James Ferguson's Mechanical Paradox Orrery 1

by Ian Coote and James Donnelly.

"This machine is so much of an ORRERY, as is sufficient to shew the different lengths of days and nights, the vicissitudes of the seasons, the retrograde motion of the nodes of the Moon's orbit, the direct motion of the apogeal point of her orbit, and the months in which the Sun and Moon must be eclipsed." *James Ferguson, 1764*

Introduction

James Ferguson's mechanical paradox, described in his 1764[i] pamphlet, and in 'Select Mechanical Exercises' in 1773[ii] (hereinafter referred to as SME), is a simple piece of gearing which, if presented in a certain way, appears to subvert the usual rules. Many mechanically minded people find it intriguing and the two authors of this article decided independently to make copies, taking very different approaches. We thought it would be instructive to compare and contrast the techniques and results.

Authors

Ian Coote

I spend most of my time repairing and restoring antique clocks and watches, and studying horology in its many aspects. Regular readers of this Journal will have seen my articles on various subjects.

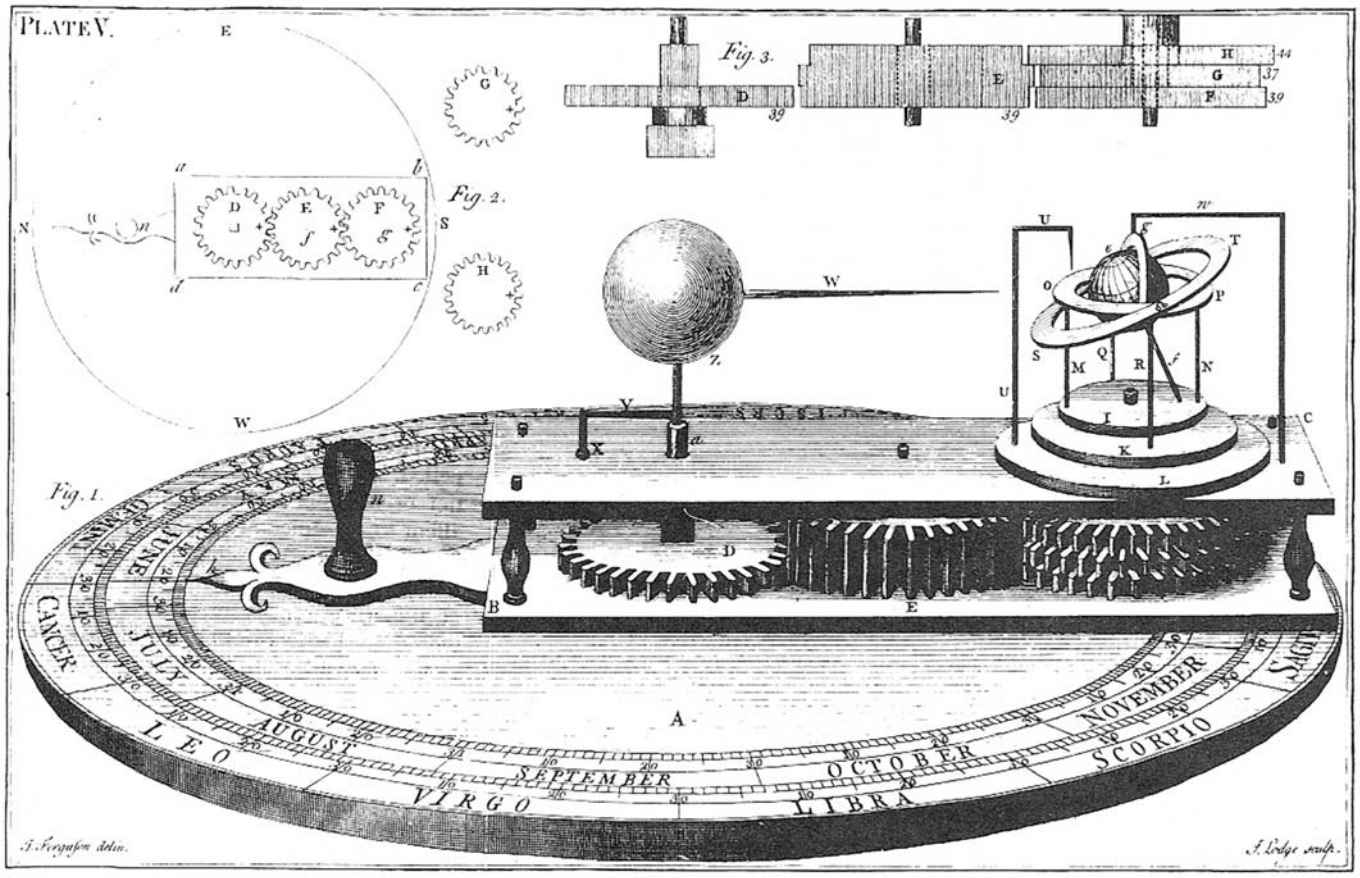
My first encounter with the paradox was many years ago, soon after joining the BHI. I visited Upton Hall on one of the study weekends that were then a regular occurrence. In exploring the library, I found an intriguing reference to the paradox in Volume 1 of HJ[iii] which I was able to follow up in the library's copy of SME. Soon after that visit, I turned my hand to making a small model to demonstrate the idea, **Figure 3**, and later published a web page about the paradox[iv] and the model. This led to a number of enquiries, including someone who asked if I could make him a full scale model. I agreed in principle and decided to make a batch of five.

