John Kaye of Liverpool – Can his clock predict the time and height of high water at Liverpool?

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Much has been written about rolling moon tidal dials which show the time of high water at a particular location. The clock by John Kaye, which provides the focus for this article, has a universal tidal ring attached to its moon dial, but also shows the time, and uniquely the height of high water, using three other parts of its dial, namely: data engraved on a fixed arch (above the moon dial), data engraved on a subsidiary dial showing the effects of the moon's elliptical orbit, and data engraved on a second subsidiary dial showing the effects of wind speed and direction. Our purpose was to understand and use this extra data and to establish its accuracy (particularly the heights of high water) both when it was made c.1775 and today. In addition, the clock took us on a round-the-world voyage, led by the locations on its chapter ring; the accuracy of the placement of these and the reasons for their selection was also studied.

The dial which provides the focus of this article may be familiar to members who recall seeing it in this journal in 2007, when it was described to publicise the *Your Time* exhibition which was held at the Williamson Museum and Art Gallery in 2008.[1] The dial is from a fine, mahogany longcase clock made in Liverpool by John Kaye about 1775. It contains what could at first sight be thought a bewildering amount of detail in its arch, too much for the casual observer, indicating that it is a special functioning tool, rather than a clock for domestic purposes. Close inspection is rewarded by allowing 'High water at St Georges Dock' to be spotted amongst a long sequence of numbers.[2] So it is clearly a tidal dial, but there is more. Two rings appear to be showing the times of high water and another has more numbers. There are also two subsidiary dials, one marked perigee and apogee, and another showing wind directions. The chapter ring is more familiar, having a series of locations marked between the hours—some known and important today, others no longer in use. Discovering the reasons behind these locations, the use to be made of the subsidiary dials and the value of all the numbers has proved a fascinating journey.

Readers will be familiar with rings showing the moon's age with an inner ring of Roman numerals which predict times of high water at a stated location, or universal tidal rings which can be set to provide times at any location if certain lunar and tidal information is known and a pointer is set accordingly. The Roman ring on this dial could be read in this

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1. Michael Hurst and Dennis Moore, 'Exhibition Preview. John Kaye – Liverpool', *Antiquarian Horology*, December 2007, 550–553. The clock also featured on the front cover and on pages 98–99 of the *Your Time* catalogue (AHS, 2008).

2. This was inscribed in error. It should have read 'Georges Dock' after King George lll. When the name is written, there is rarely an apostrophe; it will also be omitted here.

Fig. 1. Engraved detail in the Kaye arch.

way, but there is much more information to be gleaned which is specific to Liverpool. This is the only dial we have seen which shows predicted heights of tides. This was important to ports such as Liverpool which had a large tidal range; the town's enclosed docks meant that there had to be a certain level of water above the dock's sill to allow ships' safe entry or exit. This complicated the logistics of ship movements in and out of docks which had to be organised around a relatively short window of opportunity when there was sufficient water above the sill.

As the rolling moon disc indicates only times of high water for whichever location it is set, this analysis will concentrate on the data on the fixed arch above it.

It is no surprise that this was made in Liverpool, as detailed records were kept by the dock master of the Old Dock and water bailiff for the port, William Hutchinson from 1764 to 1793.[3] He recorded not only the times and heights of each tide, but also wind direction and strength, the age of the moon and its position regarding its elliptical orbit (the varying distance between the moon and the earth). Such data was priceless, and is still valued today. The Holden brothers appreciated this data and used the first four years of it to create the country's first tide prediction tables in 1770.[4] These proved so reliable that in time it was made an offence (with a fine of £5) for a Mersey pilot to leave the port without a watch and the tables.[5] Bound into a treatise

3. William Hutchinson (1715/16–1801) was born in Newcastle-upon-Tyne and spent his early life at sea. He began by assisting a ship's cook on colliers delivering coal from Tyneside to London and later joined the Royal Navy rising through the ranks until he was able to captain his own vessels. During the Seven Years' War he became a privateer, sailing from Liverpool to the Americas and around Europe in search of enemy vessels to plunder and/or capture. He gained a reputation as a wise and fair captain who ran well-regulated ships. He gave up life at sea in 1759 when he accepted the post of dock master and water bailiff. His tidal records were kept from 1764 to 1793 and are still of value today.

4. Philip L. Woodworth, 'Three Georges and one Richard Holden: the Liverpool tide table makers', *Transactions of the Historic Society of Lancashire and Cheshire*, vol. 151, 19–51. The theory behind the creation of the tables, kept secret for many years, was adapted from the work of Swiss physicist and mathematician Daniel Bernoulli. Richard Holden initially worked with his brother George(1), who was succeeded by his son George(2) and his son George(3). George(1) has been given most credit for the tables, probably erroneously. The tables continued to be published by the Holdens through three generations and were then continued by others until the later part of the twentieth century.

5. Philip L. Woodworth, 'William Hutchinson – Local Hero', in *Ocean Challenge*, vol. 8, no. 3 (1998), 47–51.

Figs 2 and 3. These images of the clock and dial show small subsidiary dials to the left and right under the fixed arch: neither of these is driven by the clock, they are set manually, both are important when forecasting the level of high water at the next tide. The chapter ring shows coastal locations between the hours; when the hour hand points to each name it will be approximately noon or midnight there. Several other clocks incorporate this feature for calculating the time at various locations throughout the world. The place names, in this case, all west of Liverpool, cross the Atlantic and are dotted around the Americas and across the Pacific.

written and published by Hutchinson in 1777, was *A Chart of the Harbour of Liverpool with soundings at Low Water Spring Tides by PP Burdett, 1771*. It advised mariners that at the Old Dock gates, 'at three Hours before and after High Water, at all Times of the Moon, there is about 4½ Feet Water'.[6]

It is not known who created the layout to be engraved on Kaye's arch, but it could well have been Richard Holden who was known to be skilled in mathematics and was a friend of Hutchinson. Analysis of this data on the fixed arch will show that it contradicts and therefore supersedes the more standard timings on the revolving moon dial.

