

DOI: 10.5281/zenodo.3340103

USING THE TRIANGLE 6-8-10 IN LAND SURVEY PROBLEMS IN RHIND MATHEMATICAL PAPYRUS

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Received: 19/04/2019

Accepted: 15/07/2019

ABSTRACT

For nearly a century there is an ongoing debate about, have the ancient Egyptians known any case of the Pythagorean Theorem and that the triangle 3-4-5 is right-angled? According to the opinions of most scholars, there is no written evidence regarding this dispute. Hence, this paper shows the written evidence in a problem on land survey in the so-called Rhind Mathematical Papyrus-RMP of circa 1550BC, which has been separated by the early scholars into two problems: RMP#53 and RMP#54. The paper shows that RMP#53-54 is one problem on reckoning the dimensions of a triangular plot of land with sides 6-8-10 and its sections, where the triangle's height is a radius of a circular horizon that increases by adding one-tenth of the triangle's hypotenuse. Besides, it shows that the reckonings of RMP#55 are based on the same triangle sketch of RMP#53-54. The paper proves that the ancient Egyptians knew this triangle almost thousand years before the days of Pythagoras. The paper also shows that the ancient Egyptians did not only use the unit fractions but have also used complex fractions.

KEYWORDS: Egyptian Mathematics, Rhind Papyrus, RMP#53-54-55, Triangle 3-4-5, Pythagorean Theorem, Unit Fractions, Complex fractions.

1. INTRODUCTION

In planning land subdivisions, after producing the site-plans, the planner do reckon in details the exact dimensions of the design to be plotted on site. The shapes of land plots are either thematic by repeating the same rectangle, or non-thematic of diverse forms that are constructed by addition of geometric shapes or by subtracting parts of it, e.g., a circle, a concentric shape, a triangle, a square, or a rectangle. The accuracy of reckoning the dimensions depends on understanding the basics of simple geometry, the trigonometric calculus, and the idea of spreading out a circular curve. According to Democritus 460-370BC, in ancient Egypt, the professionals in this field were called the Harpedon-aptae (Heath, 1921, p.121) that has been translated by Egyptologists as rope-stretchers (Sarton, 1993, p.39). This is because they have been depicted in several scenes (e.g. in the Theban tomb TT38) while supervising their labours that survey lands with ropes, similar to the steel chain of 22 yards (~20m) that is still used in land survey until today (Whyte & Paul, 1997, pp.52-53). Harpedon-aptae sounds like the current Egyptian term *Harriepht A'pateh* that means professionals (of) lands, respectively. Regarding their mathematical knowledge, Herodotus (440BCE, 2-109, p.399) said, the art of measuring lands or geometry (*Υεωμετρική*) first came to be known in Egypt. However, the technical-math book that they have used in their works never was exclusively identified as one of the discovered ancient Egyptian papyri, such as the so-called Rhind Mathematical Papyrus-RMP that includes similar reckoning cases, because on the one hand, many words in its prelude have been wrongly translated, e.g., see its early translation by Chace *et al* (1927-1929, p.49). Based on reviewing the hieratic text of RMP's prelude (see, e.g., Clagett, 1999, plate-1, p.326), using new reading methods (Aboulfotouh, 2017), the first two lines that are written mostly with red colour state the contents of RMP. Line-1 begins with: a part from the total-length, on square/rectangle land-plots, on radial/curved distance of a circular horizon, on parts of the area, on reckoning., etc. Line-3 says: Book on "Binary-Segments as Parts of the Unit", in year 33, 4th month of the inundation season, king/warrior [*Qeriass*] the egalitarian, (and) support(er) of the Harpedon. Line-4 states the purpose of it, to measure lands (*Qeyas Phat-hat*, *A'pateh*, or aptae) and the name of the scribe "*Tahmes Adin*" who copied it during the days of the folk of *Add* (Hyksos) from a papyrus titled "Book on Sub-intervals of the Unit". The true purpose of many of RMP's problems particularly the problems without geometric figures were not understood, and accordingly the early philologists as E.A.W. Budge have asserted that the papyrus does

not contain a systematic treatise on mathematics, nor does it attempt to deal with the subject from a scientific standpoint (cf. Nature, 1898, pp.73-74).