As a restorer, I am used to making parts for clocks, but I rather underestimated the heavy commitment of time required to construct a complete apparatus, even such an apparently simple one. Having done much of the preliminary work I had to put it aside and it was several years before I decided to finish just one model. By this time the original customer had lost interest, so I made the BHI 150th Exhibition in 2008 my new target. It was (just) completed on time and exhibited, complete with electric motor drive.

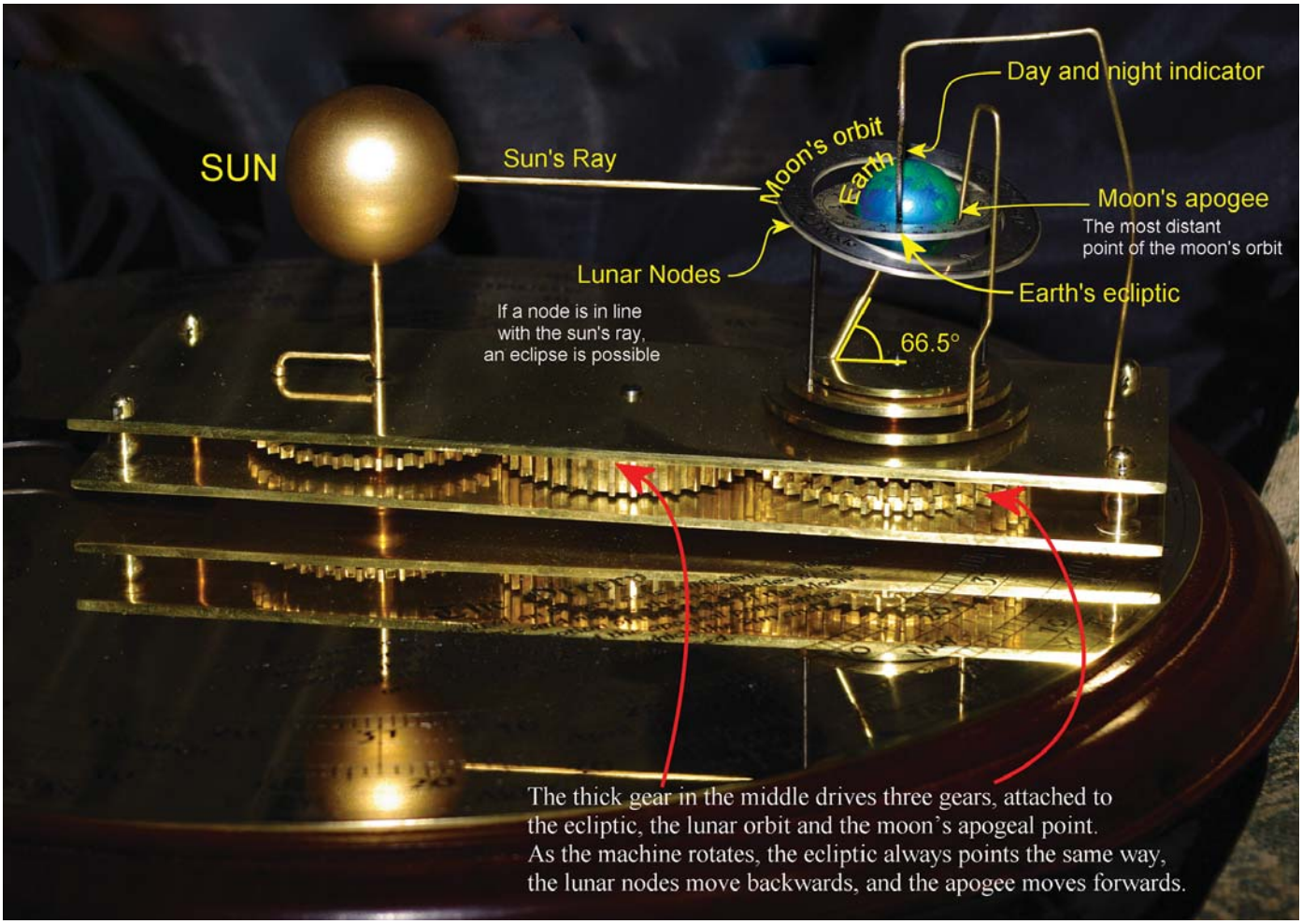
James Donnelly

I am a software engineer with a fascination for making things in my home workshop. From my earliest childhood visits to the Science Museum in London with my father, the intersection of art, craftsmanship, and science found in 18th century scientific instruments has captured my imagination.The Science Museum's collection of steam engine models was inspiring, and for years I wondered about the men who made them and the tools used.

My father is a physicist who has collaborated with gifted scientific instrument makers for his research. Over the years he introduced me to machinists with formidable skills and accomplishments. The men in the machine shops of the



1. The orrery from Select Mechanical Exercises.



2. Features of the Mechanical Paradox Orrery.

University of Oregon physics department and Hewlett Packard (where I worked for 27 years) contributed more than they will ever know to my ambitions for my home workshop.

My long term goal for my shop is to create reproductions of orreries and other antique scientific instruments, and I have adopted the model engineering hobby to satisfy my interests in engines and learn the skills needed for making intricate parts. The ratio of good parts to scrap metal has improved over the years, and I'm now emboldened to tackle more complex projects.