6. William Hutchinson, *Treatise on Practical Seamanship*, published by the author, 1777. This was sold at seaports throughout the country and was subsequently enlarged and re-printed. Its subtitle is virtually a list of contents: *TREATISE ON PRACTICAL SEAMANSHIP; With HINTS and REMARKS relating thereto: Designed to contribute something towards fixing RULES UPON Philosophical and Rational PRINCIPALS; TO Make SHIPS, and the MANAGEMENT of them AND ALSO NAVIGATION, in GENERAL, more PERFECT, AND Consequently less DANGEROUS AND DESTRUCTIVE TO HEALTH, LIVES, AND PROPERTY.*

Table 1	Kaye's fixed arch data	
Age of Moon	Time of high water hrs:mins	Mean height of sea feet:ins
1	11:40	18'3"
2	12:20	19'0"
3	1:00	18'6"
4	1:20	17'9"
5	1:50	16'6"
6	2:20	14'4"
7	3:00	13'6"
8	3:50	12'9"
9	4:40	12'3"
10	6:00	12'6"
11	7:00	13'6"
12	8:10	14'6"
13	9:20	16'0"
14	10:30	16'10"
15	11:10	18'2"
16	12:10	18'9"
17	12:40	18'10"
18	1:10	18'6"
19	1:40	17'10"
20	2:10	16'10"
21	2:50	15'2"
22	3:30	13'10"
23	4:30	13'0"
24	5:30	12'4"
25	6:30	12'0"
26	7:30	12'6"
27	8:30	13'6"
28	9:40	15'0"
29	10:30	16'6"
29½	11:00	17'3"
This information was gathered by the authors and Phil Woodworth by advancing the moon disc through its lunar month.		

The analysis which follows was carried out to determine how good John Kaye's clock was, and still is, at forecasting the time and height of high water at Liverpool.

John Kaye's fixed arch

Before dealing with the numbers, the observer needs to extract the 'descriptions' engraved with the two sets of data on the arch. The outer sequence incorporates letters hidden amongst the numbers: 'Mean Height of the SEA', whilst the inner set hides: 'High Water at St GEORGES Dock LIVERPOOL'.

Once these words have been extracted it is clear that the outer half circle represents mean height of the sea in feet, whilst the inner represents the time of high water at Georges Dock Liverpool. Table 1 simply extracts the data from the fixed arch and presents it in tabular form.

In order to align the time and height with the moon's age it is necessary to use the small arrow on the moon dial (beside 29).

Using the pointer at the top of the moon disc, Fig. 1 shows the moon's age as 15 days (ie. full moon). The small pointer at 29 should then be used to read off the time and height from the fixed arch (not the Roman numbers on the moon disc) and in this case, the time of high water is just after 11 o'clock and the height is a little over 18 feet.

Using Fig. 3 as an example, the moon is about 7½ days old and, again using the small arrow, the time of high water is nearly 3.30 and the height about 13 feet. Table 1 has been constructed in this manner.

At the time the clock was made, Georges was the new large dock, not far from the smaller Old Dock where William Hutchinson was dock master; his measurements relate to the Old Dock Sill and would equally relate to the new dock.[7] Data were kept twice daily (night and day) for almost thirty years with few gaps. He wrote that he recorded

> the time and height of the tides flowing at the old dock gates [*from*] the sill of the gates, from whence is [*sic*] marks in the stone work upward to twenty-two feet and a half, from which the heights of the tides are taken [8]

and that anyone thinking of recording tides 'ought always to set his watch right immediately before, by some good sundial; for these calculations are made according to [*local apparent*] solar time'.[9]

7. All docks built after the Old Dock had their depths recorded so that comparisons could be made with the Old Dock sill, which still provides the chart datum for Liverpool.

8. Hutchinson, *Treatise*, p. 140.

9. Hutchinson, *Treatise*, p. 144.

The next stage is to assess how good this data was in the second half of the eighteenth century. Fortunately, we have access to Hutchinson's records;[10] Table 2 contains his data for November/December 1770. He included the moon's age, apogee/perigee, morning and evening tide times, height of water, and wind strength and direction. Apogee is the point at which the moon is furthest from the earth, perigee when it is closest. The difference between the two extremes is approximately 28,000 miles.[11]

Table 2	Hutchinson's data for Nov/Dec 1770				
1770	Age of Moon		Morning tide hrs:mins	Height of water ft:ins	Wind mph
Nov 17	29½	new moon	11:00	17'0"	SE 20
18	1		11:40	17'7"	SSE 15
19	2		none		ENE 15
20	3		0:35	16'9"	NE 7
21	4		1:15	16'1"	S 5
22	5	apogee	1:40	15'9"	SSE 5
23	6		2:20	14'9"	S 5
24	7		3:00	13'2"	W 5
25	8	quarter	3:50	12'7"	SSE 5
26	9		5:00	12'9"	W 30
27	10		6:10	11'7"	N 20
28	11		7:25	12'0"	LIGHT
29	12		8:15	14'9"	SSE 10
30	13		9:10	15'0"	calm
Dec 1	14		9:45	16'0"	SSE 5
2	15	full moon	10:30	17'3"	W 5
3	16		11:15	18'3"	WSW 5
4	17		12:00	18'8"	S 3
5	18		0:25	18'4"	SSE 7
6	19	perigee	1:30	20'9"	W 50
7	20		2:00	18'6"	NW 30
8	21		2:55	16'8"	W 10
9	22	quarter	3:45	14'8"	NNW 7
10	23		4:40	13'10"	calm
11	24		6:05	13'4"	S 5
12	25		7:00	16'11"	W 40
13	26		8:30	15'4"	SSE 10
14	27		9:10	15'6"	WSW 10
15	28		9:55	16'2"	calm
16	29		10:45	16'10"	W25
17	29½	new moon	11:20	18'1"	W 30
18	1		11:55	17'9"	SE 20
19	2		0:25	20'0"	WSW 50
20	3		0:50	16'3"	WSW 40
21	4		1:30	16'9"	N 30
The information in Table 2 is not far away from the data predicted in the fixed arch. Further analysis may reduce any discrepancies further.					

