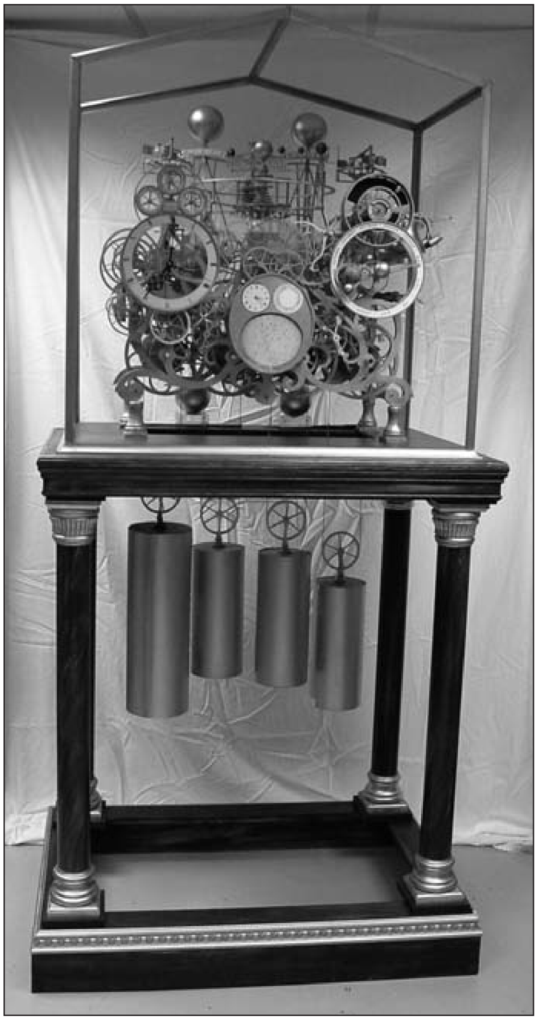
An Astronomical Skeleton Clock

By Mark Frank (IL)

This article describes a work in progress, a wooden model of a three-train, quarter-striking skeleton clock with an additional train for astronomical functions. The planned features are for all trains to be equipped with epicyclical maintaining power and 8-day duration. The dual escapement and pendulum layouts are loosely based on John Harrison's grasshopper design, as applied in his H1 sea clock, and they have a four-second period. Drive to the escapement is supplied through an independent dual remontoire based on Jean Wagner's swinging frame design.[1] The remontoire periods are each 30 seconds. The celestial train trips once per minute. All complications (except the calendar work) are driven from this train and all are demonstrable together or separately in forward or reverse. The orrery is capable of demonstration in two different magnitudes of speed. The movement is 25" wide x 29" high x 16" deep; the case is 36" wide x 77" high x 24" deep. The estimated gross weight will be 600-700 lb. The movement is to be built by Buchanan of Chelmsford, Australia.



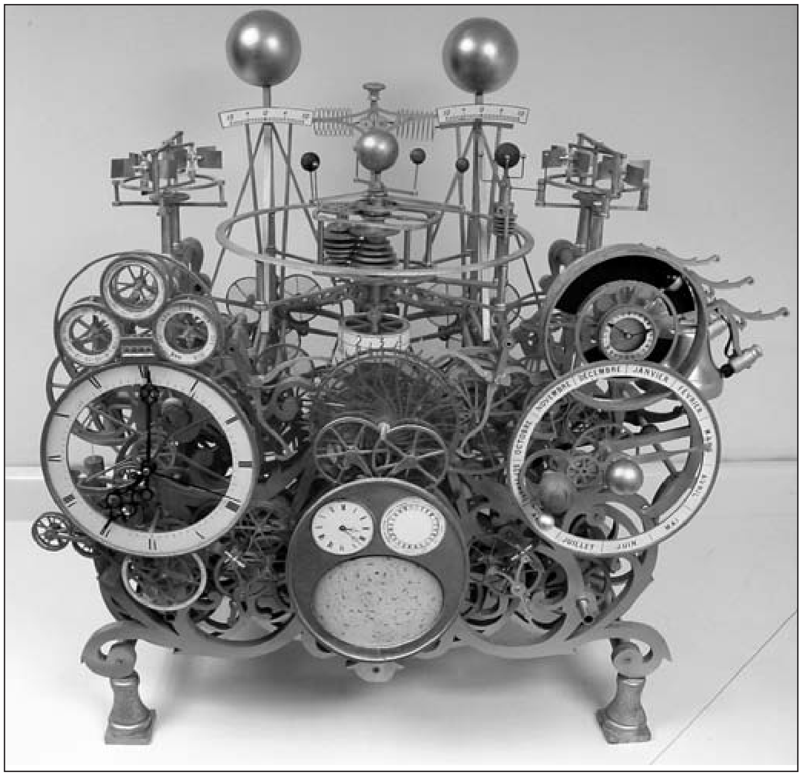


Figure 1, above right. The astronomical skeleton clock model in display case. **Figure 2, above.** Front elevation of the movement.

The Dream Behind the Design

I wanted to create, for lack of a better term, my "dream clock." It had to incorporate four main principals: scale, complexity, movement and, of course, beauty. The combination is used to maximize visual impact, which is reflected in the design of the remontoire and strike flies: the use of 90-degree triple-set bevel wheels for the equation, remontoire, and maintaining power systems in place of flat sun and planet differentials, which is the conventional systems more commonly seen, and the dual remontoire and counterrotating escapement systems. The strike train's operation is altered from convention to make maximum use of special flies. All moons are operational for Jupiter and Saturn in the orrery. Even the rate at which the compound pendulums oscillate was carefully chosen to give a hypnotic effect; thus they use a longer period of four seconds rather than the standard two seconds.

