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Lucky Chance, Fraud or Deception?

The Trials and Tribulations of Harrison's H4

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Introduction by Jonathan Betts MBE FSA FBHI

Anthony has kindly asked me to add a few words of introduction, having been associated with this project since its inception. First, I must congratulate him on the creation of the most beautiful timekeeper as part of this project. 'T45', as it is known, is the most exquisitely made and finished clock.* Its performance, in spite of having only one of the familiar features of the developed chronometer (the correct scale of high-energy oscillator with large amplitude and high frequency), shows that H4 was indeed the breakthrough horologists needed in the 1750s to produce a successful longitude timekeeper.

Unlike H4, T45 employs Harrison's remontoire in a horizontal orientation, with all pivots lying on their sides. This might have caused greater frictional variations in the output, but does not seem to have affected the clock's performance significantly and the whole project has been very valuable in showing what the design is capable of achieving. Anthony's narrative also provides a much needed reminder of the Harrisons' frustrations at the hands of the Astronomer Royal Nevil Maskelyne, whose 1766 trial of H4 following its two successful sea trials was a travesty. Ask any professional watch and chronometer maker today, whose livelihood depended on a fair trial of the performance of their best chronometer, how they would feel if their chronometer were taken from them without notice or preparation, left in a cupboard for several months then, during a trial, subjected to excessive temperature variations on a window sill and being moved into positions for which it was never intended to perform! Sorry, but recent ill-informed attempts to suggest Maskelyne was blameless in this matter are wilfully wrong-headed. With Humphrey Quill's biography of John Harrison now 55 years old, it is high time a fair and well-balanced modern account of his life and work was published.

What follows is proposed as an attempt to answer an outstanding question relating to the history of chronometry and John Harrison's timekeeper H4, **Figure 1**. That is: was it really as good as the results obtained with it during two proving voyages in 1761–2 and 1764, and an official test at Greenwich in 1766–7? Was the technology that was employed sound?

Anyone reading the most recent account of Harrison's life given by Dava Sobel in her book *Longitude* [1], or the earlier volumes by Humphrey Quill [2] or R. T. Gould [3], would be left without definitive answers to these questions. More recently, the technology was described in some detail by the author in a series of articles in this journal. They appeared in the first three months of 2002. The question remains… how well did H4 actually go on a day to day basis?

The official tests were unsatisfactory, to say the least. The results of the first one, the voyage to Jamaica, must have been good — 'too good to be true' — for the Board of Longitude, the official body in charge, who managed to lose them. This followed its inability to organise the test properly, finally sending off H4 by sea in the middle of winter to an island in the Caribbean whose longitude was not even known accurately. The return journey was hazardous in the extreme, the ship fracturing its rudder in a severe storm and only being saved with its precious cargo *in extremis*. The second voyage, to Barbados, at least was better organised, with two astronomers sent in advance to determine the longitude of the island. All went well until a dispute arose because the astronomer in charge, Nevil Maskelyne, had a vested interest in an alternative method of finding longitude using the predicted position of the moon against the background of stars (the Lunar Distance method). A conflict of interest was certainly involved.

In spite of this, the voyage was successfully concluded. Four mathematicians were then engaged to calculate the error of H4 in relation to the longitude of the island. The result of their calculations was recorded on a small piece of paper, still present amongst the Board of Longitude papers, **Figure 2**.

It should be borne in mind that these results refer only to the elapsed time between the beginning and end of the voyage. They give no indication of what happened to the rate from day to day, though on both voyages the watch was evidently keeping time on arrival at Madeira. On each occasion, it predicted the ship's arrival against the estimates of the navigating officers. It is reasonable to assume that its rate remained very close throughout.

