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Another look at the *nb.t* in the Moscow Mathematical Papyrus

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ABSTRACT

This paper makes a case that the *nb.t* or "basket" whose surface area is calculated in Problem 10 of the Moscow Mathematical Papyrus is a segment of a circle whose two given dimensions – base of 9 and height of $4\frac{1}{2}$ – identify it as a semicircular segment. The area is found by configuring the two given dimensions as the sides of a rectangle and then reducing the long side of the rectangle by two successive reductions of $\frac{1}{9}$: $9 - \frac{1}{9} = 8$, and $8 - \frac{1}{9} = 7\frac{1}{9}$, the product of $7\frac{1}{9}$ and $4\frac{1}{2}$ yielding the area of the figure, 32. The shape of the *nb.t* has also been construed by other scholars as a hemisphere and as the lateral area of a semicylinder, with plausible-sounding arguments mustered in favor of those interpretations. Those interpretations, however, depend upon operations not otherwise attested in the Middle Egyptian mathematical papyri. The interpretation put forth here is that the *nb.t* belongs to a family of two-dimensional plane figures having a flat base called a *tp-r*, this dimension shortened by a figure-specific algorithm and multiplied together with a given second dimension to give the area of the figure.

KEYWORDS

Moscow Mathematical Papyrus – Egyptian geometry – W. W. Struve – T. Eric Peet

نظرة أخرى على *nb.t* ببردية موسكو الرياضية

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الملخص

تؤكد هذه الورقة أن *nb.t* أو «السلة»، التى تم حساب مساحة سطحها فى المسألة 10 من بردية موسكو الرياضية، هى جزء من دائرة يحددها بعدان معروفان - القاعدة 9 والارتفاع ½4 - على أنها جزء نصف دائرى. يتم تحديد المساحة من خلال استخدام البعدين المذكورين كأضلاع لمستطيل، ثم تقليل الضلع الأطول فى المستطيل بمقدار تخفيضين متتاليين 8 = ⅑ – 9 : ⅑ وكذلك ⅑7 = ⅑ – 8، حاصل ضرب ⅑7 فى ½4 يعطى مساحة الشكل، 32. وقد فسر علماء آخرون شكل *nb.t* على أنه نصف كرة أو مساحة جانبية لنصف أسطوانة، مع تقديم حجج تبدو معقولة لصالح هذه التفسيرات. ومع ذلك، فإن تلك التفسيرات تعتمد على عمليات لم يتم إثباتها فى البرديات الرياضية المصرية التى تعود إلى الدولة الوسطى. التفسير المقدم فى هذه الورقة هو أن *nb.t* تنتمى إلى عائلة من الأشكال المستوية ثنائية الأبعاد ذات قاعدة مسطحة تُعرف باسم *tp-r*. يتم تقليص هذا البُعد باستخدام خوارزمية خاصة بالشكل، ثم يُضرب هذا البعد فى بُعد ثانٍ محدد لإيجاد مساحة الشكل.

الكلمات المفتاحية

بردية موسكو الرياضية – الهندسة المصرية – W. W. Struve – T. Eric Peet

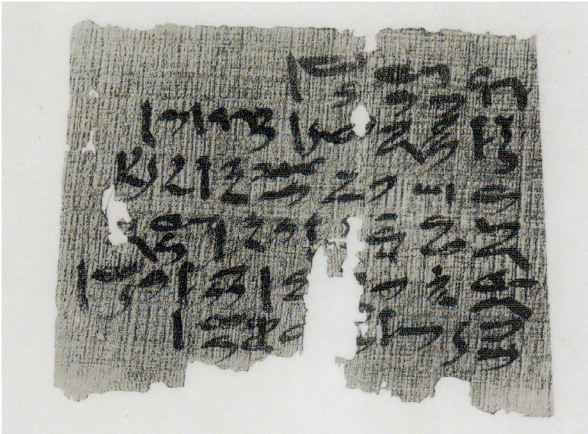
The subject of this piece is a mathematical problem in which the problem solver is asked to calculate the surface area of some kind of basket-shaped geometric figure. But it turns out to be far from a straightforward operation, however, because there is a damaged word in the text and also a possible scribal omission of a measurement of one of the object's dimensions. These ambiguities open up the possibility of more than one interpretation of just exactly what the object is supposed to be. The proposed shapes that have gained the most traction are a hemisphere, a semicircle, and the lateral area of a semicylinder. This paper analyzes the problem with a view to ascertaining which of these shapes is most likely to be the right one.

Ever since its publication in 1930, Problem 10 of the Moscow Mathematical Papyrus (P. Moscow 4676) has continued to challenge its interpreters. The problem deals with calculating the surface area of a geometric figure called a *nb.t* or "basket", which is described as being "half an *ỉ*[…]". Suggestions as to exactly what the *nb.t* is and how to reconstruct *ỉ*[…] have continued to appear in Egyptological publications well into the twenty-first century. This brief study will examine the various interpretations of the object, making a case that one of the early interpretations, much overlooked and underappreciated, is most likely the correct interpretation.

