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THE PROBLEMS IN THE VITRUVIAN HODOMETER REVISITED

George Hollenback*

In a previous article, Panu Hyppönen presented a reconstructed value for the diameter of the wheels of the hodometer, a mileage-measuring vehicle described by Vitruvius (*De arch*. 10,9,1–4).[1] One revolution of a wheel was said to cover a distance of 12 ½ feet, 400 such revolutions marking off a Roman mile of 5000 feet. Because modern translations give a wheel diameter of 4 feet, it has been assumed that the π value implicit in the description of the hodometer is $12\ ½ \div 4 = 3\ ⅛$, a seemingly puzzling inaccuracy since Archimedes had already come up with the more accurate upper-limit π value of $3\ ⅐$ more than a century earlier. A wheel with a diameter of 4 feet would actually cover a distance of slightly over 12 ½ feet, the cumulative effect of 400 revolutions adding a little over 26 ½ feet to each mile.

The extant Latin manuscripts, however, do not give a bare diameter of 4 feet or *pedum quaternum*; rather, they all have wording such as *et sextantis* or *et sextante* "and a sixth" or *et sextantes* "and sixths" following after *pedum quaternum*. One commentator on the passages, John Pottage, understood them to be giving a wheel diameter of $4\ ⅙$ feet, yielding an even less accurate π value, $12\ ½ \div 4\ ⅙ = 3$ (!).[2]A $4\ ⅙$-foot diameter wheel making 400 revolutions would have added about 236 feet to each mile. Because there are biblical references to circumference being three times diameter (e.g., 1 Kings 7,23), Pottage suggested that a pious scribe might have been responsible for the $4\ ⅙$ diameter

* I would like to thank the two anonymous *Arctos* manuscript reviewers whose excellent insights have been incorporated into this note.

[1] P. Hyppönen, "4π = 12.5? – The Problems in the Vitruvian Hodometer", *Arctos* 48 (2014) 185–204.

[2] J. Pottage, "The Vitruvian Value of π", *Isis* 59 (1968) 190–197.

figure, emending whatever diameter Vitruvius had originally given in order to make the text conform to the scriptural circumference-to-diameter ratio of 3.[3] Later translators then took the liberty of omitting the troublesome fraction from the diameter of 4 $\frac{1}{6}$ in order to produce the more mathematically respectable π value of 3 $\frac{1}{8}$ associated with a diameter of 4 feet even.

Since Vitruvius stated he was describing a device produced by his predecessors, the hodometer was more than likely the product of the Alexandrian scientific community, which certainly would have been familiar with the π approximation of 3 $\frac{1}{7}$ and would have accordingly made use of it in designing such a device. Hyppönen has correctly reconstructed the original Vitruvian value of the diameter of the wheels by considering sufficiently small Roman fractions of a foot that yield a diameter measurement that in conjunction with a circumference of 12 ½ feet points to a π value much closer to 3 $\frac{1}{7}$ than 3 $\frac{1}{8}$:

> If . . . the wheels were constructed with a perimeter of exactly 12.5 feet, the diameter would have to be $12.5 = 2\pi r \rightarrow \pi r = 6.25 \rightarrow r \approx 1.989$ (*2) ≈ 3.979 feet. This is remarkably close to 3 $\frac{47}{48}$ . . .[4]

Hyppönen's reconstructed diameter measurement of 3 $\frac{47}{48}$ feet is $\frac{1}{48}$ of a foot—a quarter of an inch—short of 4 feet. Expressed in typical Roman foot-and-inch measurement style, 3 $\frac{47}{48}$ feet would be 3 (feet) + 11 (inches) + ½ (inch) + ¼ (inch); spelled out, it would be *pedum trium deuncis semunciae sicilici*. Hyppönen goes on to note that one way this could have been represented

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[3] Pottage (above n. 2) 195–6.

