the upper centre. There are two small dials in the lower central space: on the left is a world time dial and two-speed demonstration drive and on the right is a thermometer. At bottom centre is the planisphere with the Sun roving through the Zodiac. There are a dozen other small silvered setting dials scattered throughout the interior of the machine. **Figure 4 (See Rear Cover)** reveals the rear elevation with the compound pendulums.

Figure 5 shows the area where the time train resides: the two large wheels that extend from the frame are the dual Wagner gravity remontoires, one of three types of remontoire in this clock. Each of the two fly governor towers controls one of the pair of 30-second cycle Wagner remontoires, which

alternately let off every 15 seconds. Like the escapement, the tower on the right positioned above the strike train is driven remotely from the time train on the left — another nod to symmetry. So it is that along with the pendulums and escapement, which is positioned front and centre, something is always moving to entertain the viewer.

Figure 6 is the opposite side dominated by the strike train module which contains both the quarter and hour strike functions. The celestial train, controlled by a Robin remontoire, is located in the centre behind the escape wheels. One of the things I dislike when looking at a skeleton clock from the side, even on a three-train quarter-striker, is that it is a rather sparse view of arbors with not much else between the plates. I think we have managed to avoid that scenario here!

The project began in 2006 and represents 12 years of fabrication work spread out between then and 2020. As has been mentioned, it was created by the firm Buchanan of Chelmsford. The overall dimensions are 28 inches wide, 28 inches high and 18 inches in depth (71 cm × 71 cm × 46 cm).

Detail of Major Components

Figure 7 shows the orrery with its complement of planets made of semi-precious stones. The rutilated quartz Sun shimmers and acts as a lens to view the moving pendulums from behind. Jupiter and Saturn have four and five orbiting moons respectively, all made from pearls. Mercury, Mars, Jupiter and Saturn display their eccentric orbits correctly, with subsidiary dials showing the aphelion and perihelion in both astronomical units (AU) and millions of kilometers (Mkm), with Jupiter and Saturn also having their tilts represented with respect to the ecliptic. A challenging complication is represented in **Figure 8**: the motion of the Sun and Moon, with the latter being devilishly difficult to display correctly on a two-dimensional dial due to the number of anomalies in its orbit. Few clocks have attempted this in the past and even fewer have used Antide Janvier's slant-wheel variable differentials, as seen in this photo. Movable, seasonal horizon shutters show time of sunrise and sunset, length of day, night, and the Moon's age, phase and hours since and until the Moon's rising and setting. We will explore this module in more detail later.



Figure 7. The orrery, planets out to Saturn.



Figure 8. Front side of the Sun/Moon complication.

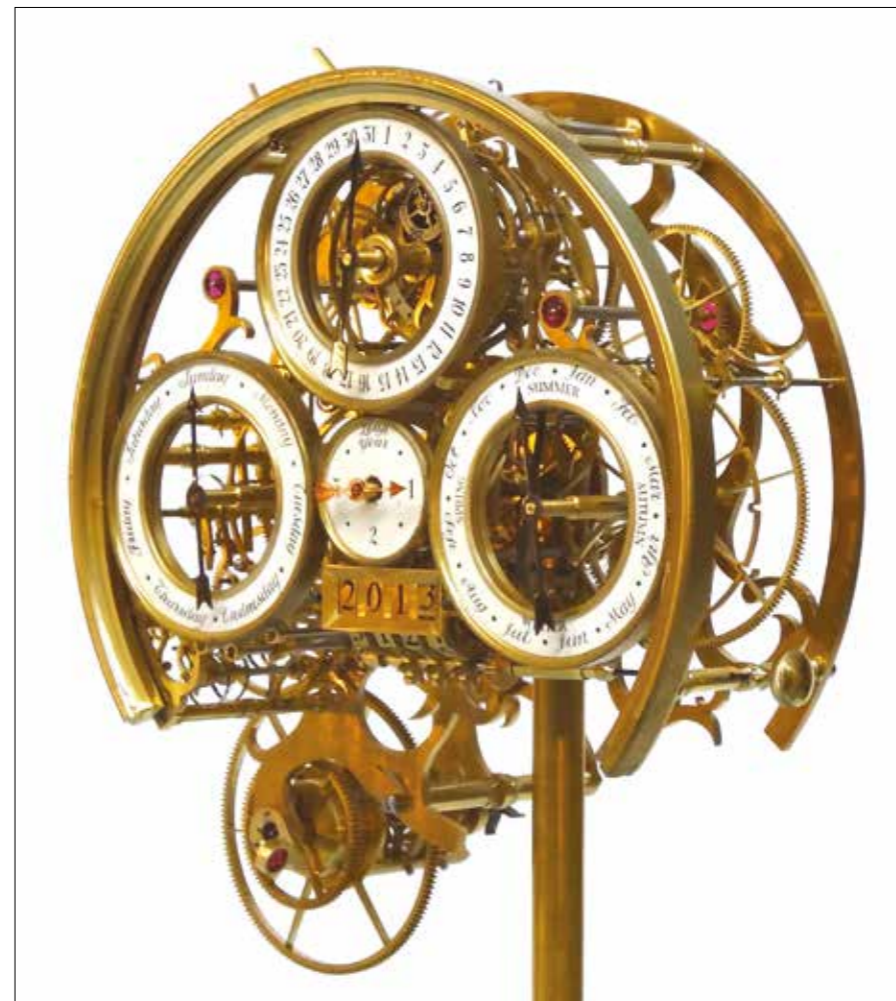


Figure 9. 400-year reversible perpetual calendar.