I first learned of the mechanical paradox orrery in John Millburn's book '*Wheelwright of the Heavens*'[v]. The elegance of the design was compelling, and I was intrigued by the idea that a novice might be able to make one. In 2004 I found Ian's web page describing his prototype. I wrote to Ian with a couple of questions, and was inspired by his replies. Several years passed, and by coincidence we both got serious about building the orrery at about the same time. I decided to make two, one for myself and one for my father. I finished my orreries on Christmas Eve of 2008, just in time to give one to my father on Christmas Day[vi].

James Ferguson (1710–1776)

Ferguson was the self-educated son of a Scottish crofter. His education was enhanced by several servant positions with people who contributed to his interests. By age 10 he was building models of spinning wheels and mills, and studied the stars by night while tending sheep. Moving to Edinburgh in 1734, Ferguson began to support himself as a limner (painting miniatures). He moved to Inverness where he published his Astronomical Rotula for showing the motions of the planets, places of the sun and moon, &c, (a document similar to an ephemeris, but using circular rotating volvelles). His final move was to London in 1743. By 1748 Ferguson began to give lectures on scientific subjects, and his apparatus facilitated these lectures significantly. In 1763 Ferguson became a Fellow of the Royal Society of London. Ferguson's famous Select Mechanical Exercises, with a Short Account of the Life of the Author was published in 1773. Besides being one of the first popularisers of science, his influence extended considerably, with Thomas Paine and William Herschel reportedly studying his publications. George III, while Prince of Wales, attended Ferguson's lectures and rewarded him with an annual pension of £50 from the Privy Purse until his death in 1776. Although not primarily a horologist, he designed a number of clocks. He was friendly with Benjamin Franklin and apparently inspired Franklin to design his famous 3-wheeled clock, later designing his own versions. An astronomical clock to his design was described by Reid[vii].