RMP has been discovered in 1858 AD in Thebes of Upper Egypt, and it is now in the British Museum (10057 and 10058). The first translation of RMP was by Eisenloher (1877) in German language. It was followed by two famous English translations, one by Thomas Eric Peet (1923) and the other one was by Arnold Buffum Chace *et al* (1927-1929). The works of these scholars have been explained, studied, and/or reinterpreted in research articles, e.g., by Archibald (1930) and in books by later scholars, e.g., Van Der Waerden (1975), Gillings (1982), Robins & Shute (1987), Clagett (1999), and recently in books by, e.g., Michel (2014) and Imhausen (2016). The great achievement of the early philologists and math scholars is that they were able to identify the precise values of numeric signs in the hieratic math-texts, which enabled the latter to figure out how the calculations proceed in most of the problems of RMP and other papyri such as Moscow Mathematical Papyrus (Struve, 1930). On the other hand, in their translations, despite that the hieratic numeral signs had been correctly translated, the early philologists did not understand nearly all the geometric notations in the text, particularly in the problems without figures. The apparent reason is that they had dealt with all the geometric and some math notations as hieratic-letters and accordingly assigned for each geometric or math symbol the nearest hieroglyphic sign in shape; hence, they created false words not included in the papyrus. Besides, words such as radius, diameter, line, and length were also misunderstood. An example of a mistranslated math notation is the inclined curved stroke  in RMP#54&55. In these two problems, the ancient Egyptian Harpedon-aptae have used it after the sum of an integer and a unit fraction, e.g., $(7 + \frac{1}{2})$, to denote the denominator 100, i.e., writing the complex fraction $(7 + \frac{1}{2})/100$, which implies the decimal fraction 0.075 of three digits after the comma (see Fig.1d). The early philologists have translated this inclined curved stroke as cubit-strips (Chace *et al*, 1927, Vol.1, p.95). RMP includes about sixty misinterpreted symbols that are either geometric, trigonometric, or math notations. Accordingly, the purpose of the reckonings in many of the problems of RMP has been changed from the realm of plane geometry (in horizontal or vertical planes) to the realm of materials and volume calculus. For example, the problems from RMP#35 to RMP#47 have been classified on reckoning the divisions of loaves, the volumes of cylindrical, rectangular granaries, or the divisions of a unit of volume that philologists have called a Heqat measure (e.g.,

Clagett, 1999, p.117). The red box in Fig.1f shows a hieratic math notation $\mathfrak{J}$ that implies a length or a measurement-value; see its design justification in Fig.2g. It is used in nine of these thirteen problems and in most reckonings in RMP, which implies solving problems only on plane geometry, or closely related to it. The shorter form of it $\mathfrak{j}$ under a dot, together with the symbol of arc units $\mathfrak{S}$, denote a degree of arc; it is used, e.g., in RMP#40 on subdividing 100 units that equal the length of one degree of arc (or 60 seconds as sub-dividers $\mathfrak{j}$) into 5 diverse intervals; Chace *et al* (1927-1929, Vol.1, p.12) translated the first two symbols together as loaves. Besides, in RMP, the following seven problems after RMP#47, that have been classified on reckoning areas, were numbered as eight problems from RMP#48 to RMP#55 because the sixth problem in this group had been incorrectly divided into two problems: RMP#53 and RMP#54, where math scholars thought that both parts are on reckoning an area. In this particular problem (see Fig.1), despite that the hieratic text goes from right to left, the part on the left-side that includes a sketch of a triangle has been numbered RMP#53 and the part on the right-side that includes the header sentence of the problem has been numbered RMP#54. Thus, due to these errors by the early philologists, math scholars have found it hard to correlate the red numbers that are written on the sketch with the remainder of the text in RMP#53, without assuming that the ancient Egyptian Harpedon-aptae did some errors in writing the numbers, or the scribe did some errors in copying it. Moreover, the philological mistakes in the early translation efforts have indirectly led math scholars to assert that there is no written evidence proves that the ancient Egyptians knew any case of the Pythagorean Theorem, e.g., similar to the Babylonian clay tablet (YBC 7289) of circa 1700 BC that shows the dimensions of a square and its diagonals (Pedersen, 1993, p.4). Gillings (1981, Appendix-5, p.242) have cited opinions of other scholars regarding this issue. According to Peet (1923, p.32), nothing in the Egyptian mathematics suggests that they were acquainted with the triangle 3-4-5; Archibald (1949, p.16) said, there is no document to prove that they knew even particular case of the Pythagorean Theorem; and Heath (1962) said, there seems to be no evidence that they knew that triangle 3-4-5 is right angled. Also, Robins & Shute (1985, p.112), Rossi (2004, p.71), and Imhausen (2009, pp.781-800) have pointed out that even if we observed it in the dimensions of some ancient Egyptian buildings there is no written evidence. Contrary to the norms of the realm of mathematics, in studying the use of geometry in ancient designs, e.g., in planning or architecture, there is no need for written evidences. For example, Ranieri