Figure 10. Tellurion.

The third-order, 400-year, reversible perpetual calendar in **Figure 9** proved to be the most difficult to design and build, though with 550 parts, it is still behind the counts of the Sun and Moon module (665) and the orrery (900). However, the calendar's design was unlike any conventional horological wheelwork. It functions as a small analogue computer; there are few conventional wheels when compared to the number of levers, cranks, cams and springs. The punishment dealt out by the calendar made the tellurion easier at 400 parts, **Figure 10**. It is, however, capable of predicting a solar or lunar eclipse path across the surface of the globe in the past or future, the Sun's and Moon's horizons on Earth, the sidereal and synodic months and the lunar nodes.

The mechanism for and the completed planisphere is seen in **Figures 11 and 12**. The wheelwork looks a bit like a great wheel skeleton clock, with the large wheel coming in at just under 5 inches (12 cm) across and with 516 teeth. The dial mask, including the longitude and latitude grid is made from one piece and like the rest of the enamel dials, its bezel is gold plated.

The Latin phrase was part of an epic poem, *Metamorphosis*, which was written by Publius Ovidius Naso (commonly referred to as Ovid) in AD 8. It translates as: 'To man God gave an upwards gaze, bidding him to behold the sky, and raise his erect countenance towards the stars.' In the poem's context, it refers to the moment when God separated humanity from the animals by giving it the ability to stand erect and gaze toward the heavens, presumably to unite it with the divine and in contrast with the downward earthly gaze of animals. Obviously Ovid was not familiar with primates! However, given when he lived and that he was from Greece, that's understandable.

Figures 13 and 14 show the planisphere and tellurion dials. They were custom made in China by the firm ProClocks.² At the beginning of this project I considered engraved dial work, but I have always appreciated the fine enamel work represented in French clocks. Most scratch-built clocks do not use enamel dials because this skill must be outsourced, as most clockmakers cannot do this type of speciality work. However, it is a tribute to Buchanan that it was able to produce all the artwork — numbers, lettering,



Figure 11. Planisphere mechanism.



Figure 12. Planisphere module.

script, figures and colour – for the enamellers to reproduce. The planisphere dial is large enough at 6.25 inches (16 cm), to allow for intricate detailing. The haze of the Milky Way is not a coloured background, but is composed of thousands of small, medium and larger dots. The constellation names are all done in a calligraphic font with the background colour a brighter blue in the centre and deepening to a dark blue on the perimeter. This reproduces exactly what I had asked Buchanan to design, and what ProClocks carried out. The dial required great skill and many firings in the kiln for each color. The seven-inch (18 cm) tellurion dial has complex figures and colouring, and is based upon Antide Janvier's tellurion dial from his masterpiece clock, which also featured his invention of the slant wheel variable differential used in the Sun/Moon complication. The orrery dial carries through this same polychrome design, and is 13 inches (33 cm) in diameter.

The remaining front dials represent the mean solar, sidereal and equation of time, thermometer, world time, strike selector and equation setting dials. These modules were simpler than those illustrated and are left to the reader to explore further on my website and four online papers, which cover the project in greater detail.³⁺⁴

Figures 15 and 16A–C show in greater detail the left and right sectors of the clock's main dial work illustrating the symmetry of design. On the left side, Figure 15, and starting from the top is the calendar, in the middle, the mean solar, sidereal, and equation of time and below the equation calendar setting dial, the small subsidiary dial to the right is the world time and demonstration dial. On the right, Figure 16A, are the Sun and moon module, below this the tellurion and below that the strike selector; to the left is the thermometer calibrated in Fahrenheit and Celsius.

Figure 17 shows a top three-quarter elevation of the machine, revealing the extreme complexity. In the words of the clockmaker from Buchanan: 'If a spaghetti factory made wheels it would look like this.'

A Closer Look at the Sun and Moon Complication Module Using Antide Janvier's Variable Differentials

This module uses a special and rarely seen mechanical device in horology: a set of variable differentials first designed by Antide Janvier in 1791. They are used to 'correct' the Moon's anomalous orbit so the complex three-dimensional movement can be displayed with accuracy on a two-dimensional dial. Representing the motion of the Moon as it appears in the sky in a mechanical fashion upon a two dimensional dial is very difficult. The combined gravitational influence of the Sun and Earth cause many perturbations. Together these are known as anomalies and over time they make the accumulated orbital positions of the Moon look more like a toroid than a circle or ellipse (see Figures 18–21). In practice there are five major anomalies associated with the Moon's orbital movement and two associated with the Earth's tilt and orbit. In theory there are dozens, but the main seven will account for over 98% of these. The seven anomalies are arranged in their order of the greatest to least error in the number of minutes and degrees from an idealised orbit. These corrections will give the time the moon leads or lags from the mean or average position of the moon in its orbit.