10. Hutchinson donated his records (minus those of the first four years which he gave to the Holdens) to the Liverpool Library. A microfilm copy is available at Liverpool Record Office, Liverpool Library (LRO,LL).

11. www.nasa.gov

When perigee coincides with a full moon, it is referred to as a 'supermoon' and looks larger than usual because of its greater proximity to earth. When perigee and a full moon coincide, we get the highest tides (these sometimes occur a day or two later).

As the information provided on John Kaye's fixed arch is for conditions affected by the moon's age only, other influences on Hutchinson's observations need to be removed to 'normalise' the data. The arch data, with the subsidiary dials, provides the means to do this.

The times of high water shown on the Kaye fixed arch is very closely aligned with Hutchinson's 1770 records. Table 3 shows that the alignment is just as good today.

Hutchinson understood that local tides did not follow a pattern based on simple lunar observations; there was more at play:

> At *Leverpool* I have observed ships coming in at neap tides about the quarters of the moon, when instead of meeting with high water, as expected by the common way of reckoning, they have found it about a quarter ebb, that for want of water enough they have often struck or come a-ground and laid upon the bar, when loss or great damage has often been the consequence.[12]

Table 3.

Kaye Fixed Arch Data			National Oceanography Centre		
Age of Moon	Time of High Water hrs:mins		Jan/Feb 2020 Morning/Afternoon Tides hrs:mins		
			11.28/23.51	Jan-25	
1	11.40		12.05/ -	26	
2	12.20		00.26/12.39	27	
3	1.00		00.59/13.12	28	
4	1.20		01.30/13.46	29	Apogee
5	1.50		02.03/14.31	30	
6	2.20		02.37/14.57	31	
7	3.00		03.15/15.39	Feb-01	
8	3.50		04.02/16.30	2	Quarter
9	4.40		05.04/17.38	3	
10	6.00		06.21/18.56	4	
11	7.00		07.39/20.08	5	
12	8.10		08.42/21.08	6	
13	9.20		09.35/21.59	7	
14	10.30		10.22/22.45	8	
15	11.10		11.06/23.30	9	Full Moon
16	12.10		11.51/ -	10	Perigee
17	12.40		00.15/12.35	11	
18	1.10		01.00/13.19	12	
19	1.40		01.44/14.03	13	
20	2.10		02.29/14.49	14	
21	2.50		03.16/15.39	15	Quarter
22	3.30		04.10/16.38	16	
23	4.30		05.16/17.54	17	
24	5.30		06.36/19.19	18	
25	6.30		7.56/20.36	19	
26	7.30		09.02/21.36	20	
27	8.30		09.54/22.23	21	
28	9.40		10.36/23.01	22	
29	10.30		11.13/23.35	23	New Moon
29½	11.00				

The timings are very close, particularly in the first half of the month. We do know that the engraving is not symmetrical which explains the divergence after lunar day 21, (but not why the fixed arch is asymmetrical).

12. Hutchinson, *Treatise*, p. 140.

The common way of reckoning mentioned by Hutchinson in this reference comprised a simple set of rules for the local time of high water based on the age or phases of the moon. This indicated that high water at full or new moon occurred at a local solar time at each location. On days after full and new moon, the high water would be expected to occur approximately forty-eight minutes later each day.[13] However, the tides do not follow the moon in such a simple way and there was no allowance for meteorological or other influences on the observed tide. This was satisfactory for land-based activities, but not so for mariners especially where wind, currents and depth and shape of the sea-bed affected the tide locally. We believe the Kaye dial was informed directly or indirectly by Hutchinson's local observations of tides, allowed for the moon's apogee and perigee and for wind direction and velocity and thus achieves greater accuracy than tidal clocks with solely a universal tidal ring attached to a rolling moon which show high tide at 12 o'clock at new and full moon.[14]

The subsidiary dials

1. The wind effect

Fig. 4. The wind dial.

Hutchinson used Smeaton's wind intensity scale (Table 4). In reading the scale on the wind subsidiary dial (Fig. 4), it is important to note that during the intervening 250 years since it was created, subtle changes in the definitions of some terms have occurred. Therefore the wind descriptions are not incorrectly placed on the dial as was thought when a description of the clock appeared in *AH* December 2007, p. 555, where the authors wrote: 'It appears that the engraver mistakenly has put 'Gale' in the 'Brisk Wind' zone and merely 'Wind' in the 'Very Strong' zone'.

An interesting feature of this dial is the engraved curved lines providing a gradient very much skewed to smaller rather than larger water level differences. Inspecting the pointer in Fig 4 shows a wind direction of west south-west, when even a very strong wind in excess of 30mph would add less than 3 feet to the water level. A gale would add about 1 foot.

Table 4. Smeaton's wind scale

Speed mph	Common appellation	Kaye's wind dial
1	Hardly perceptible	
2	Just perceptible	
3		
4	Gentle pleasant wind	
5		
10	Pleasant brisk gale	Brisk gale
15		
20	Very brisk	
25		
30	High winds	Strong wind
35		
40	Very high	
45		
50	A storm or tempest	Very strong wind
60	A great storm	
80	An hurricane	
100	An hurricane that tears up trees etc	

Royal Society Transactions, Vol. 51, 1759 p.165.

