James Ferguson's Mechanical Paradox Orrery 3

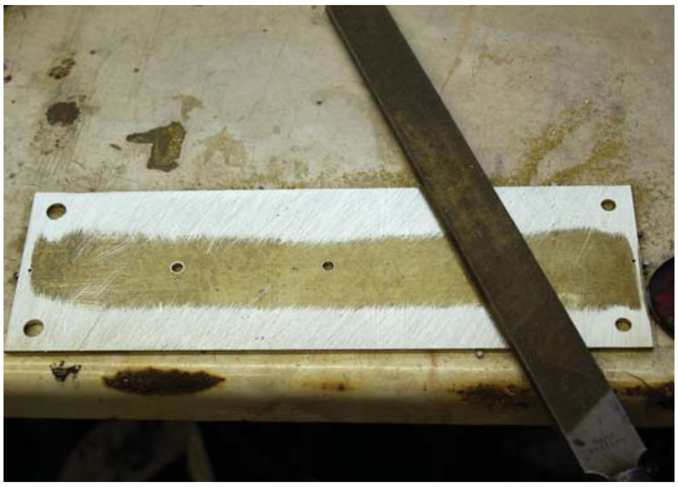
Ian Coote and James Donnelly conclude their story.

IC's Model

As stated above, the original intention was to make five of these models – one for the commissioner, one for myself and the remainder for sale to the public. Just one has been made so far.

Plates

I had a ⅛" sheet of brass in stock, and the daunting task of hack-sawing ten rectangles 9½" x 3" was avoided by asking my friendly metal-fabricator neighbour to cut it up on his large guillotine. He also punched the holes in the corners.
It seemed like a good idea, but the guillotine and punch cause a lot of distortion to the edges, and the time and work saved in cutting was more than taken up in filing it flat, especially as this brass sheet of unknown composition is tough, fibrous and hard to work. It is harder to file than mild steel and if I do decide to make more models I will have the plates ground flat with a surface grinder. This time I filed them by hand before finishing with 3M polishing film from 40μ down to 0.3μ, **Figure 24 and 25.**



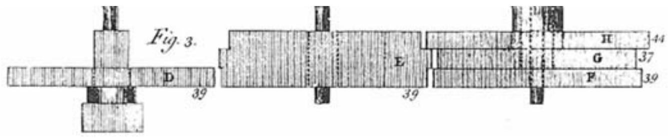
24. Filing the plates.

25. Polishing the plates

A small locating hole was drilled at each end of the plates so that they could be pinned together for accurate drilling.
Pillars were hand-turned with a graver on the Myford ML7 to a card template, then cross-drilled through the upper end for taper-pinning and riveted to the bottom plate.
A recess was milled out below the bottom plate to take the pointer. The pointer was drawn on paper, glued to a steel plate then hand-cut with a piercing saw. After filing the edges smooth with a slight chamfer, the pointer was polished then blued by heat on brass filings. The handle was turned in ebony without any prior design – it just needs to look and feel right – drilled through, countersunk and fixed with a screw, also blued. The pointer was screwed to the bottom plate with countersunk screws.

Wheels

The problem with this design is that three gears of the same diameter but different tooth numbers must work into a single thick gear, so tooth profiles must be a compromise. If the correct cutter for 39 teeth is used, the teeth on the 37 tooth gear will be too thick, and those on the 44 tooth gear too thin.
JF's original model was made with wooden gears to allow them to form their own shape. He also suggested that the thick wheel could be made in brass in stepped form, like three different diameter gears on the same centre, **Figure 26**. This would overcome the problem, but it seems like a cheat as it destroys the illusion of a paradox. I decided to use brass gears with the same tooth numbers as described above, but with a single diameter centre gear as I had done with the original small model. Involute cutters were used in the hope that they would be more forgiving of the incorrect tooth form. **Figure 27** shows the rough cut gear teeth.
Having decided to use involute teeth in the hope that they would be more forgiving of the incorrect profile, I had to ask my friend Bill Turner to cut them, in the absence of suitable equipment in my workshop. The thinner gears were cut from 1/8" sheet, and the thick ones from a length of 2½" diameter round rod.