1. **Great Anomaly:** This is the effect of the Moon's elliptical orbit around the Earth and has a $\pm 6.58^\circ$ (26.322 minutes) effect every anomalistic month which



Figure 13. Planisphere dial, 6.25 inches (16 cm).



Figure 14. Tellurion dial, 7 inches (18 cm).



Figure 15. Left side, calendar, mean, sidereal, equation time.



Figure 16A. Right side, Sun and Moon module, tellurion, strike selector, thermometer.



Figure 16B. International time dial and demonstration drive.

Figure 16C. Thermometer dial.



Figure 17. Top three-quarter view of the machine.

is defined as the time between the Moon's successive perigees and is approximately 27.55 days.

2. **Projection:** Two factors are needed to account for the Earth's 23.5° tilt from the ecliptic as well as its elliptical orbit around the Sun. These factors are the same as those needed to compute the equation of time. The projection is $\pm 2.464^\circ$ which translates to about ± 9.857 minutes in time. It has a period of one half of the tropical month or 13.661 days.

3. **Evection:** This is the change in the Moon's ecliptic longitude: This is caused by the gravitational pull of the Sun and Earth, which causes the Moon to accelerate as it moves toward and decelerate as it moves away from the Sun. The period is 31.81 days. This is $\pm 1.274^\circ$, equalling 5.097 minutes.
4. **Variation:** The combined effect of the Sun and Earth on the Moon's orbit at lunar conjunction (when the Earth, Moon and Sun, in that order, are in alignment)



Figure 18. Moon's accrued orbital anomaly, one year.

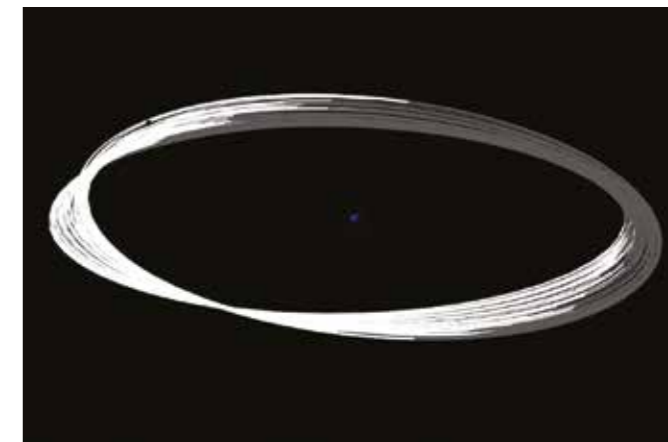


Figure 19. Moon's accrued orbital anomaly, five years.



Figure 20. Moon's accrued orbital anomaly, ten years.

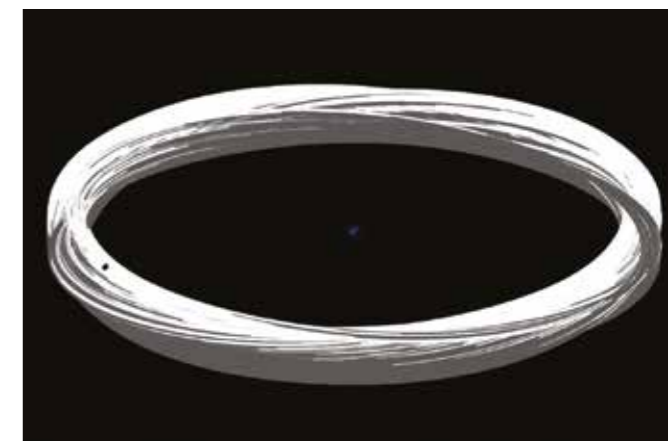


Figure 21. Moon's accrued orbital anomaly, 60 years.

and at lunar opposition (when the Moon, Earth and Sun, in that order, are in alignment). The Variation is $\pm 0.658^\circ$ equalling 2.632 minutes and has a period of half a synodic month, or 14.77 days. This is commonly known as a lunar month, which is 29.531 days.

5. **Reduction:** This is $\pm 0.214^\circ$ equalling 0.8569 minutes and has a period of one half of the anomalistic month or 13.77 days and is due to the tilt of the Moon's orbit of 5.8° to the ecliptic.
6. **Annual Equation:** This is $\pm 0.186^\circ$ equalling 0.856 minutes and has the period of one anomalistic year or 330.60 days. It is the combined influence of the Sun and Earth on the Moon owing to the Earth's elliptical orbit.
7. **Solar Equation:** This encompasses two more very minor anomalies associated with the Sun.

We have chosen the two orbital corrections that involve the greatest time corrections in minutes: the Great Anomaly at 26.322 minutes, and the Projection (which has two components) at 9.857 minutes. All of the seven orbital anomalies require correction of just under 46 minutes; our two main corrections will account for 36.179 minutes or 79.3% of the Moon's complex orbit. The combined total of all anomalies comes to ± 45.621 minutes from a simple rolling moon dial.