It took two years to think through the design: what I wanted the clock to do, the dial

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[1] For more information about remontoire see my paper at http://www.my-time-machines.net/speech_ final_web.pdf.

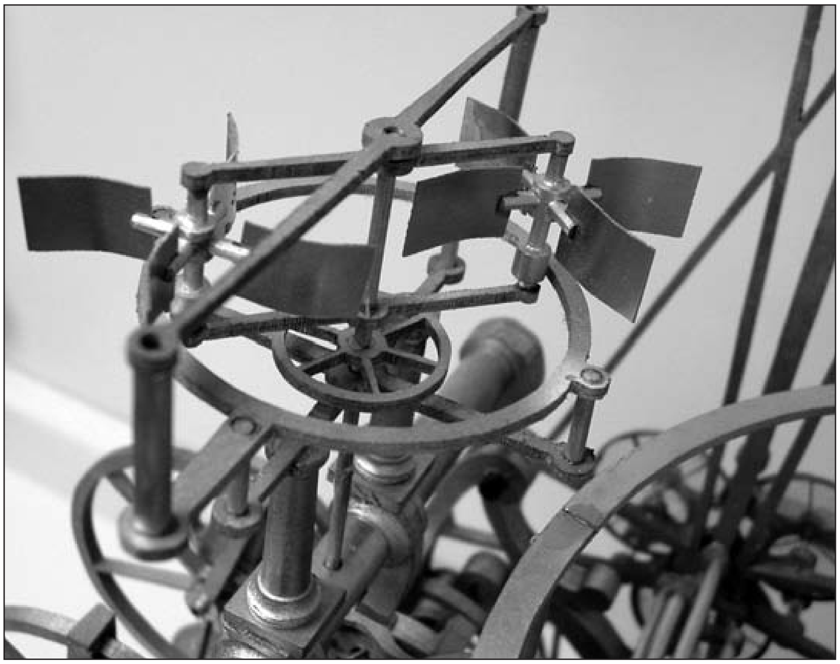


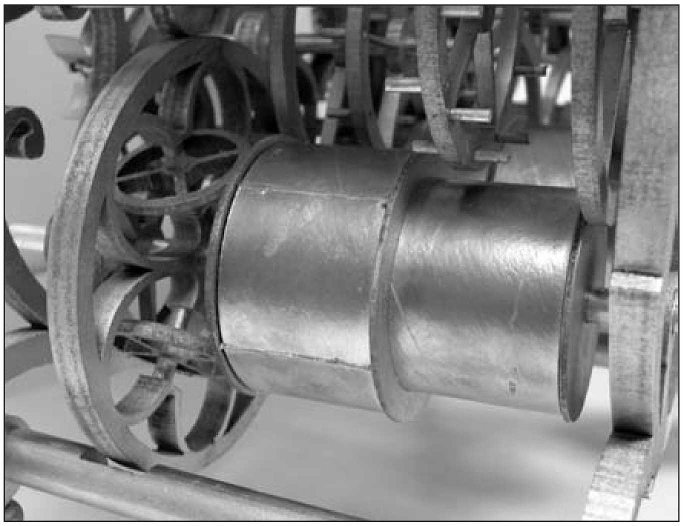
Figure 3. One of a pair of compound epicyclical flies mediating the two remontoire**.**

layout, escapement, remontoire design, and other specifics like the fly fan designs. I borrowed liberally from the master clockmakers of the past: Jean Wagner's remontoire, John Harrison's escapement, Fasoldt's strike flies, Janvier's orrery, P. Hahn's tellurium, Tompion's equation work, and Condliff's frame.

My biggest fear was that, while each component may be beautiful in its own right, the amalgamation might look like . . . well . . . just an amalgamation. A careful six-month collaboration between myself and the fabricator, Buchanan of Chelmsford, who is a clockmaker with skills equal to any of the masters from horological history, helped to bring about the mock-up you see here.

I wanted to represent in the astronomical parts of the clock a depiction of the world around us at various scales and incorporate how the things we see with our own eyes look from near and farther into space. When the celestial train is demonstrated, the interaction of the sky as it would be from my hometown, with the stars and sun moving across the sky in the planisphere, can be seen. The sun and moon rise and set in their separate dials and show the length of the day and night, relative to each other, and give the ability to see when all these things happen contemporaneously as well as in the past and in the future. Then one can move a bit into space to see the earth-moon system around the sun through the tellurium and how this system affects the way we see the stars and sun in the planisphere and in the sun-moon rising and setting dials. Finally, with a further magnitude of distance we see the entire solar system (at least as it was known to Janvier in the late eighteenth century). This looks back into the tellurium, planisphere, and finally the sun-moon dials. At this scale we see how much smaller our place in His creation really is!

Figure 4. One of the four compound barrels used to minimize the drop needed for an 8-day duration. Each is also equipped with epicyclical maintaining power.



The mock-up contains only the main wheels and rough outlines of the actual clock. Even so, it is quite an impressive work for wood and paper and represents only a fraction of the final wheel and parts count. It is estimated that the finished product will contain over 200 wheels and 5,000 parts.

Construction will take three years. You will be able to see the clock being built on my website: www.my-time-machines.net.

Highlights of the Design

Jeweling. All pivots are jeweled throughout the clock (including the orrery). The going train, including the remontoire and all antifriction wheels that support the escapement wheels and the pendulums, have jeweled chatons, but the main wheels (barrels) and the first wheel up each train do not. These wheels are in chaton roller bearings with faux jeweling to hide the bearing. The escapement pallets and other sliding surfaces are jeweled.