(2014) and Perez-Enriquez (2014) have shown some evidences on the use of this theorem in the design of the Greek temples during the 1st Millennium BC. In this regard, Aboulfotouh (2012) showed that the ancient Egyptians were aware about the fact that the diagonal of a rectangle of 3*4 units equals 5 units, and they used it in the design of the hieratic sign that denotes 10. It is a rectangle similar to that mentioned in problem#6 in Moscow Mathematical Papyrus (Clagett, 1999, p.215). Therefore mathematically, here the paper shows that RMP#53-54&55 include the written evidence regarding that the ancient Egyptian Harpedon-aptae were well acquainted about this triangle and the related calculations within the domain of a circular horizon. It shows how they reckoned the dimensions of a triangular plot of land with sides 6-8-10 and its sections, using the complex fractions, almost thousand years before the days of Pythagoras.

2. EARLY OPINIONS ON RMP#53-54

Fig.1 shows the hieratic text of RMP#53-54. The triangle's figure in the left-side (RMP#53) is a free-hand sketch, and without correlating the correct meaning of the text particularly the first word with red colour, in the right-side (RMP#54), to the red numbers on the figure, it may give an impression that it is an isosceles triangle. In this regard, De Young (2009, p.345) measured the angles of this triangle's freehand sketch, in clockwise order, and he found it equal 20°, 82°, and 78°.

Regarding RMP#53, Chace *et al* (1927, Vol.1, pp.93-94) said, it is difficult to explain, and the difficulty is increased by some numerical mistakes, and the most probable explanation is that the author is undertaking to determine the areas of certain sections of an isosceles triangle. Clagett (1999, pp.164-165 & p.197) said, clearly the figure as drawn is an isosceles triangle; but the numbers given on the figure, if correct, make it impossible for the figure with its three sections to be an isosceles triangle; thus, he assumed it is on reckoning areas of sections of a compound trapezoidal-triangular figure. Similarly, Miatello (2015, pp.63-67) changed the figure of RMP#53 and assumed that it deals with the calculation of the area of a triangle attached to two trapezia. Also, Michel (2015, pp.410-415) formulated her assumptions based on that RMP#53 deals with the computation of multiple areas included in an isosceles triangle. Regarding RMP#54, following the opinions of Eisenloher and Peet, Chace *et al* (1927, Vol.1, p.95) assumed it is on finding the answer to: what equal areas should be taken from 10 fields if the sum of these areas is to be 7 setat? Scholars have claimed that setat is an Egyptian area unit that equals 10,000 square cubits (Chace *et al*, 1927, Vol.1, p.33 &

Gillings, 1981, p.209). In line with opinions of the early scholars, Imhausen (2016, p.118) pointed out that problems 48–53 determine areas of various

shapes, and problems 54–55 divide a given area into a number of smaller areas.