Figures 18–21 illustrate the Moon's orbit around the Earth for one, five, ten and 60 years respectively. The last

caption shows a rather thick torus, around the Earth. One can readily see why it is so difficult to describe the Moon's orbit and, therefore, the rise and set times of the Moon on a two-dimensional dial, accurately.

What has been discussed so far, however, concerns the movement of the Moon only; an astronomical discussion. We still need an additional correction which is far greater in magnitude than those astronomical anomalies to get a respectable representation of the Moon's orbital movement on a dial to agree with what we observe in reality. These are terrestrial corrections that account for the Earth's tilt to the ecliptic as well as its elliptical orbit around the Sun. The cam work needed is latitude-dependent, unlike the equation of time cam as represented by the Projection differential, which is not.⁵ Both draw upon the same characteristics of the Earth's tilt and orbit, but the equation mechanism relates to the position of the Sun when at its zenith as it relates to an observer on Earth compared to the local time at noon on a clock; the horizon cams relate to when the Sun, or in this case the Moon, appears above or disappears below the Earth's horizon in concert to the seasonal variations. Therefore, there is the need to calibrate the cams for latitude. The total difference in time is six hours and 12 minutes from the shortest to the longest day. Using the prior two Moon anomalies as well as the horizon cam work we have a total of four corrections which will allow for one to see on the dial the position of the Moon or Sun correspond to what one sees in the sky at the latitude of Chicago, Illinois at 41.88 degrees North where

the clock will first reside. Using the horizon shutters in concert with the glass dial that contains the Moon and is controlled by the variable differentials we can calculate not only the time of the Moon's rise and setting, but also the number of hours before, as well as after, for the rise and set.

Figure 22 depicts in graphical form the five anomalies of the Moon's orbit as outlined above. When curved into a circle, these can be directly translated to the creation of the topological surface of each cylindrical cam needed to depict these movements mechanically. When one tries to research the characteristics of these anomalies on the internet or other modern sources, there is little information as to how these orbital fluctuations are translated into a mechanical form; only the technical characteristic, as explained in astronomical terms. We have chosen the two largest terms and, when compared with the remaining three, these are by far the most consequential anomalies.

In horology there are four main ways to produce a variable output from a constant input speed, which is often needed to produce astronomical complications (the equation of time, for example) on a dial. These are through cams, pin and slot wheel variations, non-circular, irregularly shaped or off-set axis wheels and variable differentials. Cams have been known since antiquity and their first use is unknown. Pin and slot wheels are found in the Antikythera mechanism's Moon train, estimated to be from about 87 BC.⁶ Irregularly shaped wheels from a simple oval used in the St. Albans tower clock, circa 1356, to beautifully intricate shapes used in Giovanni de Dondi's astrarium, circa 1365 and 1381.⁷⁺⁸

The variable differential used in this example was invented by Antide Janvier in 1791 for his Chef-d'Oeuvre (Masterpiece) clock made between 1789 and 1801 to represent the equation of time. It is, in my opinion, one of the most beautiful, yet at the same time, mind-bending mechanical contrivances seen in horology.⁹

Figure 23 is an illustration of the projection variable differential. It takes a while to understand just how this works, given that there is a wheel that looks, to all intents and purposes, to be unable to function. After some study, however, one comes to the 'aha!' moment. The wheel is inclined 23.5°, the same as the Earth's tilt to the ecliptic plane. Janvier

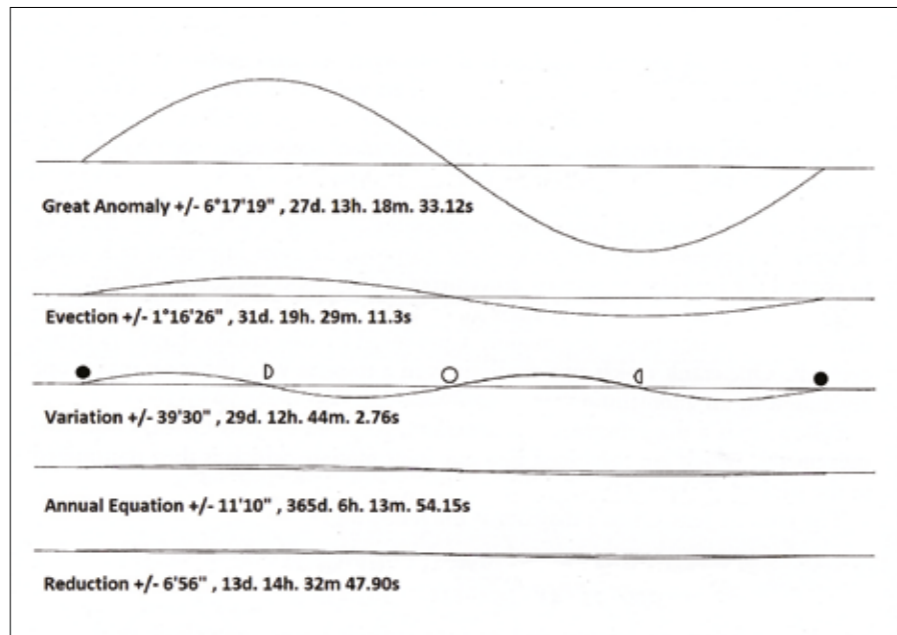


Figure 22. The five main anomalies represented as sine waves.