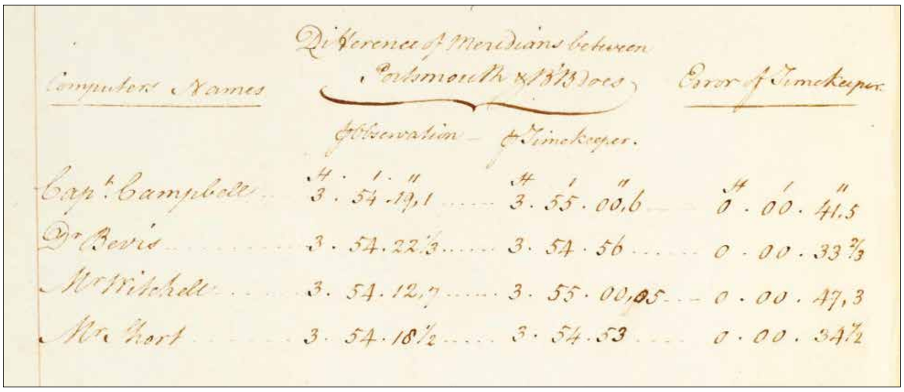
Luckily, this original document has survived, giving an average error of H4 of only 39.2 seconds on arrival at the island. Not only was the result remarkable enough in its own right, it was well within the smallest error allowed to win the whole of the Longitude reward of £20,000, stated to be ½° ,or two minutes of time. The members of the Board of Longitude were forced to accept the result, hence the title of this article!

However, believing that watches were incapable of such stable timekeeping, and suspecting that the results may have been some kind of fluke, they wanted to know more about

* T for Tensator, and 4 and 5 for H4 and H5, on which the mechanism is based.

Images by the author.

Figure 1. H4 dial and back plate.



Computers Names	Difference of Meridians between Portsmouth & Barbadoes: Observation	Difference of Meridians between Portsmouth & Barbadoes: Timekeeper	Error of Timekeeper
	H ′ ″	H ′ ″	H ′ ″
Capt. Campbell	3 . 54 . 19,1	3 . 55 . 00,6	0 . 00 . 41,5
Dr Bevis	3 . 54 . 22⅔	3 . 54 . 56	0 . 00 . 33⅔
Mr Witchell	3 . 54 . 12,7	3 . 55 . 00,05	0 . 00 . 47,3
Mr Short	3 . 54 . 18½	3 . 54 . 53	0 . 00 . 34½

Figure 2. Copy of the original document, Board of Longitude papers. The two middle columns show the longitude of Barbados in hours, minutes and seconds of arc, firstly as calculated from the work of the astronomers, then as indicated by H4. The right-hand column indicates the error of H4 in seconds of time, represented by the difference between the two middle columns for each mathematician.
Ref: Board of Longitude papers for 19 January 1765, archival ref: RGO 14/5 page 70.

the mechanism of the timekeeper. To obtain answers, they nominated the members of a sub-committee to carry out an examination of the watch and report back the result. It consisted of two of their number and four others who were either instrument makers or practising horologists, backed up by the Astronomer Royal (by then Nevil Maskelyne), the same person who had an interest in and was much in favour of the alternative, astronomical, method of finding longitude.

After six days, the members of the Committee pronounced themselves satisfied and issued a certificate to that effect. The Board of Longitude accepted and was obliged to endorse the certificate, giving authority at the same time for Harrison to receive the first £10,000 of the reward. However, in addition, Harrison was to reassemble the watch immediately and hand it over to a representative of the Admiralty. When the nominated person refused, the watch was to be handed to Larcum Kendall, to estimate to make a copy. This requirement also fell through and Harrison was finally requested to deposit the timekeeper at the Admiralty. There, it was relegated to a store room, locked up and sealed for the next six months. A more pointless exercise would be hard to imagine, since it would have been of assistance to both John Harrison himself and Larcum Kendall, both of whom had been engaged by the Board to make copies. Finally, the Board woke up and ordered the timekeeper to be sent to Greenwich for what turned out to be its only official land based test, to be conducted by none other than… Nevil Maskelyne.