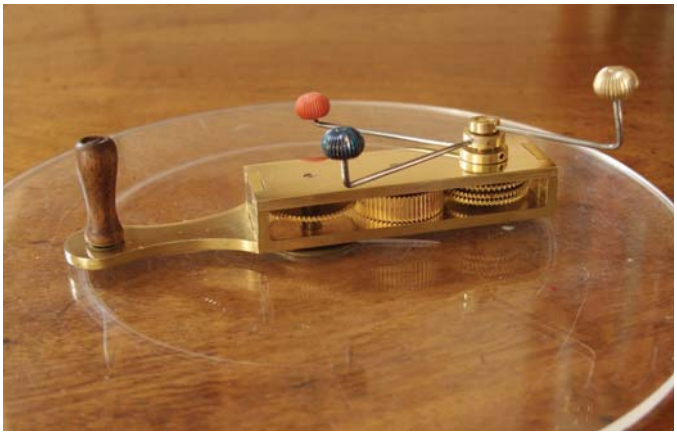
The Paradox

Here is a simplified version of the paradox:

Three wheels on the same axis mesh with one thick wheel. Turn the thick wheel. One of the thin wheels goes forward, one backwards, and one goes no way at all!

Quoting John Millburn[v]:

'One evening Ferguson went to a weekly gathering (probably a dining or drinking club), where one of the other people present, a watchmaker, 'began to hold forth against a Trinity of persons in the God-head, wondering at the impudence of the person who broached such an absurd doctrine'. Ferguson, who was sitting just opposite to him, 'gave him a severe frowning look', whereupon the watchmaker asked his opinion concerning the Trinity. Ferguson suggested that they should



3. The first model.

talk about the watchmaker's business instead, and asked him whether he understood how one gear wheel turned another. 'I hope I do, said he'.

'Then, said I, suppose you make one wheel as thick as other three, and cut teeth in them all, and then put the three thin wheels all loose on one axis, and set the thick wheel to them, so that its teeth may take into those of the three thin ones; now turn the thick wheel round: how must it turn the others? Says he, your question is almost an affront to common sense; for everyone who knows anything of the matter must know that, turn the thick wheel which way you will, all the other three must be turned the contrary way by it. Sir, said I, I believe you think so. Think! says he, it is beyond a thought - it is a demonstration that they must. Sir, said I, I would not have you be too sure, lest you possibly be mistaken; and now what would you say if I should say that, turn the thick wheel whichever way you will, it shall turn one of the thin wheels the same way, the other the contrary way, and the third no way at all. Says he, I would say there was never anything proposed that could be more absurd, as being not only above reason, but contrary thereto. Very well, says I. Now, Sir, is there anything in your ideas more absurd about the received doctrine of the Trinity than in this proposition of mine? There is not, said he; and if I could believe the one, I should believe the other too.'

Ferguson then said that he could make such a machine, and would bring it along to show to the assembled company the following week. He did so, and asked the watchmaker to explain it. The watchmaker turned it to and fro, took it to pieces and put it back together again, and confessed that he was thoroughly perplexed. *'The thing is not only above all reason, but it is even contrary to all mechanical principles'.*

'For shame, Sir, said I, ask me not how it is, for it is a simpler machine than any clock or watch that you ever made or mended; and if you may be so easily non-plused by so simple a thing in your own way of business, no wonder you should be so about the Trinity; but learn from this not for the future to reckon every thing absurd and impossible that you cannot comprehend.'

4. Gears.

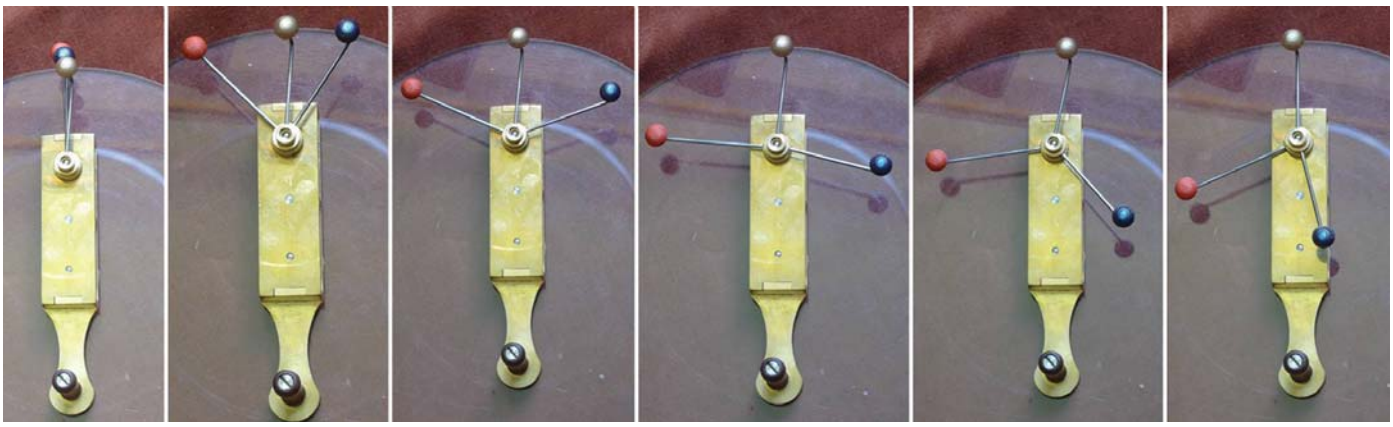
The 'paradox' arises when in a train of gears A, B, and C, gear A is fixed and gears B and C have epicyclic motion around it. Gear A of the orrery is the gear under the Sun and is fixed to the base, **Figure 4.** These motions are what illustrate the motion of the nodes of the Moon's orbit and the apogee of the Moon's orbit. When all three gears have the same number of teeth, gear B rotates twice for each rotation and gear C maintains its orientation to a fixed frame of reference. That keeps the Earth's axis pointed in the same direction (early Cancer). When gear C has fewer teeth than gears A and B, it will slowly turn in the same direction as that of the mechanism, illustrating the advancement of the apogee of the Moon's orbit. When gear C has a few more teeth, it turns in the direction opposite the mechanism, in this case illustrating the regression of the nodes.