13. David E. Cartwright, *Tides. A Scientific History* (Cambridge: Cambridge University Press, 1999).

14. These dials need to be set with a pointer by observation to local high tide time on the days of full or new moon. They could then be read on subsequent days as the moon roller rotated (without moving the pointer).

2. The elliptical anomalistic orbit of the Moon

Owing to the elliptical orbit, the force exerted by the moon will vary; stronger when it is closer to the earth (perigee) and weaker when it is furthest (apogee). This subsidiary dial is also not worked by clockwork (as it could be with its 27½ day anomalistic month) but needs to be manually set. In Fig. 5, the dial has been set to the 10th day after apogee in its cycle. This shows that high water will be delayed by 10 minutes and that because of the closeness of the moon, the high water level will be raised by just less than 2 feet. See Table 5.

Right: Fig. 5. The anomalistic dial.

Table 5		Moon	Hutchinson's data Nov/Dec 1770			Kaye	Hutchinson	Kaye fixed arch	
1770	Age of Moon		Morning tide hrs:mins	Height of water ft:ins	Wind mph	wind effect dial	Net height of tide feet	Mean height feet:ins	Time hrs:mins
Nov 17	29½	New moon	11:00	17'0"	SE 20	0	17 feet		
18	1		11:40	17'7"	SSE 15	sub ¾	17 feet	18'3"	11:40
19	2		none		ENE 15	add 1	no tide	19'	12:20
20	3		0:35	16'9"	NE 7	add ½	17¼ feet	18'6"	1:00
21	4		1:15	16'1"	S 5	sub ¼	16 feet	17'9"	1:20
22	5	apogee	1:40	15'9"	SSE 5	sub ¼	15½ feet	16'6"	1:50
23	6		2:20	14'9"	S 5	sub ¼	14½ feet	14'4"	2:20
24	7		3:00	13'2"	W 5	sub ¼	13 feet	13'6"	3:00
25	8	quarter	3:50	12'7"	SSE 5	sub ¼	12¼ feet	12'9"	3:50
26	9		5:00	12'9"	W 30	sub 1¾	11 feet	12'3"	4:40
27	10		6:10	11'7"	N 20	add 1½	13 feet	12'6"	6:00
28	11		7:25	12'0"	light	0	12 feet	13'6"	7:00
29	12		8:15	14'9"	SSE 10	sub ¼	14½ feet	14'6"	8:10
30	13		9:10	15'0"	calm	0	15 feet	16'	9:20
Dec 1	14		9:45	16'0"	SSE 5	sub ¼	15¾ feet	16'10"	10:30
2	15	Full moon	10:30	17'3"	W 5	sub ¼	17 feet	18'2"	11:10
3	16		11:15	18'3"	WSW 5	sub ¼	18 feet	18'9"	12:10
4	17		12:00	18'8"	S 3	sub ¼	18¼ feet	18'10"	12:40
5	18		0:25	18'4"	SSE 7	sub ½	18 feet	18'6"	1:10
6	19	perigee	1:30	20'9"	W 50	sub 2	18¾ feet	17'10"	1:40
7	20		2:00	18'6"	NW 30	0	18½ feet	16'10"	2:10
8	21		2:55	16'8"	W 10	sub ¼	16¼ feet	15'2"	2:50
9	22	quarter	3:45	14'8"	NNW 7	add ¼	15 feet	13'10"	3:30
10	23		4:40	13'10"	calm	0	14 feet	13'	4:30
11	24		6:05	13'4"	S 5	sub ¼	13 feet	12'4"	5:30
12	25		7:00	16'11"	W 40	sub 2	9 feet	12'	6:30
13	26		8:30	15'4"	SSE 10	sub ¼	15 feet	12'6"	7:30
14	27		9:10	15'6"	WSW10	sub 1	14½ feet	13'6"	8:30
15	28		9:55	16'2"	calm	0	16 feet	15'	9:40
16	29		10:45	16'10"	W25	sub 1¼	15¾ feet	16'6"	10:30
17	29½	New moon	11:20	18'1"	W 30	sub 1½	16¾ feet	17'3"	11:00
18	1		11:55	17'9"	SE 20	0	17¾ feet		
19	2		0:25	20'0"	WSW 50	sub 1	19 feet		
20	3		0:50	16'3"	WSW 40	sub 1	15¼ feet		
21	4		1:30	16'9"	N 30	add 1¾	18½ feet		

The table shows a closer alignment in over half of the lunar month, but a wider divergence on 12 days. So, will the next analysis using the anomalistic data bring a closer alignment?

Table 6 shows the effect on high water using the information on this subsidiary dial, linking the data to Hutchinson's perigee and apogee notes from his 1770 recordings. So, the Kaye subsidiary dial can be used with Hutchinson's 1770 data to reverse the effect that the anomalistic orbit has had – where the Kaye dial indicates an addition to high water, this figure should be subtracted from Hutchinson's actual measurements (and increased where the dial indicates a subtraction). This should render the Hutchinson recorded data to a state unaffected by the variable forces caused by the moon's elliptical orbit. In the table, the high water information on John Kaye's fixed arch in blue and in Hutchinson's normalised observations also in blue have now significantly converged proving Hutchinson's data to be of high quality. To have such a tool in the 1770s would have provided an advantage when managing the Liverpool docks and vessel movements.

Table 6.