Materials. All plates are lacquered yellow brass. Wheels between the plates are deep pink bronze; wheels outside the plates are a lighter shade of bronze. Chatons are silver bronze, and arbors and all ferrous metal are stainless steel except for screws, pinions, and pivots. Arbor pivots are fitted to stainless arbors with appropriate hardened tool steel. Pinions are fitted to arbors from hardened chrome steel. Swiss maker Donze

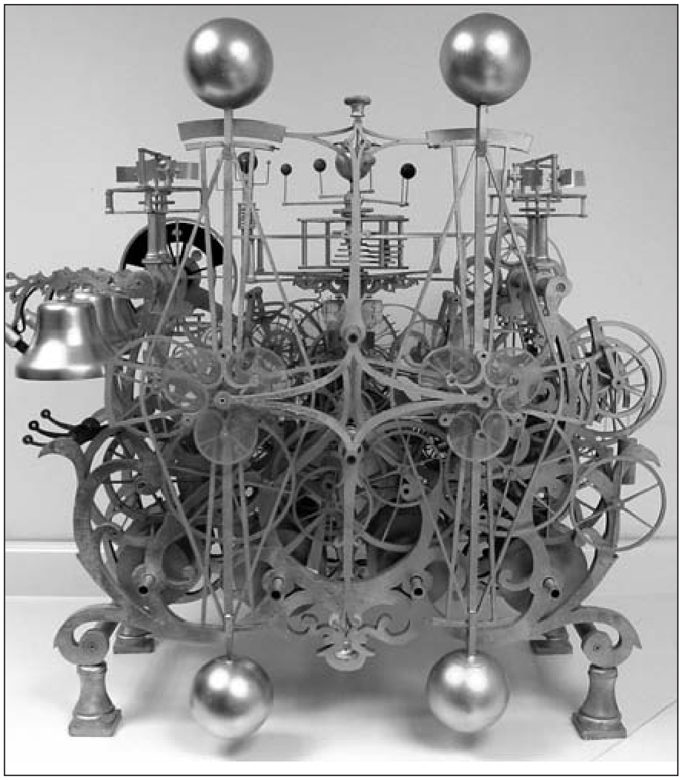


Figure 5. Rear elevation of movement.

Cadrans will supply all the porcelain dials. Dial bezels are to be knurled and gold plated.

Construction. The overall workmanship is like that of a fine watch; Buchanan's work is as good as that on any modern or, for that matter, antique clock. All arbors are tapered, and all screws are blued to "electric" blue. Other parts are blued where appropriate, such as hands, clicks, and their springs. All wheels are screwed with three blued screws to their respective collets—no press fitting. The number of wheel crossings will vary, depending on the size and location of wheels. Six spokes are predominant, and nowhere are there less than four. All surfaces are brought to a fine, high polish. This step alone is estimated to take six months. All cocks, bridges, and other parts attached to the frame will be equipped with guide pins.

By design all astronomical subsystems and dial work can be removed from the clock without having to part the main plates. In addition every part of the clock can be taken down to its individual component—no nonremovable (i.e., glued, fused, soldered, or welded) parts.

Operation

Two large, counterrotating, 40-tooth escape wheels ride on sets of antifriction wheels. Both have independent grasshopper escapements and are controlled by a four-second-period compound pendulum. The spokes on each escape wheel are specially shaped and spaced to give a kaleidoscope effect when they are operating. The pendulums are slaved together to keep the escapements in step with each other. The dual escape wheels are driven by separate remontoire, each with a 30-second period; they operate in a stepping manner, with one starting its period half way through the other's cycle. Thus, each compound, vertical fly located above the main dial works is activated every 15 seconds. Because the period of the pendulums is four seconds, the main clock dial's second hand will move every two seconds. The remontoire are driven by a differential connected to the rest of the going train.

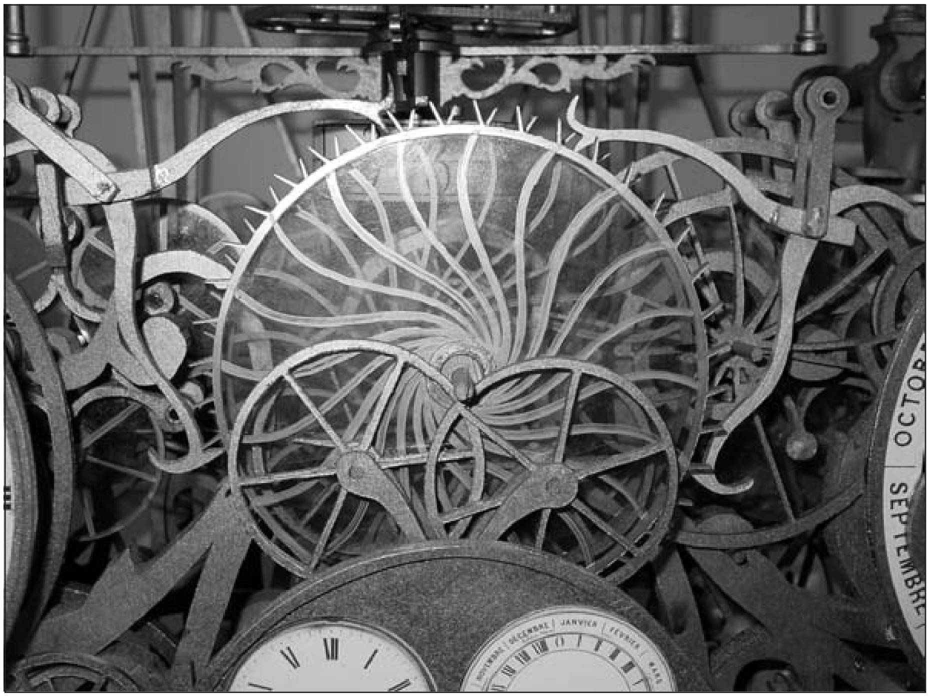


Figure 6. Dual counterrotating grasshopper escapements set upon a set of antifriction wheels.