When Harrison was requested to reassemble H4, he was not warned of the intention to submit it for a land-based test, nor given any opportunity to prepare it. After its six-month sojourn in a cupboard at the Admiralty, H4 duly arrived at Greenwich. Without more ado, it was simply wound and set, and installed in a deal box, glazed on the top and on one side, and screwed to a windowsill in the transit room. Harrison stated in a pamphlet, that the box was 'exposed to the South East'.[4] If so, then the sun would have shone in through the window and could thus have heated the box for a good part of the day. (Recent attempts to verify Harrison's remark have been unsuccessful.) The thermometer, however, was installed in a shadier part of the room, undoubtedly giving a misleading reading at the moment of inspection. There was also no record of what happened between visits. The box had been fitted with two locks. One key was in Maskelyne's possession, the other was held by retired seamen of the Royal Hospital. Both key holders had to be present before the box could be opened, as happened on a daily basis for winding the watch, checking the rate against the sidereal regulator and noting the daytime temperature. The times of day when these observations were made were not recorded. If they varied, then this would have made a material difference to the apparent stability of the timekeeper, bearing in mind that it had a not insignificant rate. Nor is it mentioned that at night the observing room might have been opened up to allow observations by the transit telescope. Any drop in temperature that occurred, particularly in the colder months, would also have remained unrecorded.

The test lasted from 6 May 1766 to 4 March 1767, after which the results were published and, as might have been expected, were not good.[5] At the outset, the timekeeper had a gaining rate of about 20 seconds/day, dial up. It was then subjected to four tests where it was inclined at 20° to the horizontal and four more in the vertical positions. It had never been prepared for such positional tests. During the winter months of 1766 to 1767 the weather got very cold, even below freezing on occasions, yet towards the end of the test the rate had recovered to almost the same as at the start. Whilst not completely useless, this whole exercise hardly provides a fair indication of H4's performance under more favourable and less rigorous conditions, and in particular what might have happened had Harrison been given the opportunity to prepare the timekeeper in the first place. **Figure 3** shows an example of the rate of H4 (in red) against temperature (in blue) at Greenwich, in dial up position, following initial tests in various other positions. While the temperature remained stable, so did the rate.

The next two graphs, **Figure 4**, show the rate of H4 in December 1766, then in January/February 1767, experiencing extreme conditions for which it was not prepared, and also demonstrating the effect of change of temperature on the rate. For the remainder of 1767 until the end of the test, the rate returned more or less to what it had been at the start.

When these results were published by Nevil Maskelyne, he included his assessment of the unlikelihood that H4 would have been capable of maintaining its rate constant during a further voyage to the West Indies. His conclusion flew in the face of the results already achieved, and which had been accepted as qualifying for the full Longitude reward. Maskelyne's was, after all, the only official land based test of H4. It is equally useless as an indicative series of results for anyone wishing to know how well H4 was capable of keeping time on land. The records that John Harrison must have kept during the development and testing of his timekeeper unfortunately do not appear to have survived.

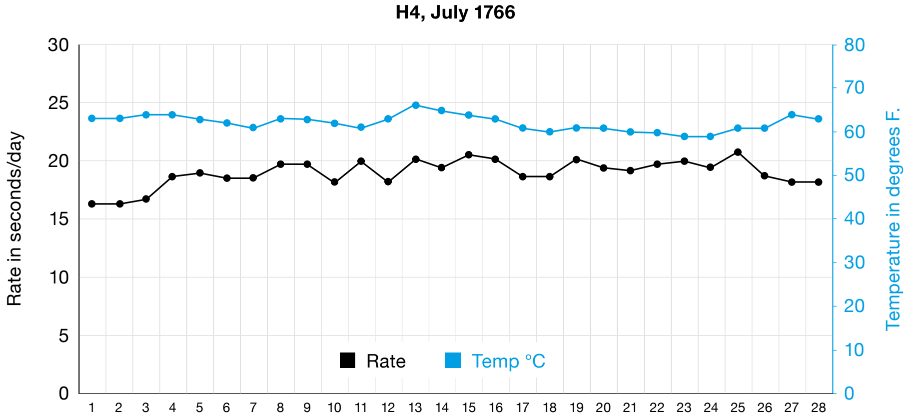


Figure 3. An example of the rate of H4 (in black) against temperature (in blue) at Greenwich, in dial up position, following initial tests in various other positions. While the temperature remained stable, so did the rate.