Age of Moon	Hutchinson Net height of tide at Old Dock (feet)	Moon's Anomalistic month	John Kaye Apogee/Perigee Subsidiary dials (feet)	John Kaye Apogee/Perigee Subsidiary dials (minutes)	Hutchinson's Adjustment for Apogee (feet)	John Kaye Fixed Arch Mean Height (feet:ins)	John Kaye Fixed Arch Time (hrs:mins)
29½	17 feet	23	add ¾	sub 24	17¾		
1	17 feet	24	add 1	sub 22	18	18'3"	11:40
2	no tide	25	add 1¼	sub 20		19'	12:20
3	17¼ feet	26	add 1½	sub 18	18¾	18'6"	1:00
4	16 feet	27	add 1¾	sub10	17¾	17'9"	1:20
5	15½ feet	A 27½	add 1¾	sub 8	17¼	16'6"	1:50
6	14½ feet	1	add 2	0	16½	14'4"	2:20
7	13 feet	2	add 2	0	15	13'6"	3:00
8	12¼ feet	3	add 1¾	add 8	14	12'9"	3:50
9	11 feet	4	add 1½	add 10	12½	12'3"	4:40
10	13 feet	5	add 1¼	add 15	14¼	12'6"	6:00
11	12 feet	6	add 1	add 20	13	13'6"	7:00
12	14½ feet	7	add 1	add 22	15½	14'6"	8:10
13	15 feet	8	add ½	add 24	15½	16'	9:20
14	15¾ feet	9	0	add 24	15¾	16'10"	10:30
15	17 feet	10	sub ½	add 22	16½	18'2"	11:10
16	18 feet	11	sub 1	add 20	17	18'9"	12:10
17	18¼ feet	12	sub 1¼	add 18	17	18'10"	12:40
18	18 feet	13	sub 1½	add 12	16½	18'6"	1:10
19	18¾ feet	P 14	sub 1¾	add 8	17	17'10"	1:40
20	18½ feet	15	sub 2	0	16½	16'10"	2:10
21	16¼ feet	16	sub 1¾	sub 8	14¼	15'2"	2:50
22	15 feet	17	sub 1½	sub 12	13½	13'10"	3:30
23	14 feet	18	sub 1¼	sub 18	12¾	13'	4:30
24	13 feet	19	sub 1	sub 20	12	12'4"	5:30
25	9 feet	20	sub¾	sub 22	8¼	12'	6:30
26	15 feet	21	0	sub 24	15	12'6"	7:30
27	14½ feet	22	add ½	sub 25	15	13'6"	8:30
28	16 feet	23	add ¾	sub 24	16¾	15'	9:40
29	15¾ feet	24	add 1	sub 22	16¾	16'6"	10:30
29½	16¾ feet	25	add 1¼	sub 20	18	17'3"	11:00
	17¾ feet	26	add 1½	sub 18	19¼		
	19 feet	27	add 1¾	sub 10	20¾		
	13¼ feet	A 27½	add 1¾	sub 8	15		
	18½ feet						

The alignment of heights, though not to the standard that the NOC would expect today, is truly amazing for an instrument made in the 1770s, utilising only three of the many variables. When problems of phasing of the two columns of water height are taken into consideration, the John Kaye dial is even more astonishing.

Could this 'instrument' be of use today? There is no shortage of tidal data published today. One of the leading world institutions on the movement of water on our planet is the National Oceanography Centre based in Liverpool (NOC).[15] Apart from still having two mechanical tide forecasting machines, one of which was used to plan the D. Day landings of World War II, (The Doodson-Légé machine with forty-two variables which affect the tides), the NOC uses complex computer technology utilising not only the effects of the planetary motions, but also the complex effects of topography.

It must be borne in mind that three variables were considered by John Kaye:

1. The moon's position on its lunar 29½ day orbit (new and full moons provide higher tides).
2. The moon's position on its anomalistic 27½ day orbit (supermoon is closer to the earth).
3. Wind speed and direction.