Figure 1. The hieratic text of RMP#53-54: RMP#54 includes the parts that are marked with the green letters B, C, and D; in part-D, the red-box shows the ancient Egyptian way of writing $\frac{1}{2}$ above 7 and dividing their sum by the denominator 100 (a long inclined curved stroke). RMP#53 includes the parts that are marked with the green letters E, F, and A (a triangle sketch); in part-F, the red box shows the math notation that implies a length or a measurement-value (see Fig.2g for explanation). Used with permission from the British Museum.

3. THE TRUE PURPOSE OF RMP#53-54&55

In RMP#53-54, the ancient Egyptian (Harpedonaptae) had drawn a right-angled triangle and divided it into three sections. The hypothetical context that based upon it the ancient Egyptian had done the calculations is described in four sentences to inform the reader about the purpose of this problem. The four sentences are marked in the translation, in Fig.2b&f, with Latin numbers: *i* & *ii* in the part of RMP#54 and *iii* & *iv* in the part of RMP#53, where the first two lines in Fig.1b&f show the corresponding hieratic texts, respectively. The two parts together is one problem on reckoning the dimensions of a triangular plot of land, using the correlation between two systems of measurement-intervals. RMP#53-54 explains two ways to reckon the dimensions of a right-angled triangle with sides 6-8-10 and its three sections, where its height is a radius of a circle that its length is partitioned into $\frac{2}{5}$, $\frac{2}{5}$, and $\frac{1}{5}$, from the triangle's apex, respectively. The circle is not shown in the figure, but the term "radius of a circle" (*Qutert*) is mentioned in the first sentence-*i* with red colour. It is also mentioned in the fourth sentence-*iv* with black colour. The first system of measurement-intervals is the circle's standard-diameter (of the decimal-digit *Ahad*) of 9 units, as in RMP#48 (see, e.g., Clagett, 1999, p.162). The second system of measurement-intervals is the 7 design-modules that were used to divide a height of a pyramid as in the pyramids' models in RMP#56-58 and in pyramids of the fourth dynasty in Giza and Dahshur plateaus (Aboulfotouh, 2015). In the drawings, it is like the 7 mean-palms in the Egyptian royal cubit of 52.5cm (Aboulfotouh, 2015), as math scholars observe it this way (see, e.g., Gillings, 1981, p.185). In RMP#53-54,

the triangle's hypotenuse is composed of 7 modules, or 7 mean-palms in the drawing, where the Egyptian mean-palm is 4 fingers and each mean-finger is 18.75mm long (Sarton, 1936, pp.399-402 & Aboulfotouh, 2015). Using the ratios 6:8:10, the ancient Egyptian reckoned the length of the hypotenuse in the standard-units of the circle, and reckoned the length of the triangle's height in modules; then, he increased the triangle's height by adding $\frac{1}{10}$ of the hypotenuse and reckoned the new corresponding length of the hypotenuse in modules.

To explain RMP#53-54 in numbers, Fig.2a shows a quarter of a circle OAM with a radius OA equals $4 + \frac{1}{2}$ units (of a circle). The ancient Egyptian constructed on it a right-angled triangle OAB with sides 6-8-10, where OA is the triangle's height, and we can imagine that each of these ratios represents the number of segments *S* in each side. The reckoning steps are as follows. Firstly, given that, OA with ratio $8 = 4 + \frac{1}{2}$ units, the hypotenuse OB with ratio $10 = 5 + \frac{1}{2} + \frac{1}{8}$ units (see Fig.2e), and AB with ratio $6 = 3 + \frac{1}{4} + \frac{1}{8}$ units. Besides, the radius OA is partitioned into 5 equal parts that are distributed on 3 diverse intervals, where $GA = \frac{1}{5}$ OA and each of OH and HG equals $\frac{2}{5}$ OA. Secondly, since the lines HK and GF are parallel to the triangle's base AB and the hypotenuse OB has ratio 10, then $\frac{2}{5}$ OB = OK = KF = $2 + \frac{1}{4}$ units; and $\frac{1}{5}$ OB = FB = $1 + \frac{1}{8}$ units. Accordingly, KB = AB = $3 + \frac{1}{4} + \frac{1}{8}$ units and OF equals OA. Thirdly, since GF is parallel to AB, the sides' ratios of the triangle OAB are similar to the sides' ratios of the triangle OGF, i.e., the ratio of GF is also 6 (segments). Fourthly, if the true length of the hypotenuse OB is 7 modules (or 7 mean-palms in the drawing), OA which is 8 times $\frac{1}{10}$ of OB equals