Each fly mediating the remontoire consists of two smaller flies, each with four blades that are attached to a common rotating armature. The flies are driven by an internally toothed ring gear so when the armature rotates, the flies appear to pirouette around each other.

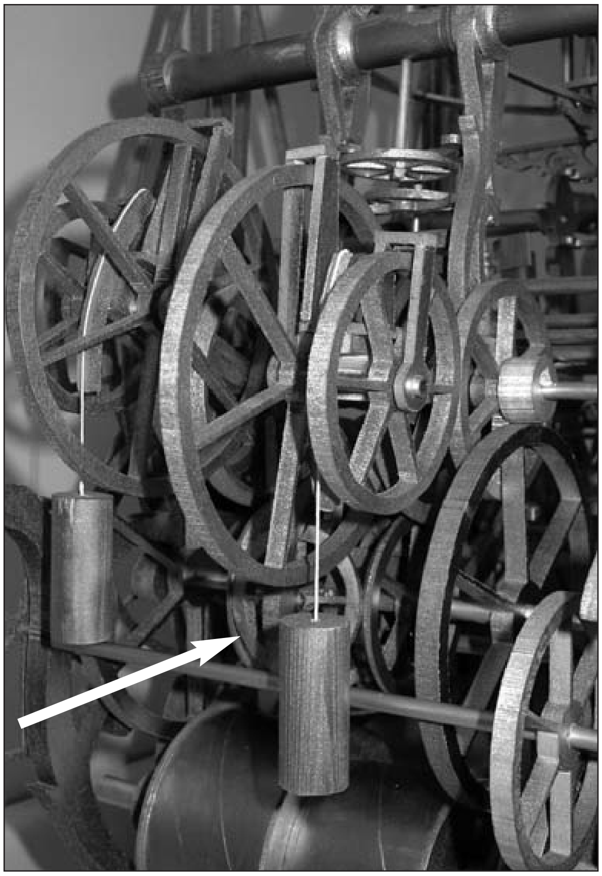


Figure 7. Double remontoire driven off a common differential (arrow points to differential).

The upper pivots of the flies and armature will use faceted jewels to give a dazzling effect when activated.

Arbors that drive the remontoire flies, the strike train flies, and each escape wheel are made from twisted and polished six-sided stock. When they are activated, it looks like the power is "traveling" in the direction of the fly. The celestial train is tripped once per minute by the going train and is mediated by its own fly. All complications (except the calendar) are driven via this train. The celestial train can be disconnected from the going train without stopping the clock, enabling demonstration of the astronomical indicators at will with use of a hand crank.

All astronomical indicators can be demonstrated together or separately and in forward or reverse. The orrery, since it has very slow orbits for the outer planets, can be demonstrated separately at a faster speed, which would otherwise be too fast for the other indicators that cycle on a daily to yearly basis.

The strike train operates in a special manner to make use of both the quarter and hour strike flies every 15 minutes. The Whitechapel bell factory in England specially cast and tuned three bells for this project. On the first three quarters the small and medium bells are struck in the normal manner for a "bim-bam" effect, one through three times. For each of these quarters the largest bell is also struck once, afterward. On the fourth quarter the bim-bam is struck four times with the largest bell striking the hour in the conventional manner. Each fly is mounted in a rotating cage made of stainless steel to make its movement stand out from the frame. These, like the remontoire flies mounted above, also pirouette, but in a totally different manner.

Dial Descriptions and Explanation of Functions

Mean solar time: Indicates the regular local time we are all familiar with—"clock" time with seconds, minutes, and hours (black hands).

Equation of time: Indicates the difference between clock time and "sun" time according to the relative position of the sun in the sky as would be measured by a standard sundial (gold hand with sun).