26. Ferguson's stepped gear.

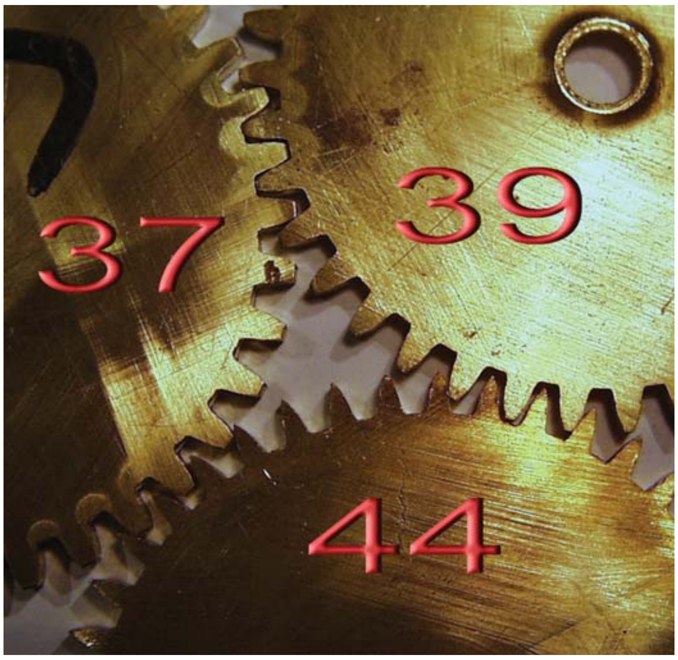
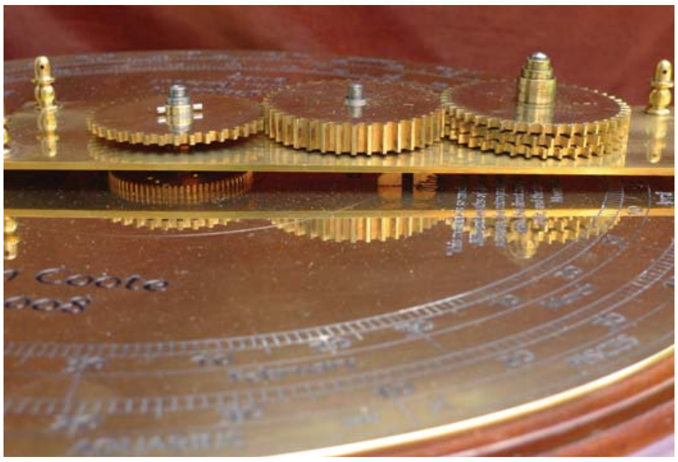


Figure 27. Meshing of the gears.

After finishing and polishing, the fixed wheel was mounted on a short brass tube. This was drilled and pinned to the steel arbor which is screwed to the base board and supports the bottom plate. JF used a squared arbor and square hole to hold the wheel - my method is quicker.
The thick wheel was mounted by friction onto a steel arbor pivoted into the two plates.

A third steel arbor was screwed into the bottom plate to carry the three driven gears which are mounted on concentric brass tubes, made to measure from brass rod. The tubes are a press fit into the wheels, **Figure 28**.



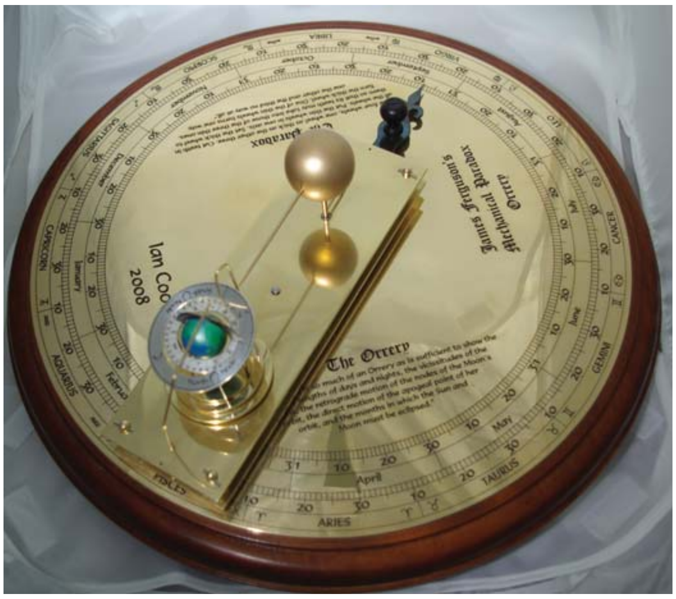
28. Setting up the gears.