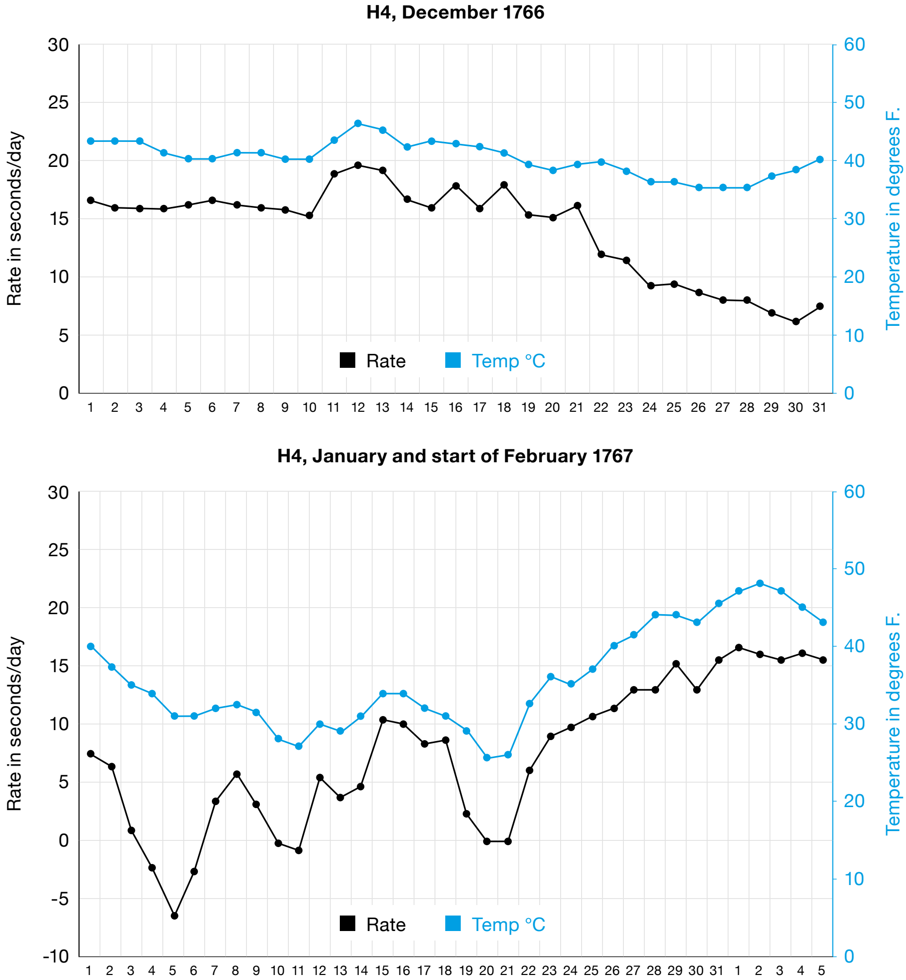


Figure 4. Rate against temperature for just over two months. As soon as the temperature dipped in December, the rate followed, but still recovered when the warmth returned, indicating that the amount of compensation was too great. On the Fahrenheit temperature scale, freezing occurs at 32°F.

Completion of H5

The Board of Longitude had demanded that John Harrison make two more timekeepers similar to H4. He only managed to complete one, known as H5, **Figure 6**, assisted by his son William. Although dated 1770, H5 was not fully adjusted until 1772. John was by then 79 years old. Unfortunately, by that stage, relations between the Harrisons and the Board had broken down due to new and onerous requirements being imposed for the test of the new timekeeper. In desperation, the father and son appealed to the King, George III, who offered to test H5 at his private observatory at Richmond. This offer must have come as a great relief to both Harrisons. The test was to be conducted in the presence of the King by his resident astronomer Dr Stephen Demainbray, with William Harrison also present, and took place at midday each day. Unfortunately the test got off to a bad start, until the King remembered that a quantity of magnetic lodestones had been stored close beneath the place reserved for the timekeeper. As a consequence, H5 behaved very erratically until the lodestones had been removed. It then recovered. That at least is the story that has come down to us, related by John Harrison's grandson using the name of Johan Horrins, an anagram of his name.[6]