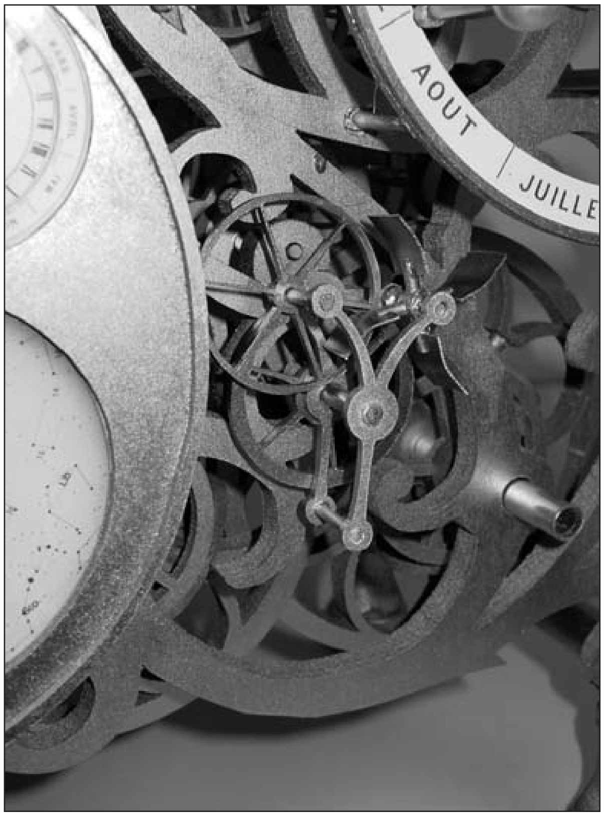
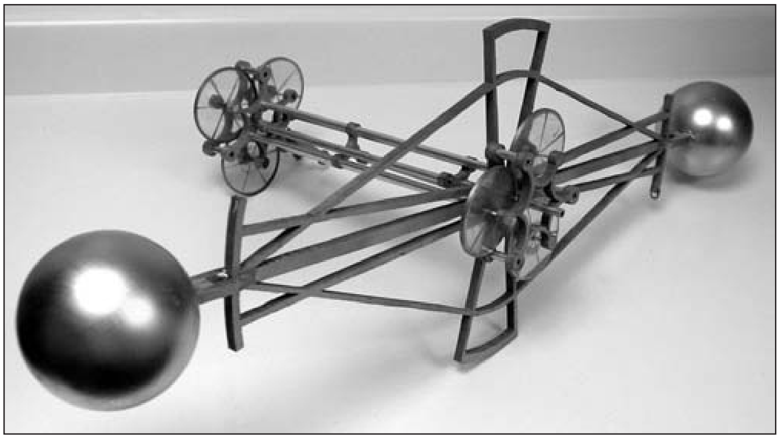


Figure 8, left. Balance based on Harrison's H1 marine clock, with the addition of a set of antifriction bearings. **Figure 9, below.** One of a pair of epicyclic flies mediating the strike trains.



The earth's orbit around the sun is elliptical, not circular, and the axis of its daily orbit is inclined at 23.45 degrees to the plane of that orbit. These factors combine to give us the seasons, but they present the sundial with the problem of an irregularity in the apparent movement of the sun. Unless corrected, only on four days of the year will sundial time coincide exactly with the more regular clock time. The formula for this correction is the Equation of Time. At first the difference was calculated by using intricate tables to adjust the time between regular and sundial time. Later these formulas were represented mechanically via a kidney-shaped cam that rotated once per year and could then be read off a dial. An idler arm follows this cam and when it is attached to a hand, the difference can be read off a sector dial directly. The addition of a differential gear system (used here) allows a "sundial" minute hand to move ahead or behind the regular minute hand by the amount of the difference between the two time systems as they vary continuously throughout the year. This is from just under -14 minutes around mid-February when sun time is slow relative to clock time and just over +16 minutes at the beginning of November when sun time is fast relative to clock time. There are also two minor peaks in mid-May when sun time is nearly 4 minutes fast and in late July when sun time is just over 6 minutes slow, hence the kidney shape (Figure 11).

Figure 10. Mean solar (clock time) dial. The sun hand indicates the time as would be read on a sundial. The difference in minutes between it and the clock time minute hand is the equation of time.

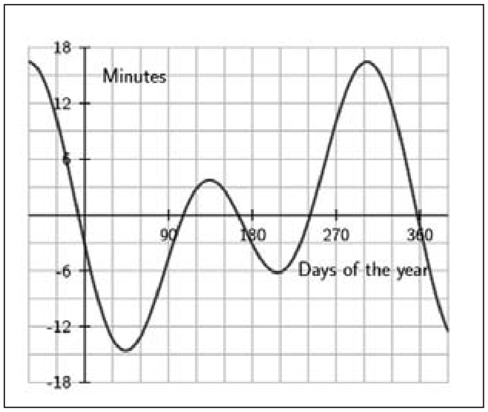


Figure 11, left. Graph depicting difference between mean solar (clock time) and sun time.
Figure 12, right. The kidney-shaped cam translates the differences seen on the graph between clock time and time as would be seen on a sundial into a physical shape.

Perpetual calendar: Accounts for leap years and is accurate for 400 years. This is the only complication driven by the going train.

The calendar currently in worldwide use for secular purposes is based on a cycle of 400 years comprising 146,097 days, giving a year of average length 365.242375 days. The Gregorian calendar is a modification of the Julian calendar in which leap years are omitted in years divisible by 100 but not divisible by 400. By this rule, the year 1900 was not a leap year (1900 is divisible by 100 and not divisible by 400), but the year 2000 was a leap year (2000 is divisible by 400). Therefore, the total number of days in 400 years is given by 400 x 365 + 100 - 3 = 146,097. This also gives an exact number of 146,097 / 7 = 20,871 weeks per 400-year cycle.