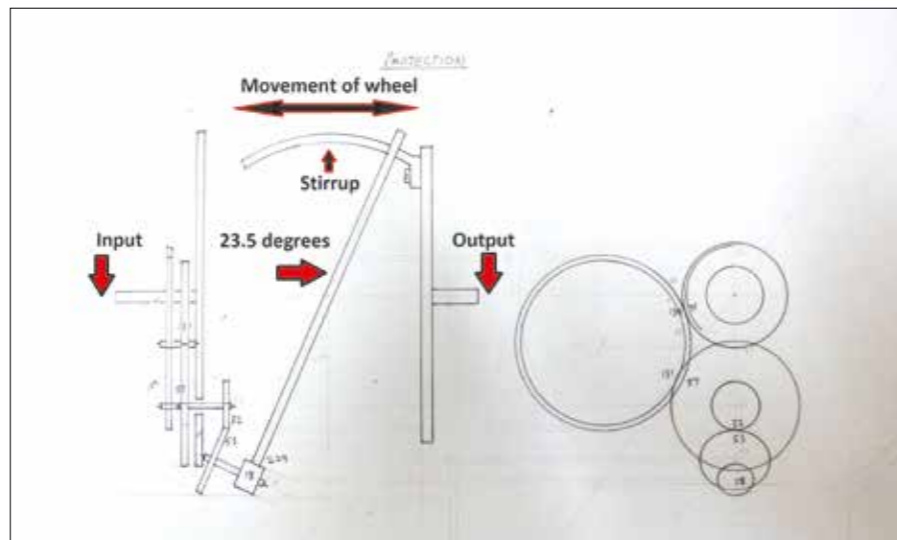


Figure 23. Scale drawing for the Projection differential.

described his device as 'Equation du Temps par les Causes qui la Produisent', ('Equation of time by the causes that produce it'). What better way to describe the slant wheel's mimicking of the Earth's actual tilt? The mechanism faithfully reproduces, as in nature, the discrepancy between solar time and mean solar time, resulting from the inclination of the Earth to the ecliptic and turning in mean time, transmitting its motion to a wheel inclined at in the same plane as the Earth's equator, namely 23.5°. The different angular speed of these wheels occur as the wheel moves along the curve of the stirrup and results in their coincidence 180° apart twice annually. Between these extremes, the angular speed of the second wheel (output-solar time) varies either ahead or behind the driving wheel (input-mean solar time), just as in nature, actual solar time is ahead or behind mean solar time throughout the year. The variable speed of the differential output is what sets this type of differential apart from conventional single-speed examples.

Figure 24 shows the schematic of the Sun/Moon rise-set complication. Our Moon rise-and-set dial is fairly small at just over 3 1/2 inches or 10cm in diameter, so any further corrections would be barely noticeable at this scale. Even 36 minutes for the two Moon anomalies will be hard to discern. This is really more of an exercise to incorporate a classic complication with a set of interesting mechanics rather than important additional informational accuracy in the dial. The complexity of this