Both H4 and H5 have large balances, about 57 mm diameter, **Figure 5**, and made of steel, hardened and tempered. The magnetic field strength of a lodestone is not great, especially by comparison with modern magnets. Even so, there must have been sufficient strength from a quantity of them to cause H5's moving balance to induce electric currents in the steel and thus act as a braking mechanism. It would appear that the rapid movement did not cause the steel to become magnetised; if this had happened, the timekeeper would have been seriously compromised and the test ruined.

Notes Regarding Bringing to Time and Adjusting the Compensation

Figure 5 shows H4's upper plate with the balance cock removed. The bimetallic compensation curb runs horizontally across the middle of the picture. The fixed end is secured to a mounting that allows some positional adjustment. Having passed under the balance and balance spring, the free end carries the two curb pins. These embrace the spring at the point where the slightly curved 'tail' joins the spiral proper. There is no facility to make mean time adjustments such as were incorporated initially, before being abandoned. When asked about this question of bringing to time during the examination of H4, Harrison replied that he loosened the wedge holding the inner end of the spring to the collet and either withdrew the end slightly, or pushed it in deeper before securing it again with the wedge. Adjusting the amount of compensation involved either thinning the bimetal to increase it, or burnishing the bimetal top and bottom to decrease it. Harrison also added that when everything was correctly adjusted, the timekeeper could be taken to pieces, cleaned and reassembled and would go as before, since there were otherwise no adjustments.[7] In the light of experience, it is possible to add that adjustments made as just described are long, tedious and trying on the nerves, even with the benefit of modern testing and monitoring equipment!

Figures 5.

The initial intention was that the test should last six weeks, that being the approximate duration at the time, for a voyage from England to the West Indies. H5's performance was so good that the King asked for it to be extended for a further four weeks, to avoid any possibility of criticism. Dr Demainbray kept a register of the daily rate of H5 during this test at Kew.[8] The last actual entry in the register, taken at 12.00 o'clock, on the 29th of July 1772, records that H5 was fast by 6.3 seconds and had lost 0.4 seconds in the previous 24 hours. On the next page there are some calculations, to include the equation of time and that the regulator clock was 1.8 seconds slow. Beside that, Dr Demainbray has written that the watch was fast by 4.5 seconds. His signature is beneath. That is to say that after 10 weeks continuous going, H5 had gained 4.5 seconds. The daily record starts on the 19th of May 1772 and the last entry is on the 29th of July 1772, **Figure 7**.

That concludes the official and semi-official results of the two land-based tests of H4 and H5. They remain all we have to go on except for the two voyages. Is it possible to conclude that there is no question of 'Lucky Chance, Fraud or Deception'? Both timekeepers still exist, so could they be subjected to modern tests? Possibly, although after some 250 years would such tests, always assuming that they were permitted, have any real meaning? H4 has had a good deal of running time whilst on display at the National Maritime Museum, has had parts changed including a broken mainspring and some additional jewelling in order to keep it going. H5 is in much better condition but has been through several hands in order to be cleaned and re-oiled. It still has its original mainspring though, of course, fatigued after some use and suffering the effects of old age.

As an alternative way of answering these questions, why not remake the mechanism and then test it with the benefit of modern means of monitoring? A basic problem remained: no drawings or other record of the dimensions of the parts existed. All that was available was the work published in 1767, *Principles of Mr Harrison's Timekeeper with plates of the same, by order of the Commissioners of Longitude*, prepared for them by Nevil Maskelyne. The intention at that time was to provide sufficient information to allow other watchmakers to make copies of H4. Unfortunately, *Principles* was and is inadequate for that purpose, the information given being insufficient. Nothing has been done to replace it since.

Figure 6. H5 dial and back plate.

Images by Clarissa Bruce, courtesy of The Worshipful Company of Clockmakers.