Baseboard and dial

My case restorer turned the mahogany boards from an old wardrobe door. I rubbed them down and French polished them, adding three brass knobs from the junk box as feet.

The original plan was to glue a paper dial to the baseboard as in Ferguson's original, and dial restorer Tim Garrett drew a fine large ecliptic dial for me. However, when I decided to put it into the BHI 150 show I chose the more showy appearance of a brass dial. After investigating a range of options, I was recommended to Hockerill Engraving[ix] who agreed to make all the dials from etched brass at a reasonable price. Unfortunately, it proved difficult to transfer the hand-drawn design, and I redrew the designs using TurboCad and Corel Draw. An advantage of etching over engraving is that any amount of detail can be included at no extra cost, so I used the space in the dial centre to include some of Ferguson's descriptions, **Figure 29**.

Hockerill Engraving were patiently helpful and the end result was superb (apart from the mistakes that crept into my design). The small dials were produced in the same way, then cut out and finished by hand. They were silvered for visual contrast. The dials and all metal parts were finished with Renaissance Wax™ rather than lacquer.



29. The dial.

30. Centre arbor assembly.

The main arbor was mounted in the centre of the dial, held from below by a 2BA screw. This assembly also holds the dial in place on the baseboard, **Figure 30.**

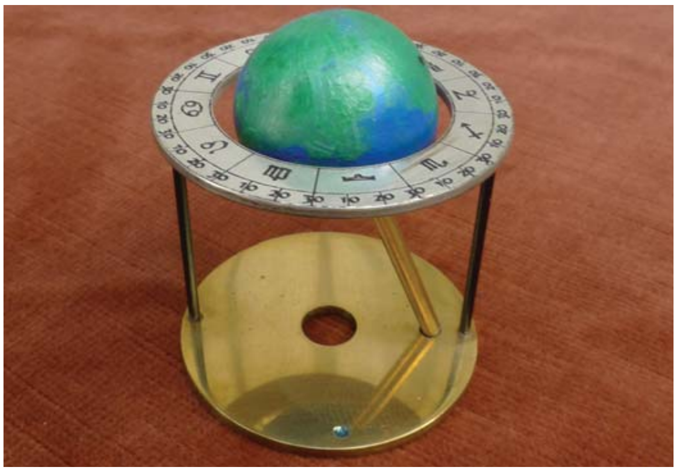
Sun and Earth

My Sun was a disappointment. I made five when I first began the project, using the traditional process of coating wooden balls in layers of gesso and burnished clay, then gilding with gold leaf – a technique I have used on a number of occasions for longcase finials. They looked stunning, but on returning to them after a few years, they all had small patches of cracked gesso. Attempts at repair were unsuccessful and there was no time to start again, so I had to take off the gesso and resort to gold paint, **Figure 31**. It looks okay, but not a patch on the gold leaf.The Sun's ray pointer is a brass rod, turned to a point.

31. Painting the Sun.

The pointed bottom end of the Sun's mounting rod rests in a hollow in the top of the arbor. A hole was drilled in this mounting rod to carry the side piece which was silver soldered in place. The side piece pushes into a hole in the top plate to make the Sun rotate with the plates.