Millburn's description '… a simplified version of the arrangement commonly employed in orreries to produce parallel motion by three equal gears, plus a slow advance or regression' explains it perfectly but unremarkably. It takes a conjuror's genius to present it as an insoluble paradox. My original small model demonstrates the paradox more clearly than the orrery, as I used different gearing to emphasise the effect, **Figure 5**.

The Orrery

Ferguson's orrery is unusual in that it illustrates the movement of the nodes and apogee of the Moon's orbit instead of the Moon's position. The Moon's orbit is elliptical, with an eccentricity of about 5.49% (fairly large by Solar System standards). The difference in the perceived size of the Moon between the perigee (the closest approach to the Earth) and apogee (the farthest point from the Earth) is about 12% and the brightness varies by 30%. The precession of the apogee around the Earth is just less than nine years. The pointer on the orrery fixed to the bottom plate represents the position of the apogee of the Moon's orbit.

The Moon's orbit is inclined 5.14° with respect to the plane of



5. Five turns of the model demonstrate the paradox. Red goes backwards, blue goes forwards and gold goes nowhere at all.

the ecliptic (the plane of the Earth's orbit around the Sun.) The points where the Moon's orbit intersects the ecliptic are called the nodes. The conditions for an eclipse require that a node intersect the line of light from the Sun to the Earth and that the Moon be present at the node at the same time. These nodes recess around the Earth with a period of about 18½ years. The sloped ring on the orrery represents the Moon's orbit with a dragon's head representing the ascending node (or North node) and the tail of the dragon representing the descending node (or South node).

The Earth's axis is inclined 23.5° with respect to the ecliptic and remains fixed in that orientation with respect to the zodiac. The orrery illustrates this with a zodiac inscribed on the ring representing the plane of the ecliptic. This small zodiac is always aligned with the large ecliptic dial.

The day/night indicator mounted to the frame facilitates conversations about the different lengths of days and nights throughout the year.

The calendar ring on the base illustrates both the conventional 365 day calendar and the western zodiac with 360 divisions. Ferguson's 1764 engraving shows the effect of Britain's adoption of the Gregorian calendar in 1752, but we don't know with certainty which calendar was on his original model.

References

[i]Ferguson, James. The description and use of a new machine, called the mechanical paradox; invented by James Ferguson, F.R.S. London 1764
A transcription of the text can be found at http://www.horo-logical.co.uk/sme.html

[ii]Ferguson, James. Select Mechanical Exercises, with a Short Account of the Life of the Author, written by himself. 1773

[iii]Horological Journal Vol. I pp.49 & 163; Vol. II p.8. 1860. Available for free download at Google Books http://tinyurl.com/ns8nz6

[iv]http://www.horo-logical.co.uk/paradox.html

[v]Millburn, John R. and King, Henry C. Wheelwright of the Heavens: The Life and Work of James Ferguson, F.R.S. Vade-Mecum 1988

[vi] A fuller description of the construction of JD's model has been submitted to Digital Machinist magazine.

[vii]Reid, John S. Antiquarian Horology vol. XIII pp. 45-50. September 1981

Part 2 in October's HJ.