For many years H4 has been a part of the horological collection at the National Maritime Museum at Greenwich. The official custodian was the Hydrographer of the Navy who had transferred the safe keeping of H4 to the Museum. Successive holders of that office have simply refused to allow dimensions to be taken, which is an irony in itself since the timekeeper had been acquired for the nation with the express purpose of allowing anyone who might wish to copy it to gain access to it. The reason for the refusal has been quoted as a fear that inferior copies might be made and sold, bringing the original into disrepute. As far as is known, no copy has ever been made until very recent times. This is not too surprising, given the complexity of the mechanism, the difficulty of making some of the parts — the diamond pallets for instance — and especially the fact that the technology applied to accurate portable timekeepers moved on so rapidly. Following Harrison's demonstration of the optimum specification for the oscillator for a practical chronometer, by the end of the eighteenth century the essential components of the modern chronometer had been developed and finalised, resulting in the availability of relatively cheap and accurate timekeepers in some quantity.

Although the Hydrographer's refusal situation had been in force for many years, a decision was taken in 1983 that the two famous timekeepers made by John Harrison — that is, H4 and H5 — together with Larcum Kendall's copy of H4 known as K1, should undergo a thorough clean and conservation. This was to be done in the workshop of the National Maritime Museum. In this way, an opportunity arose for a careful study and comparison of the three mechanisms, together with the taking of accurate measurements of their component parts. It was the first time that such a thing had ever been done. Although the embargo on making copies was still in force, it did not apply to the remaking of the essential mechanism in a form not resembling any of the originals but otherwise faithful to them. As a result of this study, my clock incorporating the mechanism, **see Figure 9 and Front and Rear covers**, was in a partially completed but running state in time for the Symposium at Harvard University in 1993, in commemoration

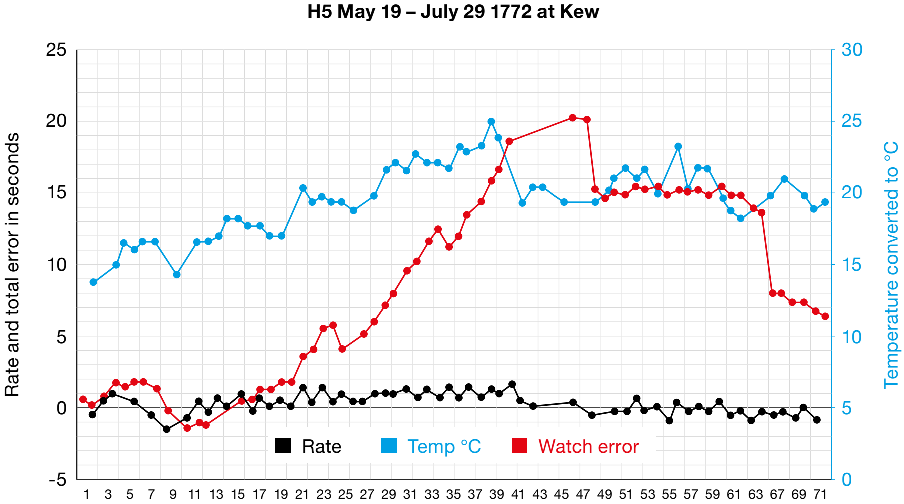


Figure 7. Graph showing the daily rate of H5 (in) during the test at George III's observatory at Richmond during ten weeks. The total accumulated error of the hands of the watch is shown in red and the temperature in blue. Although the daily rate was close, never exceeding two seconds and usually less, either gaining or losing, the maximum accumulated error as shown by the hands still reached just over 20 seconds, before falling back to just over six seconds.