$5 + 1/2 + 1/10$ modules (see Fig.2d). Fifthly, if we increased the length of the triangle's height OA by adding AC that is $1/10$ of OB , the length of the hypotenuse OB will increase by adding BD that equals $1/8$ of OB , i.e., OD will become $(9/8) \cdot 7 = 7 + 1/2 +$

$1/4 + 1/8$ modules (see Fig.2f). Similarly (and alternatively), in the triangle OGF , if OF is 7 modules, $OG = 5 + 1/2 + 1/10$ modules, and since AC is $1/8$ of OA (and $OA = OF$), then OC (as a radius similar to OE) will be $7 + 1/2 + 1/4 + 1/8$ modules.

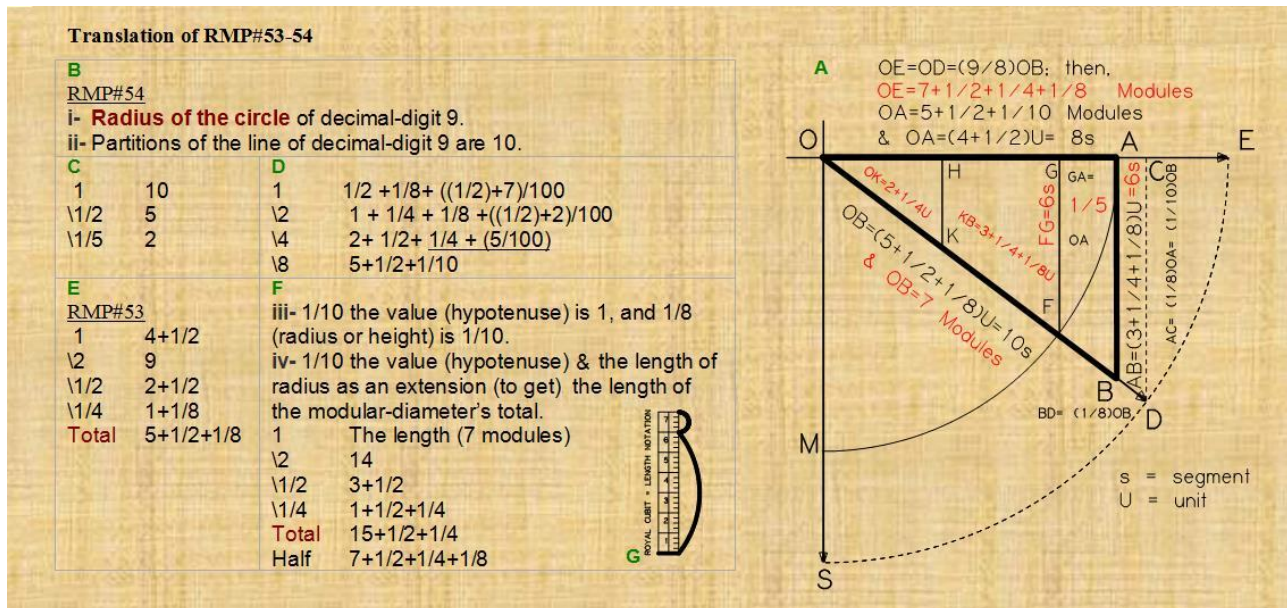


Figure 2. Translation of the hieratic text of RMP#53-54, using the same parts' symbols in Fig.1 in green colour, (A) shows the hypothetical context for reckoning the dimensions of a right-angled triangular plot of land with sides 6-8-10 and its sections within quarter of a circular horizon. Inside the triangle, the text marked with red colour is that shown on the triangle in Fig.1a, and the length of KB appears in the papyrus as $(3 + 1/4)$ instead of $(3 + 1/4 + 1/8)$ units (of a circle). (B) shows the header-lines that are numbered i & ii. (C) shows the reckoning of $1/2$ and $1/5$ the diameter of 10 equal parts, where OA is 5 parts. (D) shows the reckoning of the number of modules in the 8 segments of OA , with reference to the share of each of the 10 segments from the 7 modules of OB ; in this part the underlined value of $[(1/4) + (5/100)]$ was copied as $[(1/2) + 5]$ in the papyrus. (E) shows the reckoning of the number of units (of a circle) in OB with reference to the number of units in OA . (F) shows the sentence-lines that are numbered iii & iv, and it shows the reckoning of the length of OD , as a radius, in case if OA is increased by adding $1/10$ the length of OB , which also equals $1/8$ the length of OA . And, (G) shows the design of a hieratic math notation, related to the 7 modules (mean-palms) of the Egyptian royal cubit, which implies a length or a measurement-value; it is used in part-f of the text (see the hieratic notation in the red box in Fig.1.f).