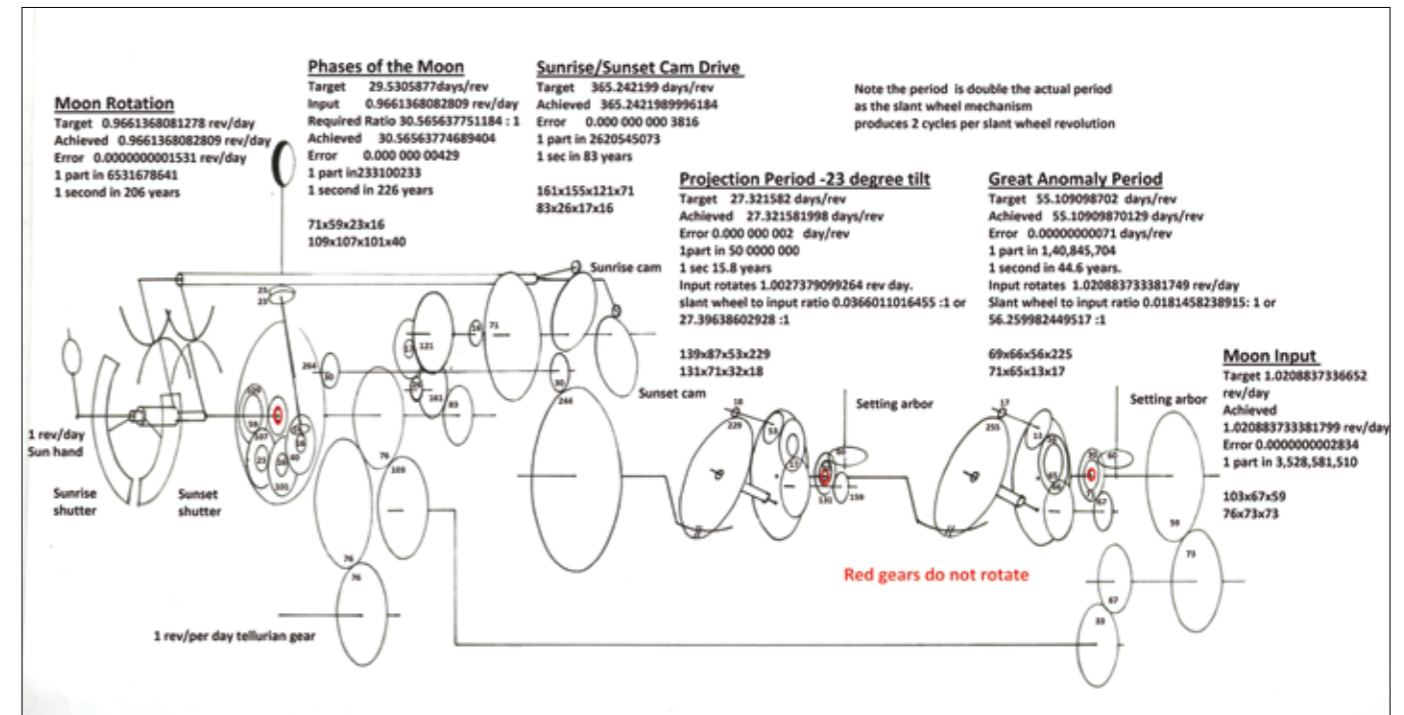


Figure 24. Schematic of the Sun/Moon rise-set complication.

Sun and Moon rise-and-set dial indications:

1. Time of sunrise
2. Time of sunset
3. Visual position of the Sun in the sky
4. Length of day
5. Length of night
6. Visual position of the Moon in the sky
7. Visual indication of the phase of the moon
8. Age of the Moon
9. Angle hour of the Moon (height in the sky) in degrees
10. Degrees to moonrise
11. Degrees to moonset
12. Hours until moonrise (we have a double hour scale on the rotating degree scale, but stretched slightly compared with a real hour dial. The Moon rotates in the dial in 24 hours and 55 minutes.) Zero hours is at the Moon and the hours count away from this point, so the hour to the east of the horizon marker gives you the hours until moonrise.
13. Hours since moonrise
14. Hours until moonset
15. Hours since moonset



Within the complication, not on the front dial:

16. Age of the Great Anomaly
17. Age of the Tropical month
18. Horizon setting; annual calendar reads in real time
19. Age of the Great Anomaly
20. Age of the Tropical month
21. Horizon setting; annual calendar reads in real time.

Figure 25. Dial layout.



Figure 26. 54 wheel blanks, pinions plus miscellaneous parts.



Figure 27. Setting jewel pivots in the jig borer with the microscope.



Figure 32. The Projection differential (left) and Great Anomaly differential (right), slaved together to produce a combined output.



Figure 28. The Projection differential 'in the rough'.



Figure 29. The crossing-out process on a scroll saw.



Figure 30. The differential is fully jewelled.



Figure 31. Differential with setting knob, dial and enamel tag.