[4] Hyppönen (above n. 1) 192. My own approach to the problem was to convert the 12 ½ -foot circumference to 600 quarter inch increments and divide by the Archimedian upper π limit of 3 $\frac{1}{7}$ to obtain a diameter rounded up or down to the nearest quarter inch; the result was a rounding up to 191 quarter inches, which also comes out to 3 $\frac{47}{48}$ feet. Now when 600 is divided by 191, the result is 3.141361, an even more accurate π approximation than 3 $\frac{1}{7}$ (= 3.142857). When a given circumference is divided by a π approximation which is larger than the actual value of π (= 3.141592) – such as 3 $\frac{1}{7}$ (= 3.142857) – the resultant diameter figure so derived will necessarily be shorter than the actual diameter. In this case, however, the rounding *up* of the derived diameter figure to the nearest whole quarter inch more than compensated for the shortening of the diameter. When the circumference of 600 is then divided by the rounded-up diameter of 191, the serendipitous result is a π approximation even more accurate than 3 $\frac{1}{7}$. (Decimal approximations of π in this note are carried out no further than sixth place.)

by Roman numerals and symbols would be III :::::. ℒ ɔ. In this manner of notation, : represents $^{1}/_{6}$, so :::::. would be 5 ½ sixths or $^{11}/_{12}$ of a foot; ℒ represents ½ inch ; and ɔ represents ¼ inch. Through scribal error in an earlier manuscript employing this manner of notation, the III could have become IV by an inadvertent slanting of certain of the vertical strokes, and the latter portion of :::::. and the ℒ and the ɔ could have been lost along the way. A later scribe wanting to spell out what he saw in numerical form—IV followed by :::::. whose latter portion was missing or obscured —would have simply written *quaternum et sextantes*, "four and sixths". Thus for Hyppönen, *quaternum et sextantes* is not a corruption of *quaternum et sextantis*—"four and a sixth"—but is rather the corrupted vestigial remains of III :::::. ℒ ɔ as it might have been spelled out.[5]

Applying Occam's Razor, I beg to differ, suggesting that Pottage's explanation that a pious scribe emended the text to give the wheel a dimension of 4 $^{1}/_{6}$ feet is the better explanation for what is found in the extant manuscripts. The spelled-out version of 3 (feet) + 11 (inches) + ½ (inch) + ¼ (inch) given by Hyppönen as *pedum trium deuncis semunciae sicilici* can be more concisely rendered as *pedum quaternum minus sicilici*, "four feet less a quarter of an inch".[6] The scribe need only substitute *ex sextantis* for *minus sicilici* to obtain the desired *pedum quaternum et sextantis*, "four feet and a sixth (of a foot)".[7] Moreover, the emendation need not necessarily be the result of a deliberate attempt to substitute a value based on scripture for the original Vitruvian value. If the portion of the manuscript bearing the *minus sicilici* was smudged or damaged, a conscientious copyist would certainly want to attempt a reconstruction of the missing words. A copyist who had been taught a circumference-to-diameter ratio of 3 would therefore naturally assume the illegible or missing words to be *et sextantis* and accordingly set about "restoring" them. Subsequent scribal errors could account for *sextantes* in place of *sextantis* that crop up in some of the extant versions.

In conclusion, published chronologies of π values often make Vitruvius appear to be a kind of behind-the-times dunce for presenting hodometer wheel

[5] Hyppönen (above n. 1) 195–202.

[6] There is at least one other passage where Vitruvius uses *minus* to subtract one dimension from another, 10,11,8; coincidentally, *sicilicus* as a quarter-inch measure appears in the preceding 10,11,7.

[7] Note that *ex sextantis* takes up 12 spaces while *minus sicilici* takes up 14 spaces, so the substitution of the former for the latter could easily be done with a little extra room to spare.

dimensions that supposedly yield an implied π value of 3 $\frac{1}{8}$ (= 3.125) when the more accurate value of 3 $\frac{1}{7}$ (= 3.142857) was already known. In reality, Vitruvius was transmitting a value even more accurate than 3 $\frac{1}{7}$, namely 12 ½ ÷ 3 $\frac{47}{48}$ = 3.141361.

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