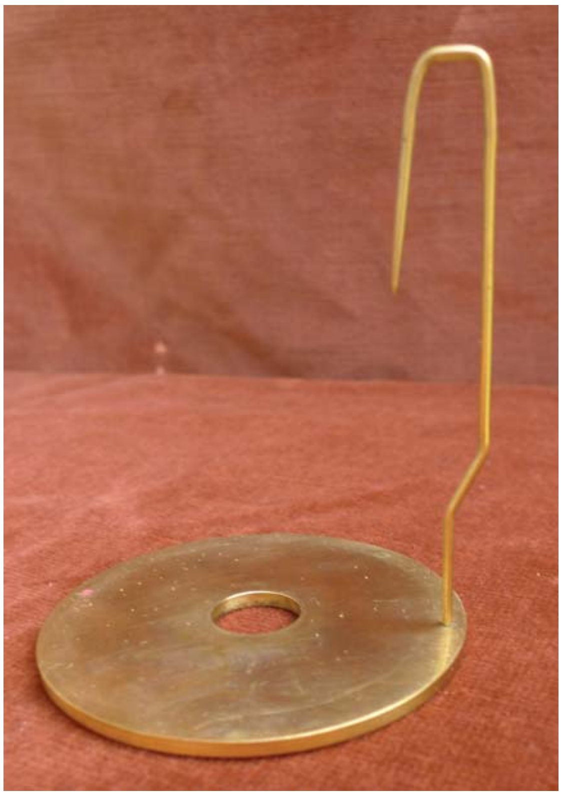
The Earth was painted freehand in acrylics, rather impressionistically. I had intended to draw on the latitude and longitude lines, but time ran out. The Earth is a push fit on a brass rod angled into the Earth's base plate at 23.5° from the vertical. It can be turned by hand to show its rotation and the extent of day and night, **Figure 32**.



32. The Earth.

Apogee

The Moon's apogee is indicated by a bent brass wire mounted on the middle base plate, which is driven by the 37 tooth gear. It indicates the position of the apogee on the small ecliptic dial, **Figure 33.**

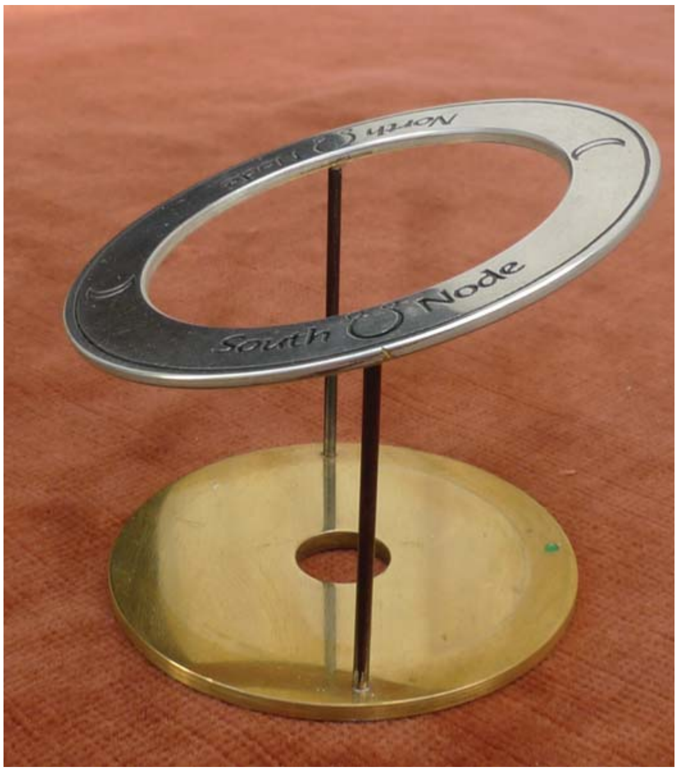


33. The apogee plate.

Lunar orbit

I used my small bench drill with the table set at the correct angle to drill the two mounting holes in the lunar orbit dial and the hole for the Earth's supporting rod. Both of the small dials are mounted on lengths of blue steel, **Figure 34.**

Figure 34. The lunar orbit plate



34. The lunar orbit plate.

Day and night

Day and night are indicated by a semicircle of brass soldered to a brass wire, mounted in a hole in the top plate. The Sun side of the semicircle (which would ideally be a full circle) is gold painted, and the back painted black. The supporting wire proved troublesome in the exhibition and was later replaced with a more solid wire, screwed to the plate.

