Riccioli on Measuring Time

***First example*: A pendulum of 3 old Roman feet 4 inches in length with a 1 pound bob**

21706 arcs in 21660 sidereal seconds

***Second example*: A pendulum of 3 old Roman feet 4 inches, with an 8 ounce iron sphere**

87758 arcs in 86400 sidereal seconds

"I set up nine companions (well instructed in this matter, who almost all publicly practiced Philosophy or Theology or Mathematics) so that they succeeded each other in the counting after about every half hour; and in the year 1642 from noon on April 2 to noon on April 3, we maintained a count of simple vibrations, whose number, from the pebbles thrown in the vase every 60 vibrations, was found to be 1466 sixties and in addition 38 vibrations. But a day of the primum mobile contains 1440 of its own minutes. The solar day indeed is 1444 primum-mobile minutes. Therefore such a pendulum in one day of the primum mobile completes sixty times 1462 vibrations and in addition 38 vibrations, when it ought to complete only 1440 if a single simple vibration corresponded to one second; therefore I added one ring to the chain so that the number of vibrations might turn out less, and it might approach more nearly in each of its vibrations to a second of the primum mobile."

***Almagestum Novum*, 1651, p. 86**

***Third example*: A pendulum of 3 old Roman feet 4 +20/100 inches with an 8 ounce iron sphere**

86998 arcs in 86400 sidereal seconds

***Fourth example*: A pendulum of 3 old Roman feet 2 +67/100 inches with a 20½ ounce brass sphere**

3212 arcs in 3192 sidereal seconds

Upshot:

***The one-second pendulum*: 3 old Roman feet 3+27/100 inches – i.e. 3927/100 inches – with a 20½ ounce brass sphere**

***The one-half second pendulum*: 9 +76/100 inches with a little brass sphere**

***The one-sixth second pendulum*: 1 + 15/100 inches with a little brass sphere weighing 4 drachmas**

"Therefore we used a pendulum of this sort for measuruing the natural movement of weights, but, in order to count its vibrations as quickly as possible, it is proper after each set of ten to raise one finger of two clasped hands, and to be extremely attentive. Indeed for greater proof to take two equal pendulums of this sort and have two counters, making their own count separately, so that it is apparent at the end of the operation whether it agrees or not."

***Ibid.*, p. 87**

Proposition IV.

Weights in perpendicular free fall move more and more quickly towards the end, in an increase of speed that is between numbers equally unequal, numbered as wholes; or so as the spaces, traversed in certain times, are among themselves as the squares of the times; or so as the spaces traversed have among themselves a duplicate proportion to that which the times during which those spaces were measured have [*among themselves*].

The whole assertion of Galileo (above) and Baliani has been very often proven by our experiments; now these are the numbers are said to be equally unequal as wholes: 1,3,5,7,9,11,13,15, &c. And so if in the first quarter of an hour some weight has completed 1 stage, in the second quarter it will complete 3, in the third, 5 stages, & thus through the rest of the progression. In order to explore this in truth, Grimaldi & I prepared in advance several clay globes of the same bulk & dropped those of 8 ounces from different towers, or house-windows, or little casements suited for taking measurements, and we first used the towers of Bologna, namely the Asinelli, which is 312 old Roman feet high, and St. Peter, 208 feet high and St. Petronius, 200 feet high, & St. James, 189 feet high, & St. Francis, 150 feet high, though we did not use their whole height, but that which was suited for the aforesaid proportion. Moreover, for discerning more precisely the time in which the dropped globes arrived at the pavement, we used two very small pendulums (see Chap. 20, prop. 13, in the second paragraph), of whom, as is clear, one simple vibration lasts for 10 thirds of the primum mobile. Among many experiments, however, the best two, the most certain of all, written below, I place in the following table, so that so I may not end up too lengthy for my reader.

Experimenta.	Vibrationes ſimplices Perpendiculi.	Tempus Vibrationibus congruens.	Spatium confectum à globo cretaceo unciarũ 8. in fine tẽporis.	Spatiũ ergo ſeorſim confectũ ſingulis tẽporibus æqualibus.	Proportio incrementi velocitatis ſimplicibus numeris expreſſa.
			Pedes Romani.	Pedes Romani.	Num. parit. impar.
I	5	0 50	10	10	1
	10	1 40	40	30	3
	15	2 30	90	50	5
	20	3 20	160	70	7
	25	4 10	250	90	9
II	6	1 0	15	15	1
	12	2 0	60	45	3
	18	3 0	135	75	5
	24	4 0	240	105	7
	ferè 26	4 ferè 20	280		

And so in the first experiment, when we observed from a height of 10 feet the aforesaid globe (the operation repeated often) come to the pavement in at least five vibrations of the aforesaid pendulum, we tested the height which a globe equal to that one passed through in 10 vibrations and found it to be 40 feet & thus for the rest. In experiment 2, however, we explored those times with an assumed height, for the height having been found to be 15 feet which the globe passed through in 6 vibrations, we concluded that, if the aforesaid proportion were correct, at the end of 12 vibrations it ought to pass through 60 feet, therefore, a height of 60 feet that would be suitable to action having been sought for, we found this to be correct, & thus for the others; we could not however find the height owed to 30 vibrations which would be useful for the rest of the progression. Now you see in the first experiment, that as the space of 10 was to 40, so the square of 5 vibrations, that is 25, is to the square of 10 vibrations, that is 100; & in the second experiment, as the space of 15 was to the space 60, so the square of 6 vibrations, that is 36, is to the square of 12 vibrations, that is 144, & thus for similar ones.

Riccioli: *New Almagest*, Book 2, Chapter 21, 1651

Constant of Proportionality: A Key Parameter

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velocity $\propto$ ***time***	***distance*** $\propto$ ***time***^{2}
g **: velocity acquired in the first second**	d_g **: distance of fall in the first second**

Galileo (remark in a letter to Peiresc, 15 January 1635)

4 cubits in the first second (197 cm)

Mersenne (in *Harmonie Universelle*, 1636, confirmed in 1640s)

12 Paris feet in the first second (394 cm)

Riccioli (in *Almagestum Novum*, 1651)

15 Roman feet in the first second (467 cm)[1]

{Huygens (in 1659, then in *Horologium Oscillatorium*, 1673)

15 Rh feet 7½ in. in the first second (490.4 cm)}

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[1] Using Riccioli's 312 old Roman ft height for the Tower of Asinelli, which is now said to be 97.2 meters high; if instead one uses 29.57 cm for the old Roman ft (Koyré, Klein), the distance of fall in the first second 444 cm, a nearly 10 percent error that is difficult to explain insofar as the error appears to be uniform across all Riccioli's announced values, and therefore cannot be attributed to either air resistance or to timing errors, but only to a uniform error across all his announced heights.