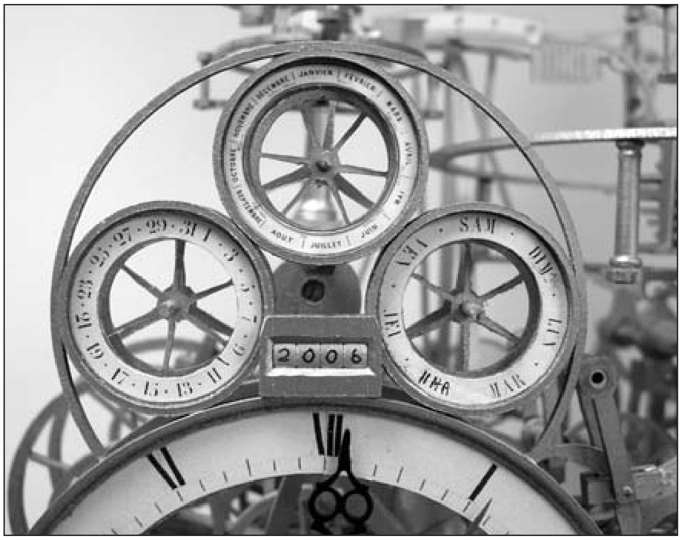
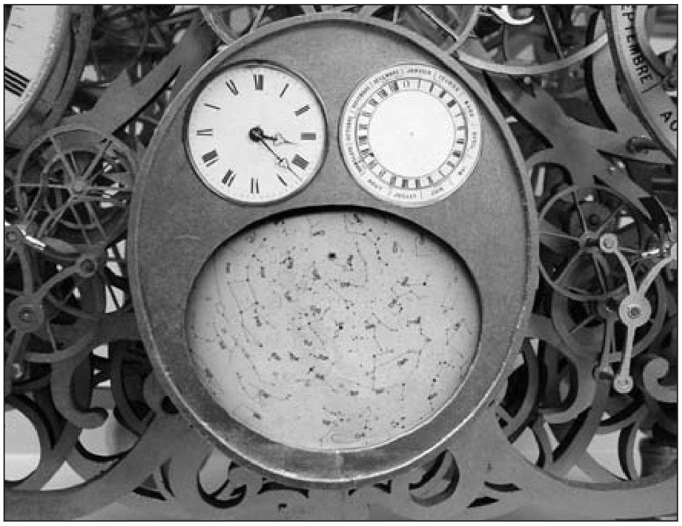


Figure 13, right. Four hundred-year perpetual calendar work.

Figures 14, right. Sidereal time is the difference between the change in the position of the Earth in its orbit in relation to the stars versus the sun. This amounts to just under four minutes/day.



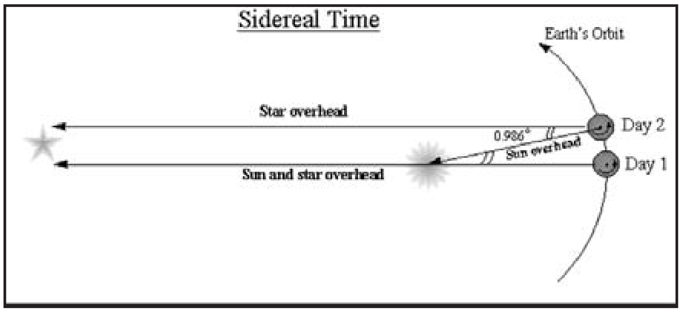


Figure 15. Planisphere star plate with its setting dial (right) and sidereal time clock (left).

Planisphere: Shows stars as they would appear at night (or if visible) in daylight for the latitude of Chicago, IL, at 41 degrees 52 minutes 11 seconds. The sun also is depicted as it would be traveling through the sky during daylight.

Setting rings for planisphere (right dial will be skeletonized): The outer ring denotes months and days, and the inner ring is marked in 24 hours, which allows for accurate positioning of the planisphere's star plate.

Sidereal time: (left dial will be skeletonized), also known as "star" time. During one day, the earth has moved a short distance along its orbit around the sun and must rotate a small extra angular distance before the sun reaches its highest point. The stars, however, are so far away that the earth's movement along its orbit makes a generally negligible difference to their apparent direction, so they return to their highest point in slightly less than 24 hours. A mean sidereal day is about 23 hours, 56 minutes, and 4.1 seconds.

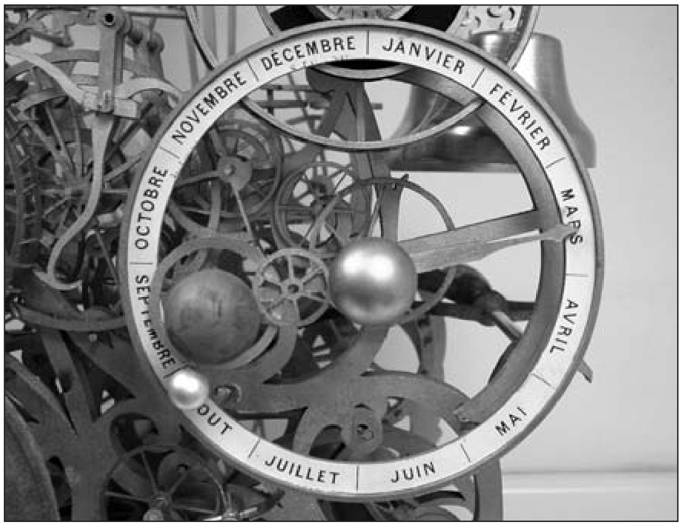
Therefore, if the mean solar time clock and sidereal time clock were synchronized at 12:00 midnight on January 1, the sidereal clock will tend to run faster than the regular clock by 3 minutes 55.9 seconds per day. After one year this difference will accumulate to exactly one day, and both clocks will again read the same time at 12:00 midnight the following year. The dial denotes the standard 12-hour rather than the usual 24-hour format to compare more easily the difference between the sidereal and mean solar time dials.