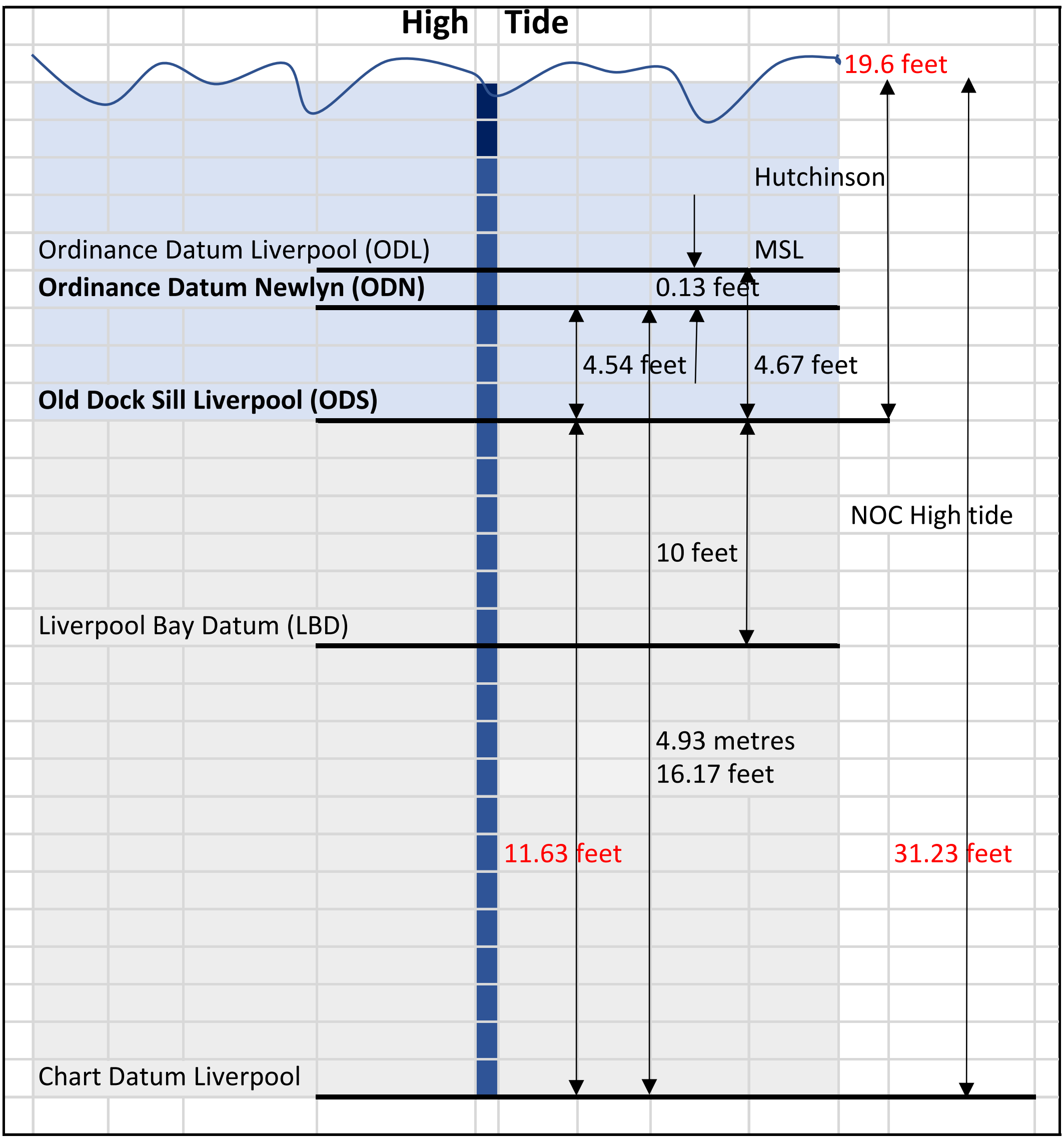


Fig. 6. Changes in sea level and the different data used to predict heights of tides.

15. There is also a centre at Southampton.

In order to further analyse John Kay's clock, it is first necessary to do two things:

1. Adjust for sea level rises between the 1770s and 2020. Sea levels have consistently risen by approximately 1.7mm per annum, which gives a sea level rise of 425mm or 1.39 feet since 1770. This means that John Kaye's figures need to be increased by 1.39 feet for a comparison to be made.

2. Adjust Hutchinson's observation taken at the Old Dock Sill (ODS) to be able to compare with the datum level used by NOC – Chart datum Liverpool. See Fig. 6.

It can be seen from Table 7 that 11.63 feet should also be added to Hutchinson's data on account of the datum line change. When added to the sea level rise (1.39 + 11.63) the rule of thumb figure becomes 13 feet – so either add 13 to Hutchinson or subtract 13 from NOC: the following Table 7 does the latter.

Table 7.

National Oceanography Centre 2020 – Gladstone Dock							John Kaye Fixed arch	
Date 2020	Moon	Age of Moon	Morning High Tide metres	Morning High Tide feet	Less 13 ft adjustment feet	Less 13 ft adjustment feet:ins	Mean Height feet:ins	Time hrs:mins
24	New at 21.24 hrs	29½	9.11	29.89	16.89	16'10"		
25		1	9.27	30.41	17.41	17'5"	18'3"	11.40
26		2	9.33	30.61	17.61	17'7"	19'	12.20
27		3	8.94	29.33	16.33	16'4"	18'6"	1.00
28		4	8.84	29.00	16.00	16'	17'9"	1.20
29	apogee	5	8.67	28.44	15.44	15'5"	16'6"	1.50
30		6	8.45	27.72	14.72	14'9"	14'4"	2.20
31	Jan	7	8.16	26.77	13.77	13'9"	13'6"	3.00
1	Feb	8	7.83	25.69	12.69	12'8"	12'9"	3.50
2		9	7.49	24.57	11.57	11'7"	12'3"	4.40
3		10	7.23	23.72	10.72	10'9"	12'6"	6.00
4		11	7.19	23.59	10.59	10'7"	13.6"	7.00
5		12	7.47	24.51	11.51	11'6"	14'6"	8.10
6		13	7.96	26.12	13.12	13'1"	16'	9.20
7		14	8.52	27.95	14.95	14'11"	16'10"	10.30
8		15	9.06	29.72	16.72	16'8"	18'2"	11.10
9	Full at 7.35 hrs	16	9.52	31.23	18.23	18'3"	18'9"	12.10
10	perigee	17	9.86	32.35	19.35	19'4"	18'10"	12.40
11		18	9.78	32.09	19.09	19'1"	18'6"	1.10
12		19	9.8	32.15	19.15	19.2"	17'10"	1.40
13		20	9.62	31.56	18.56	18'7"	16'10"	2.10
14		21	9.28	30.45	17.45	17'5"	15'2"	2.50
15		22	8.82	28.94	15.94	15'11"	13'10"	3.30
16		23	8.3	27.23	14.23	14'3"	13'	4.30
17		24	7.85	25.75	12.75	12'9"	12'4"	5.30
18		25	7.64	25.07	12.07	12'1"	12'	6.30
19		26	7.79	25.56	12.56	12'7"	12'6"	7.30
20		27	8.17	26.80	13.80	13'10"	13'6"	8.30
21		28	8.59	28.18	15.18	15'2"	15'	9.40
22		29	8.93	29.30	16.30	16'4"	16'6"	10.30
23	New at 15.34 hrs	29½	9.16	30.05	17.05	17'1"	17'3"	11.00
24		1	9.29	30.48	17.48	17'6"		
25		2	8.99	29.49	16.49	16'6"		
26	apogee	3	8.98	29.46	16.46	16'6"		
27		4	8.88	29.13	16.13	16'2"		

Despite there being too many variables to make a meaningful comparison, the alignment is closer than we had expected, and in some cases, spot on. As in previous comparisons, sequence data can be out of phase, by say a full moon occurring above, on Day 16, a day later than expected.