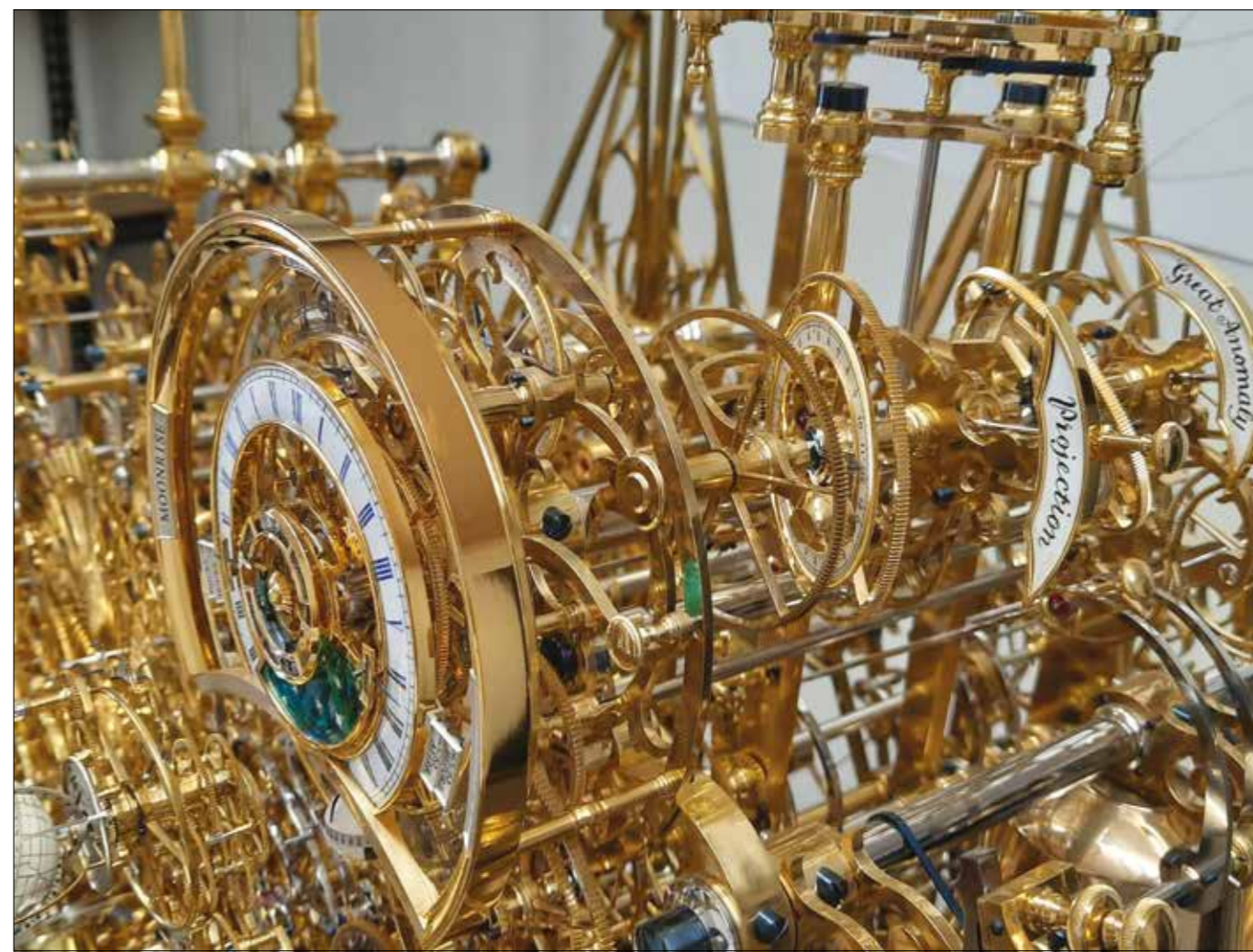


Figure 33. The Sun and Moon rise-and-set module in place within the machine.

module becomes clear in **Figure 24** — note the accuracy achieved for each section.

Figure 25 shows the layout for the Sun and Moon rise-and-set dial. This is a good illustration of one of the design principles behind this project. We are trying to pack as much information, and by analogy, complications, into the lowest number of dials, thus allowing the viewer to see the beauty of the mechanics that create the information. It would be easy, as many past clock-makers have done, to create a dial for each complication in an effort to ‘show off’ the many dials that represent each complication. However, it is my opinion that this creates a cluttered look that distracts from my main objective: the wonder of the machine.

Figure 26 shows the entire complement of 54 wheel blanks for the Sun and Moon complication. **Figure 27** shows the beginnings of the Projection variable differential where some of the jewel pivots are being located and set.

Figure 28 is the Projection differential ‘in the rough’ and **Figure 29** is a picture of the crossing-out of the main slant wheel. This, as well as all of the other wheels (more than 500) in the project, has been done by hand on a scroll saw, making over 3000 crossings. All of these needed to be filed and finished and with an average of 102 teeth per wheel, that makes 51,000 teeth to cut! The completed wheelwork for the Projection differential is shown in **Figure 30**. In addition to

the odd slant wheel, this assembly also has sets of off-set bevel wheels. The entire component with the exception of the slant wheel is jewelled. Approximately half the wheels in the project are set in jewel bearings, with the other in hybrid ceramic ball bearings as described earlier. **Figure 31** shows the differential dressed up with its knurled setting knob, silvered setting dial and enamel name tag set within a gold-plated bezel. The name tag assembly has been machined to provide perfect rotational poising of the differential.

Both variable differentials representing the Projection (left) and Great Anomaly (right) are shown together in this plastic demonstration frame, **Figure 32**. The input is from the right, driving the Great Anomaly differential; this differential’s output becomes the input for the Projection differential. The combined output is the variable rotational speed of the arbor exiting on the left. Several videos are available online to explain more fully how these differentials operate.¹⁰

Figure 33 shows the Sun and Moon rise-and-set module in place within the machine.

Part of the pleasure of making one’s fantasy a reality is sharing it with others who may be interested in seeing the creation as it happens. The project has been posted monthly on my website since its initial conceptual stages back in 2003 and will remain there permanently. If you have any questions or comments you can email me from the site.¹¹

ENDNOTES

1. Buchanan’s website is <https://www.buchananlocks.com>
2. ProClocks, Inc., 4305 Eagle Landing Pkwy. Orange Park, Florida 32065, <http://www.proclocks.com>
3. http://www.my-time-machines.net/astro_index.htm
4. http://www.my-time-machines.net/papers_and_presentations.htm
5. The equation of time cam can be seen here: http://www.my-time-machines.net/astro_11-14.htm
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10. http://www.my-time-machines.net/astro_02-17.htm
11. My website is at www.my-time-machines.net or please email mfrankl@rcn.com



Author Bio

Mark Frank has recently retired from his Chicago residential real estate management and development company. His horological interests are in the research and collecting of timepieces where one can see the mechanical works, in particular skeleton clocks, tower clocks, and bank vault timers. His main interest is in those pieces that exhibit interesting mechanical characteristics as demonstrated through complexity, novelty, or visual appeal. The clock that is the subject of this article is the culmination of many years of research, observations, and examples drawn from his collection and other private collections as well as exhibits from museums throughout Europe and the USA; all combined into a personal fantasy machine. Updates on the project have been posted monthly at www.my-time-machines.net since its initial conception in 2003. Those interested in receiving email notifications when updates are posted or have any other questions or comments may email Mr. Frank at mfrankl@rcn.com.