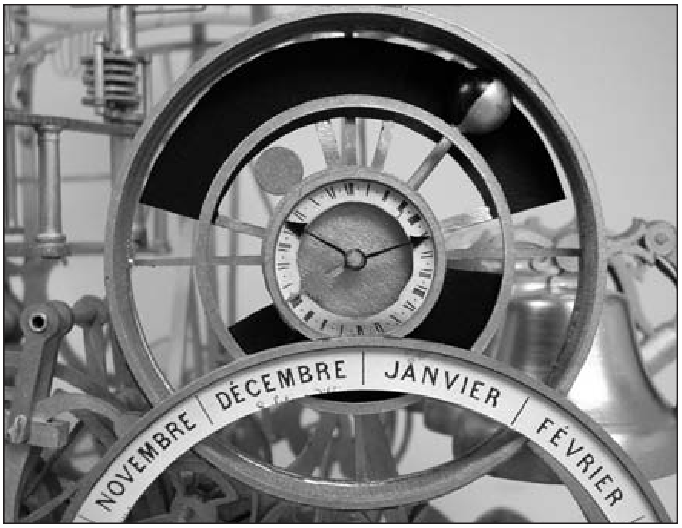
Leap years do not affect this relationship as these are man-made constructs to make our numeration of whole days fit into a single year when, in fact, a year is a fractional number of days.

Tellurium: Depicts the earth-moon-sun orbital system. The pointer to the annular ring indicates the date and month. The semicircular counterweight is behind the dial to balance the system.

Sunrise and sunset indicator (below inner ring): The sun globe goes around once a day. The black move-

Figure 16, left. Tellurium showing the sun-earth-moon orbital system.
Figure 17, right. Dials with moveable shutters to indicate sun and moon rising and setting.





able shutters rise and fall with the length of the days according to the seasons. This gives the relative lengths of day and night. The center dial shows the time of sunrise and sunset (black hands). The gold sun hand shows where the sun is when it is behind the shutters. The Vernier scales on shutters will show the length of day and night.

Moonrise and moonset indicator (outer ring): The moon goes around once a day. The black moveable shutters (black) rise and fall to indicate when the moon will rise and sink below the earth's horizon. The moon travels in front of the shutters, indicating when the moon is rising during night and during daylight since the moon can been seen sometimes during daylight hours. The moon also rotates to give its age, and the equator is engraved with the daily age 1 through 29.5. The inner dial indicates time of sunrise, sunset, and the position.

Orrery: A fully functional orrery depicts all of the planets and their moons as known in the late eighteenth century. The sun rotates, the moons orbit at correct velocities, and planets orbit within their correct elliptical orbits, but unlike in reality, all planets do orbit within one plane. Their relative distances from the sun have been distorted to keep the orrery a reasonable and legible size (inner planets a bit farther and outer planets much closer, to the sun). Two band dials located below the orrery are used to set the orrery back to its correct position after demonstration. These dials delineate months and years.

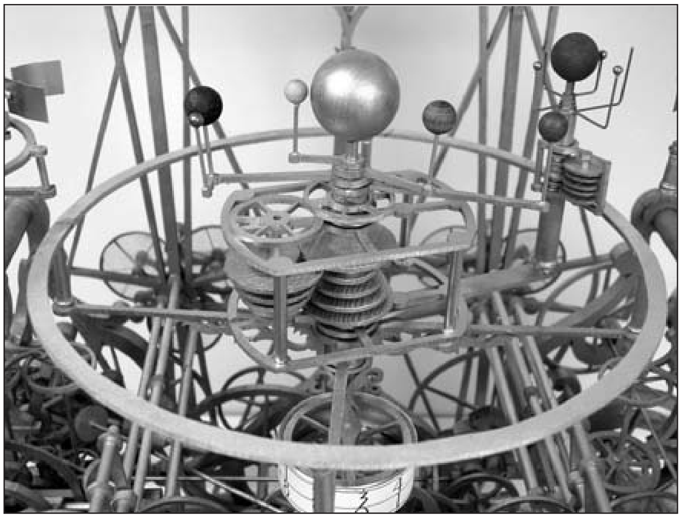


Figure 18. Fully functioning orrery with planets out to Saturn (mock-up only goes to Jupiter). All the planets' moons as they were known in Janvier's time also orbit their respective planet.

Layout From the Sun Outward as Follows:

Planet	Satellite	Orbital period (sun is rotational period)
Sun		27 days (approximate)*
Mercury		87.969 days
Venus		224.701 days
Earth		365.256 days
	Moon	27.322 days
Mars		686.981 days
Jupiter		4332.71 days (11.86 years)
	Callisto	16.689 days
	Europa	3.551 days
	Ganymede	7.154 days
	Io	1.769 days
Saturn **(not shown in mockup)**		29.458 years w/ 25.33 degree tilt for planets and it's moons
	Dione	2.737 days
	Iapetus	79.330 days
	Rhea	4.518 days
	Tethys	1.888 days
	Titan	15.945 days

* The sun is largely gaseous, so speed varies over its surface from 25 days at the equator to 36 days at the poles. Deep down, below the convective zone, everything appears to rotate with a period of 27 days.

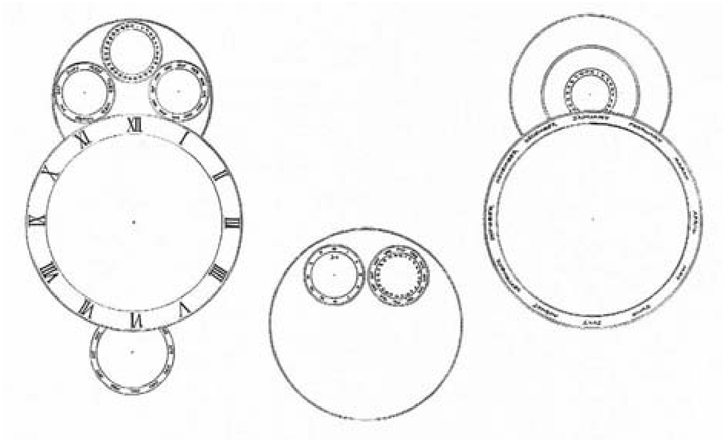
About the Author

I have been collecting clocks for the past 15 years, but only those where I can view the movement. A clock that is in a conventional wood case hides most of the fun! Hence the collection of skeleton clocks. Eleven years ago I found an old French tower clock in an architectural artifacts store—WOW a giant skeleton clock! More gears and wheels to gaze upon. Now I have over 30 tower clocks and a similar number of skeleton clocks. Both collections have an emphasis on interesting mechanical contrivances. Many have remontoire, some with a tourbillon, or unusual escapements like grasshopper, detent, coup-perdu, and various gravity types. A few years back I discovered what I think is an undiscovered niche in horology: bank vault timers. Again one can see the movements within the beautifully machined and damascened time lock cases. Most of the movements are from known makers like E. Howard, Illinois Watch Co., Waltham, and Seth Thomas.