The chapter ring

We have seen several longcase clocks by Liverpool clockmakers Finney and Kaye, which have the names of locations inserted between the Roman hour numerals on the chapter ring. These were placed specifically according to their longitude to give information regarding their local times. Information on longitudes to enable Kaye to have the locations engraved on the chapter ring had been available throughout the eighteenth century. Publications such as Nathaniel Colson's *New Mariner's Kalendar*[16] and James Ferguson's *Tables and Tracts*[17] included information on 'remarkable places' including their latitude, longitude and also Greenwich time when it was noon at each location. Also the Commissioners of Longitude[18] published their annual *Nautical Almanac and Astronomical Ephemeris* from 1767 (to 1964) which contained the lunar and solar information necessary for mariners to determine longitude. However, information on longitudes was incomplete with few details of locations in the Pacific Ocean, Australasia or the far north or south, but this dial has benefitted from information from some of James Cook's voyages (three between 1768 and 1780) and as far as we have been able to learn, is unique in having only locations west of Liverpool,[19] i.e. whose local times were behind that of Liverpool. Some of the place names are no longer in common usage and have been difficult to trace; some would have been visited by Hutchinson during his privateering career and would be familiar stop-off points for any of Liverpool's many privateers.[20] See Fig. 7.

Locations on the chapter ring (see Fig. 3)

12-1 Lisbon
This sheltered port on the Atlantic coast of Portugal has a long maritime history. (Local time between 0-1 hours behind Liverpool.)

1-2 St George's
This is São Jorge – one of the Verde Islands. (Local time between 1-2 hours behind.)

2-3 Cap Frio
This is situated on virtually the easternmost point of Brazil and would have been a regular stop-over on journeys towards Cape Horn which at this time was the only entrance into the Pacific Ocean. (Local time between 2-3 hours behind.)

3-4 Cayenne
This was a sheltered trading port on an inlet off the coast of French Guiana. (Local time between 3-4 hours behind.)

4-5 Quebec
Quebec grew from a fortified fur-trading post early in the seventeenth century. Its commanding position on the St Lawrence enabled control of trade in and out of the country. (Local time between 4-5 hours behind.)

5-6 Havana
The sheltered harbour at Havana on the north coast of Cuba has been a trading place for centuries. (Local time between 5-6 hours behind.)

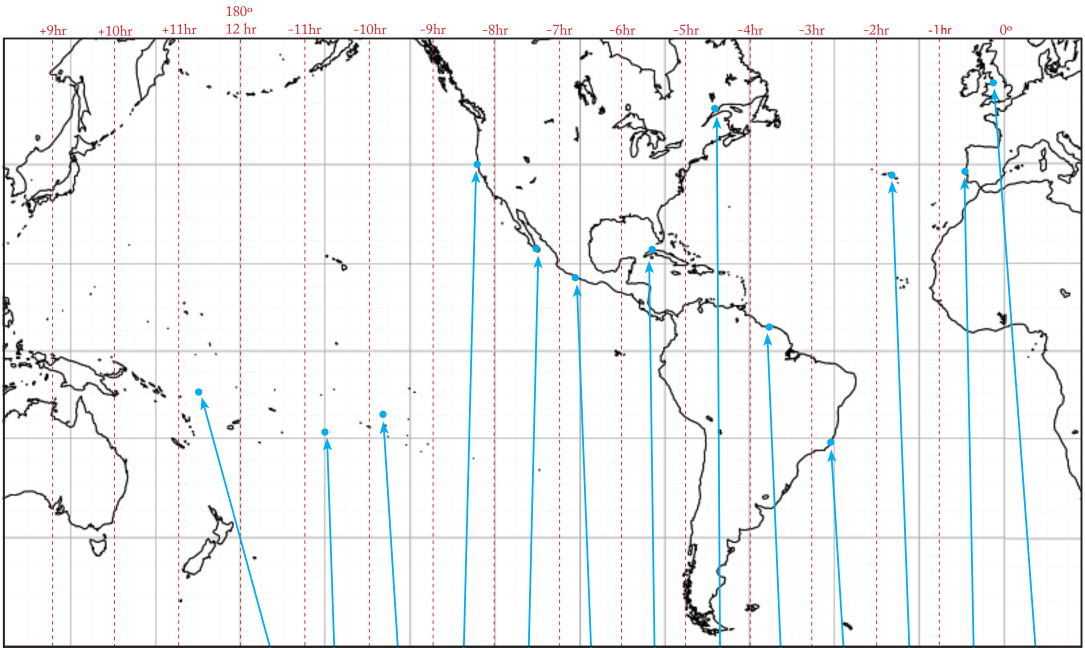
16. Seventy-five editions of this book were published between 1676 and 1785.

17. James Ferguson, *Tables and Tracts Relative to Several Arts and Sciences,* published by A. Millar and T. Cadell in London, 31 Dec 1767, pp. 264–267.

18. Nevil Maskelyne, Astronomer Royal from 1765 to 1811, was one of the Commissioners of Longitude. His observations using Colson's New Mariner's Kalendar on a voyage from Barbados in 1764 are held in Cambridge University Library.

19. The Solomon Islands (11–12) do not quite fit; they are just too far west. Today their time is ahead of Liverpool. Their position on the dial may be used, so long as one remembers the local time there would be 12 hours ahead of Liverpool, and not behind as in all the others.

20. Gomer Williams, *History of the Liverpool Privateers and Letters of Marque*, published by Wm Heinemann, London and Edw. Howell, Liverpool, 1897.