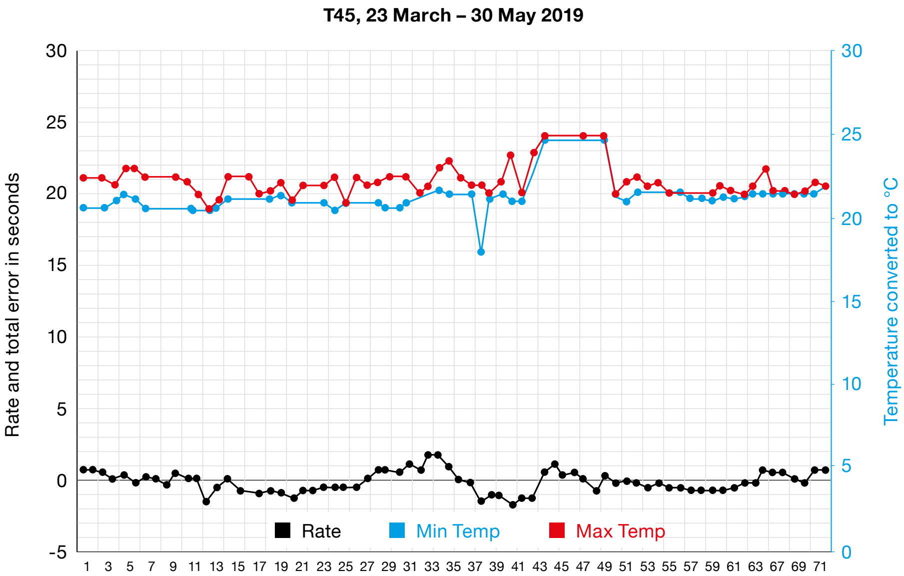


Figure 8. Test of the eight-day clock in Figure 9 whose mechanism is based on that of H4 and H5, to compare with Figure 7, during a test lasting 73 days or just over ten weeks.

Images by the author.

Figure 9. Harrison's H4/H5 mechanism reconstructed in an eight-day clock with Tensator mainsprings. The component parts from the centre wheel on through the train, copy the originals, although the arbors are extended to correspond with the separation of the plates. The Tensator springs provide an almost constant drive, similar to the fusee system that Harrison used in H4/H5 and include his maintaining power. The reserve of going indication has been added for convenience.

of the three hundredth anniversary of Harrison's birth. It took a few more years to complete the clock and a few more still to get the mechanism to run correctly and prove that it could keep time. In parallel, I recorded some of the processes involved in the aforementioned article series, 'An Analysis and Reconstruction of the Mechanism of H4'.

The following graph, **Figure 9**, shows that having recreated the original mechanism and subjected it to a test similar to the one carried out on H5, a similar result can be obtained. From that we can conclude that Harrison's technology, although with significant differences from what developed subsequently, was perfectly sound and thus settle the questions posed at the start of this article. There was simply no question of fraud, deception or lucky chance being involved during H4's two proving voyages. Those unhappy members of the Board of Longitude should finally rest in peace.

Acknowledgements

I would like to give particular thanks to Jonathan Betts for reading the text, making several suggestions, and especially for contributing the introduction. He was also responsible for providing the opportunity to measure and compare the component parts of H4 and H5, and to make a photographic record of the two movements.

I would also like to thank Carl Murray, who made the diamond pallets, and Dr Alexander Stewart for the reference for **Figure 2**.

Last but not least to my wife, Anne-Marie, who has helped in so many ways throughout this long project with much patience and forbearance.

ENDNOTES

1. Dava Sobel, *Longitude* (London: HarperCollins, 2011).
2. Humphrey Quill, *John Harrison: The Man Who Found Longitude* (London: John Baker Publishers, 1966).
3. Rupert T. Gould, *The Marine Chronometer: Its History and Development* (various editions).
4. Remarks on a Pamphlet lately published by the Rev. Mr Maskelyne, under the authority of the Board of Longitude, 1767.
5. Nevil Maskelyne, Astronomer Royal, *An Account of the going of Mr John Harrison's watch, at the Royal Observatory, from May 6th 1766 to March 4th 1767*, 13 March 1767.
6. Johan Horrins, *Memoirs of a Trait in the Character of George III*, London, 1835.
7. John Harrison and Nevil Maskelyne, 'Notes taken at the discovery of Mr Harrison's Time-Keeper,' forming part of *The Principles of Mr Harrison's Time-Keeper with plates of the same*, London, 1767.
8. King's College London Archives: The George III Museum Collection.