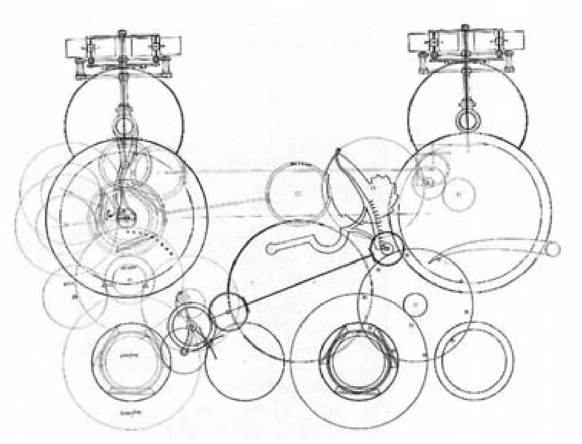
I am very interested in communicating my interest with others. My website (www.my-time-machines.net) is not a simple show and tell; it is designed to inform. A section deals with the step-by-step process of restoring an old tower clock movement. There are stop-action films and audio/video to explain the rationale, design, and function of remontoire. I have written a brief overview on the evolution of design and mechanics of tower clocks also downloadable from the site. My next article will deal with the history and design of time locks.

An Astronomical Skeleton Clock. The following drawings show only a fraction of the clock works. They are meant to be instructive and not all-inclusive!

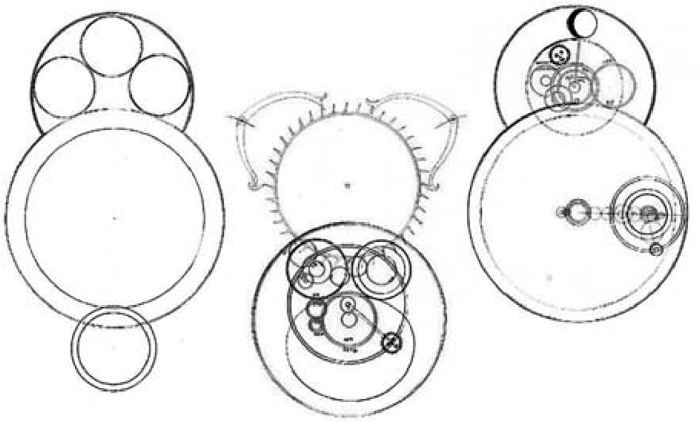
Dial Work



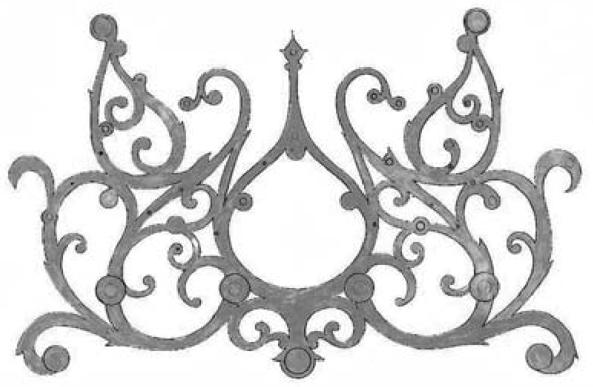
Going Train and Hour Strike Train



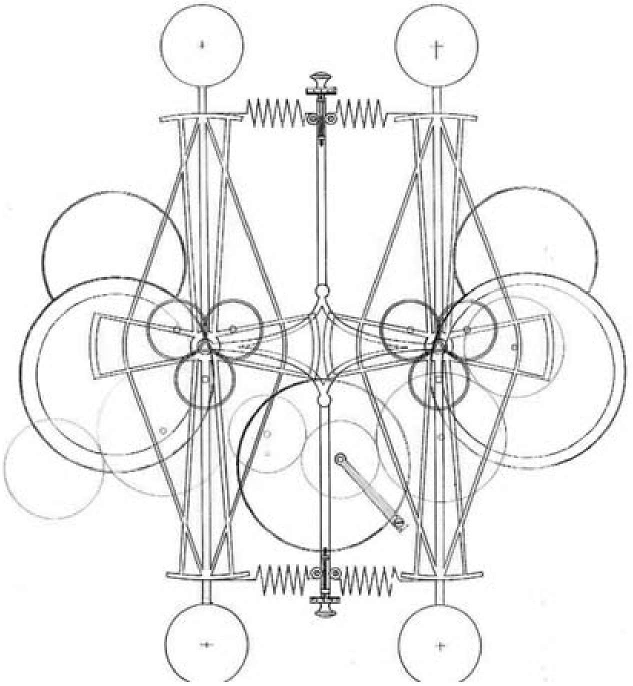
Escape Wheels and Planisphere



Frame Design



Balances



Calendar Work and Celestial Train