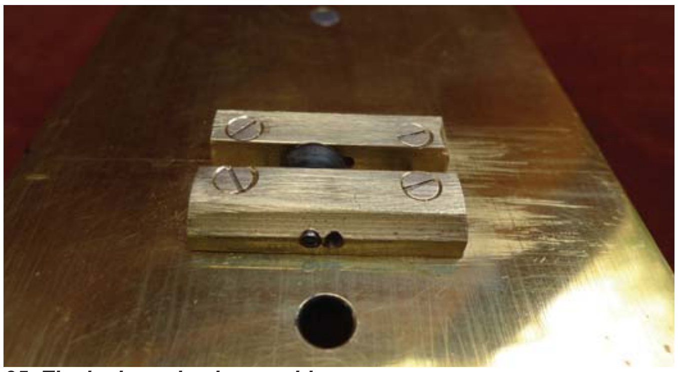
Motorising

Exhibiting such a model as a static display does not do it justice. I was happy for the public to play with the small model made for that purpose, but it was not practical for the large orrery so I decided to motorise it.

If it had been designed with a motor drive, I would have done things differently, but I had to come up with a suitable system quickly to fit the existing design.

The big problem was the main bearing. The whole design is unbalanced, with a lot of mass on the plates, only counterbalanced by the handle and pointer. It was designed to be made in wood and turned by hand, but I wanted my solid brass version to run continuously at a relatively fast speed for several days. Assuming a motor could overcome the friction, the heavily loaded bearing would wear rapidly, allowing the plates to sag until it would rub on the dial, ruining its finish and stopping the machine.

I considered ball or roller bearings for the main bearing, which would alleviate the problem to some extent, but decided instead to fit a small wheel to support the weight of the plates, **Figure 35.** The wheel was turned from hard wood and mounted in two brass blocks screwed to the underside of the bottom plate. The wheel was positioned so that the inevitable ring it would make on the dial would be inside the text.



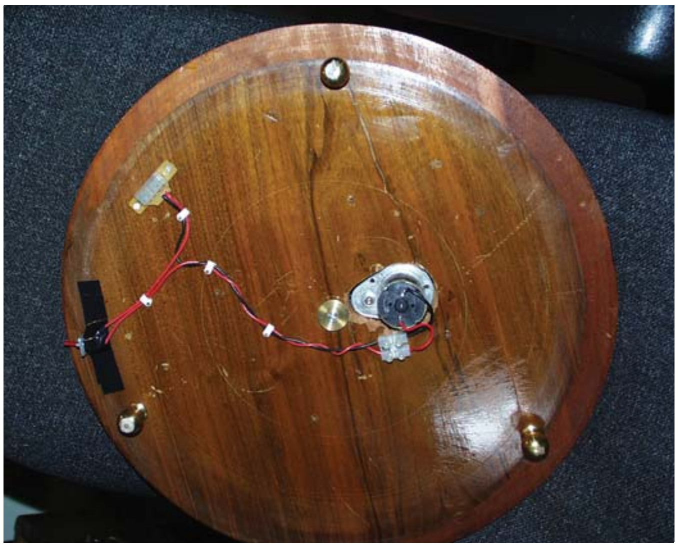
35. The jockey wheel assembly.

This jockey wheel worked well. Now I had to work out how to apply the drive in the limited space available. A belt or chain drive would have been possible, but difficult to set up as it would all be hidden under the plates.

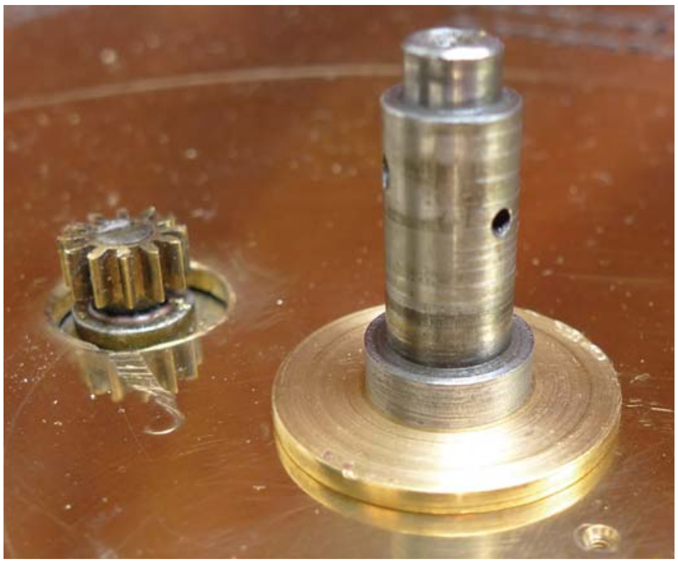
A Google search found Precision Microdrives[x] who could supply a wide range of small geared motors and I decided to try a direct geared drive with the advantage that it could be completely concealed under the frame. The first motor I tried was a tiny 12volt DC motor, just 12mm diameter, running at 20 rpm. Although sufficient to turn the machine there was no power in reserve, and I was not confident of its survival, so I replaced it with a larger (48mm) motor running at 15 rpm.