List of Complications: 71, plus five special mechanical systems

In the lists that follow, asterisked features are unusual mechanical ways of doing what is commonly seen in simpler mechanisms. Bullet points denote indications that appear on the dial, but are common enough to most clocks so as not to be considered a complication, or are duplicative.

Upper left-hand dial cluster

Third-order, 400-year perpetual and reversible calendar
Eight complications

1. Day
2. Date
3. Month
4. Year
5. Leap year indication, four-year exception, first order correction
6. 100-year exception, second order correction
7. 400-year exception, third order correction offering accuracy to 400 years
8. Entire mechanism can operate in forward or reverse giving an 800-year accuracy span

Centre left-hand dial

Main time dial

Two complications

- Mean solar time
1. Equation of time
 2. Sidereal time

Lower left-hand dial

Equation setting dial

Two complications

1. Month
2. Date

Upper right-hand dial cluster

The Sun and Moon

18 complications

Sun section, seven complications:

1. Time of sunrise / sunset
2. Visual position of the sun in the sky
3. Mean solar time
4. Length of day
5. Length of night
6. Variable seasonal horizon shutters
7. Horizon shutter setting dial, annual calendar reads in real time

Moon section, 11 complications:

1. Visual indication of the phase of the Moon
2. Age of the Moon
3. Angle hour of the Moon (height in the sky) in degrees
4. Degrees to moonrise
5. Degrees to moonset
6. Hours until moonrise (we have a double hour scale on the rotating degree scale, but stretched slightly compared to a real hour dial and the Moon rotates in the dial in 24 hours and 55 minutes). Zero hours is at the Moon and the hours count away from it, so the hour on east, the horizon marker, gives you hours until moonrise.
7. Hours since moonrise
8. Hours until moonset
9. Hours since moonset
10. Great anomaly setting dial reads in real time
11. Projection anomaly setting dial reads in real time

Centre right-hand dial

Tellurion Earth’s neighborhood

14 complications

1. Tellurion featuring the Earth, Moon, and Sun systems. The Sun also rotates
2. Additional inner planets of Mercury and Venus
3. Zodiacal house
4. Month

5. Date
6. Synodic month dial
7. Sidereal month dial
8. Adjustable 360° ring allowing user to set any point on earth as zero time, reading the time from any other point
9. Approximation of time and location of solar eclipses
10. Approximation of time and location of lunar eclipses
11. Location of sunrise and set
12. Location of moonrise and set
13. Location of Sun through the Zodiac
14. Moon’s orbital inclination in relation to Earth’s ecliptic

Lower right-hand dial

Strike control

Four complications

1. *Petite sonnerie*
2. *Grande sonnerie*
3. Quarter repeat on demand, *grande sonnerie*
4. Strike and silent

Upper centre

Grand orrery of the Sun’s neighborhood

Ten complications

1. Planets Mercury to Saturn, with Jupiter and Saturn each having four and five orbiting moons respectively
2. Dials showing aphelion and perihelion and the orbital eccentricity for Mercury, Mars, Jupiter and Saturn, and accurate distance from the Sun in astronomical units (AU) and millions of kilometres (Mkm)
3. Rotating Earth with Moon phase dial
4. Correct depiction of eccentricity of the orbits of Mercury, Mars, Jupiter and Saturn
5. Planetary tilt for Mars, Jupiter and Saturn in relation to the Sun’s ecliptic.
6. Planetary orbital distance from Sun in AU and Mkm (average for eccentric orbits; see number 2)
7. Planetary orbital time in years
8. Mass of each planet in terms of the Earth (mE)
9. Position of all orrery components in degrees, 0-360° and position in the Zodiac
10. Two speed transmission for slow and fast demonstration

Middle left centre dial

One complication

1. World time dial and celestial demonstration crank

Middle right centre dial

One complication

1. Thermometer

Lower centre dial

Planisphere of the stars above

Four complications

1. Planisphere, showing star field with major stars named, the Milky Way, and Zodiac figures
2. Sun travelling through the Zodiac’s houses across the star plate
3. Seasonal height of the Sun in the sky
4. Date and month readout, setting dial

State of wind indicators

One complication

1. Time train
 - * Celestial train
 - * Quarter strike train
 - * Hour strike train

Special mechanical complications

Six complications

1. Dual Wagner rocking frame remontoire, time train
2. Robin remontoire, celestial train
3. Spring remontoire, perpetual calendar
4. Reverse *coup perdu* to derive single jump seconds from two-second pendulums
5. Antide Janvier-type slant wheel differentials within tumbling cages
6. Temperature compensation for pendulums using Elinvar springs
 - * Compound remontoire flies
 - * Epicyclic strike train flies
 - * Celestial remontoire fly cam, controlled to release at differing time intervals
 - * Sidereal time read off double, inner concentric anti-clockwise rotating dials within mean solar time dial
 - * All calendar functions feature ‘instant trip’ at precisely midnight