POSITION ON DIAL	11-12	10-11	9-10	8-9	7-8	6-7	5-6	4-5	3-4	2-3	1-2	12-1	Noon
PLACE NAME ON DIAL (with current name, if different), and current country	SOLOMON I (Nendo Is.)	BARNARD I Cook Is. (New Zealand)	DOG Is. (Tahiti)	C. MEN-DOZIN (Cape Mendocino) USA	SHIL-VOCKS I (Baja California) (Mexico)	ACAPUL-CO (Mexico)	HAVANNA (Havana) (Cuba)	QUEBEC (Canada)	CAYENNE (French Guiana)	C. FRIO (Brazil)	St GEORGE (Azores) (Portugal)	LISBON (Portugal)	LIVERPOOL (UK)
Approximate LONGITUDE	195°W	160°W	149°W	124°W	116°W	99.8°W	82.4°W	71.2°W	52.3°W	42°W	28°W	9.8°W	4°W
All times are based on zero longitude at Greenwich at noon, pre GMT and pre time zones. Meridians in red are on 15° hourly intervals west.													

Fig. 7. Map showing locations marked on the chapter ring and their positions on the dial.

6–7 Acapulco

This city has been a busy port on the Pacific coast of Mexico since early Spanish colonial days. (Local time between 6-7 hours behind.)

7–8 Shilvocks I

This place name is no longer in use. We believe a legend sprang up amongst privateers in the eighteenth century following the exploits of George Shelvocke (sometimes spelled Shilvock) captain of the vessel *Speedwell*. In 1719, he crossed the Atlantic, calling at Cap Frio and continued down to Cape Horn and up the west coast of South America. He landed at the southern tip of the Baja California peninsula in Mexico where he re-stocked his ship. Shelvocke was impressed by the kindness and honesty of the inhabitants and considered the place a paradise.[21] He returned to England in August 1722. We have seen just one map which marks the location as an island named *Shelwoch* off the southern tip of the peninsula and a Senex globe of c.1760 which shows an island named *Shelvocks I*. [22] (Local time between 7-8 hours behind.)

8–9 C. Mendozin

Now known as Cape Mendocino, this north Californian headland has been a landmark

21. George Shelvoke, *A Voyage round the World by way of the Great South Sea*, published by John Senex, The Globe, Fleet Street, 1726 and Kenneth Poolman, *The Speedwell Voyage, A Tale of Piracy and Mutiny in the Eighteenth Century*, (Maryland USA: Naval Institute Press, 1999). Shelvocke noted that it was not known at the time whether this place was an island or part of mainland America. Towards the end of the eighteenth century, William Wordsworth read Shelvocke's journal and suggested to Coleridge that he should write a poem about an episode from the voyage about an albatross; this became *The Rime of the Ancient Mariner*.

22. Levasseur, *Atlas Universel Illustré*, 1838.

since the sixteenth century when mariners followed the prevailing westerlies across the Pacific. (Local time between 8-9 hours behind.)

9-10 Dog I.
This is one of the Tahitian Islands. James Cook was there in 1769. There was a wild Tahitian dog, now extinct because its meat was considered a delicacy. Cook developed a taste for it whilst there. (Local time between 9-10 hours hours behind.)

10-11 Bernard I.
This is one of the Cook Islands. It was named San Bernardo by the Spanish in 1595 but is now known as Pukapuka. (Local time between 10-11 hours behind.)

11-12 Solomon I.
This island group was discovered by the Spanish in 1568 and was then believed to have been the Biblical location of Ophir and King Solomon's mines. Subsequently, its location was 'lost' for at least two centuries and as a result, the Solomon Islands did not appear in contemporary almanacs when the clock was made. *The Gentleman's Magazine* of December 1773 published a map showing voyages of Wallis, Carteret, Bougainville and Cook and on it stated: 'Solomon Isles of which the existence and position are doubtful'.[23] As a result, the true location of this island group is too far west to fit in this hour-slot and it was not used on any of the other four chapter rings of this type we have seen. (Local time approximately 11-12 hours **ahead** of Liverpool.)

Using the chapter ring was simple. The clock's owner in Liverpool, (before GMT) would only need to look at the clock at, for example, noon local time to see that at Cap Frio (2-3 hours behind Liverpool), the time would be approximately 9.30am. Alternatively, they would see that at 2.30pm in Liverpool, the hour hand pointing to Cap Frio meant that it would be about noon there

The chapter ring has an annual calendar around its outer edge with names of the months and the number of days in each month; within that is a ring indicating the equation of time throughout the year with S (slow) and F (fast) to indicate the variation between local solar and mean solar time.

Conclusion

We believe this clock is unique. It was made at a time when knowledge of some parts of the world was sketchy, and sought to provide answers to several navigational problems, particularly at neap tides, mainly involving whether there would be sufficient water in a dock at Liverpool to allow ships to enter or exit. The clock was made fifty years before the semaphore system was set up along the north Wales coast to enable messages between incoming vessels and the port and almost a hundred years before the electric telegraph was functional. Who would have owned such a valuable tool? Efforts to trace its original owner have met with no success. It could well have belonged to one of the wealthy ship owners or merchants, to Liverpool dock management or to William Hutchinson himself.

Acknowledgements

We owe a huge debt of gratitude to two people: the clock's owner and Professor Phil Woodworth of National Oceanography Centre, Liverpool. Phil has advised us from the outset and in doing so has taught us a great deal about how tides affect the Mersey estuary at Liverpool. He is also an expert on William Hutchinson and has written and spoken widely on the subject and wrote a paper showing how very accurate and valuable his long series of records has been in enabling modern research into sea-level change.[24] Our thanks are also due to Peter de Clercq and his referee who gave helpful advice.

23. Thomas Suarez, *Early Mapping of the Pacific* (Singapore:Periplus Editions, 2004).

24. Philip L. Woodworth, *A Study of Changes in High Water Levels and Tides at Liverpool during the Last Two Hundred and Thirty Years with Some Historical Background*, 1999, Proudman Oceanographic Laboratory Report No. 56. and also Philip L Woodworth & David L. Blackman, 'Changes in extreme high waters at Liverpool since 1768', *International Journal of Climatology* vol. 22 (2002), 697–714.