I cut a brass gear of 72 teeth and screwed it under the bottom plate, concentric with the main bearing, **Figure 36**. The motor was mounted under the dial with its body within the baseboard, **Figure 37,** and its spindle fitted with a pinion of 12 projecting through the dial, **Figure 38**, to engage with the gear. With this arrangement, the assembly can be lifted off and replaced easily. Fitting the motor was awkward to execute, but satisfactory in operation, turning the apparatus at a stately pace of about 2 rotations per minute.

36. Driving gear.



37. The motor.



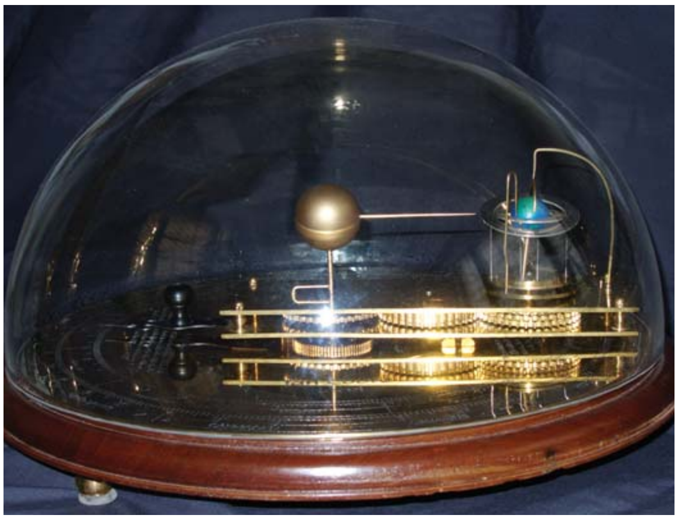
38. Driving pinion.

The motor leads were taken via a small toggle switch to a socket from an old computer supply. Being uncertain of the power supply situation at the exhibition I fitted matching plugs to a small lead acid battery and to a 12 volt transformer to provide alternatives. It was actually displayed in glass cabinet and powered from the battery, which showed no diminution of power over the three days of the exhibition. When it was later displayed for two months in Colchester, the transformer was used.

The apparatus can be used manually by adding a spacing washer to the centre arbor to raise the plates and disengage the motor pinion.

This model was made as a prototype, and there are obvious signs of changes of mind and unsuccessful experiments, but I have managed to confine these to the areas that are normally hidden.

To prepare this article, I had to dig out the dusty model from the box where it had been languishing since its last public showing at Tymperley's Museum in Colchester. Having spent so much time in construction it was clearly time to set it up for permanent display. The final touch was the addition of a celestial sphere - more accurately a 400mm. hemispherical acrylic dome. It was necessary to replace the support for the day/night indicator with a curved brass rod to clear the inside of the dome, but it seems to me a more aesthetically pleasing shape than the original right-angled bends, **Figure 39.**



39, The finished model, complete with dome.

We have both found this an intriguing and instructive project. James Ferguson may not have been the pre-eminent scientist of his day, but he was a talented observer, skilled mechanic and superb draughtsman and above all, a great teacher with an unrivalled talent for simplifying models and instruments to illustrate and explain the essential nature of a problem. In studying his life and work, it is hard to avoid being drawn into the world of 18th Century science.

The authors would very much like to hear from anyone else who has made this, or any other of Ferguson's machines.

References for Part II and III

[xiii]Donnelly, James. Drag Engraver for CNC Mills. Digital Machinist Magazine, December 2007.

[ix]Hockerill Engraving - www.hockerillengraving.co.uk

[x]Precision Microdrives Ltd - www.precisionmicrodrives.com

James Donnelly
Ian Coote

In December's Horological Journal James Buxton takes us on an Epicyclic Adventure, looking at Strutt's clock, which makes use of Ferguson's Paradox in the motionwork.