Now, regarding RMP#55, contrary to the opinion of Chace *et al* (1927, Vol.1, pp.95-96) and other scholars, this problem uses also the figure of the triangle 6-8-10 in RMP#53-54 to reckon lengths and not areas. In Fig.2a, if the length of $OA = 3$ modules, which is partitioned into 5 equal parts (with 3 intervals: $2/5$, $2/5$, & $1/5$), the length of GA as $1/5$ of 3 will equal $1/2 + 1/10$ modules (the hieratic sign of $1/10$ was wrongly copied in the papyrus). Accordingly, OH (or HG) which is 2 times GA will equal $1 + 1/8 + [(7 + 1/2)/100]$ modules; and OG which is 4 times GA will equal $2 + 1/4 + 1/8 + [(2 + 1/2)/100]$ modules. Besides, since OB is also partitioned into 5 equal parts, the share of each of the 10 segments of OB is $1/2$ part, which equals $1/8$ of the 3 modules of OA .

Moreover, the idea of increasing the horizon's radius in RMP#53-54 implies understanding the correlation between two circles with one center-point, where the radius of the inner circle (OA or OC) represents the frame of reference for the radius of the

outer circle (OB or OD , respectively). In this regard, Aboulfotouh (2007) showed that the ratio between the radii of the inner and outer circles had been used in the relativistic equations to reckon the tilts of the entrance passages of pyramids of the fourth dynasty; which means that the ancient Egyptians knew this geometric idea almost five thousand years ago.

4. CONCLUSION

This paper has shown that before 1550 BC the ancient Egyptian Land-survey professionals (Harpedon-aptae) were aware about the right-angled triangle 6-8-10, with ratios in even numbers, and similar to the triangle 3-4-5. They reckoned the dimensions of this triangle in relation to the standard diameter (9 units) of its circular horizon. In their calculations, they did not only use the unit fractions but have also used complex fractions. They used a math notation implying a denominator with value 100, under a

numerator composed of sum of an integer and a unit fraction, e.g., $[(2 + \frac{1}{2})/100]$, which equals 0.025. This implies that they did use complex fractions of the form $[(n + \frac{1}{2})/100]$, where the range of n is at least

from 1 to 9; and which represents the ancient Egyptian way for writing the decimal fraction of three digits after the comma like that we use today.

ACKNOWLEDGEMENTS

Special thanks to Dr. Jeffrey Spencer, the "Deputy Keeper of Ancient Egypt & Sudan" at the British Museum in London, for sending me part of the facsimile of Rhind Mathematical Papyrus and giving me the permission to use it in my research.

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