Because the text has lent itself to several different interpretations, a technical preview of the proposed shapes of the *nb.t* and how to calculate their areas would be in order before approaching the text. Hemisphere: Area = diameter × semicircumference. Semicylinder (half the lateral area of a cylinder divided lengthwise): Area = height × semicircular arc. Semicircle: Area = radius × half arc. The respective numerical values in each pair of dimensions are 4½ and 7⅑, which yield a product of 32. In addition to these shapes, there have been couple of other proposals that haven't gained as much of a following (see fig. 4).

There are two lineages of interpretation of the problem, one based on the text as it stands, which will be discussed first, the other based on an emended text in which what was thought to be an omitted numerical dimension of the *nb.t* is restored in line 2. The problem was originally published by Struve (1930: 157–168, Tafel IV), and the following is the English translation from the German by Peet (1931: 100); interlinear transliteration provided by the present writer (cf. figs. 1–3):

1) Form of working out a basket.
   tp n ỉr.t nb.t
2) If they mention to you a basket with a mouth
   mỉ ḏd n=k nb.t m tp-r
3) of 4½ in preservation.
   r 4½ m ʿḏ ḥꜣ
4) Let me know its surface.
   dỉ=k rḫ=ỉ ꜣḥ.t=s ỉrỉ.ḫr=k
5) Take a ninth of 9, since the basket
   ỉrỉ=k ⅑ n 9 ḥr-ntt ỉr nb.t
6) is half an egg; result 1.
   gs pw n ỉ[…] *ḫpr.ḫr 1*
7) Take the remainder, namely 8.
   ỉrỉ.ḫr=k ỉrỉ=k ḏꜣ.t m 8



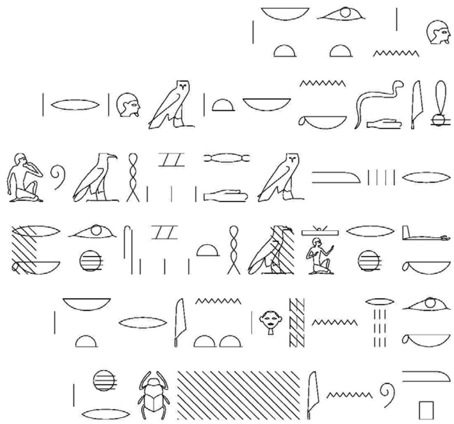
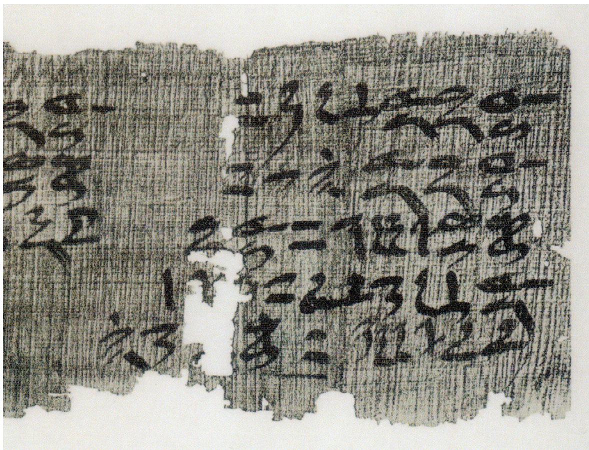


Fig. 1 Lines 1–6 (photo after Struve 1930: Tafel IV)



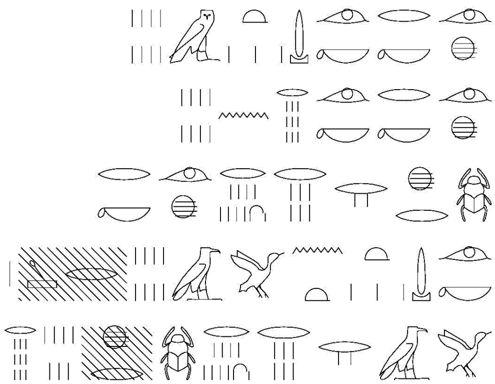
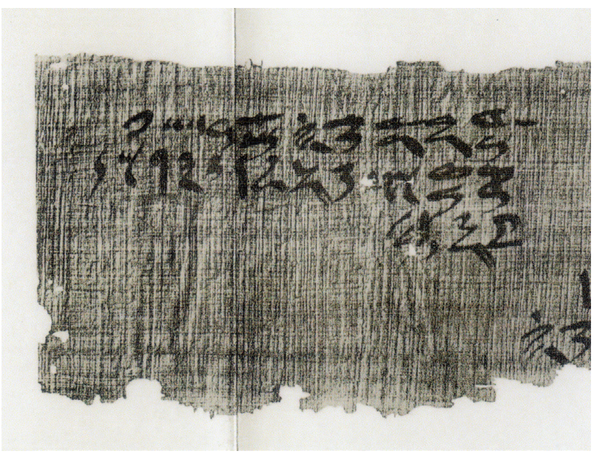


Fig. 2 Lines 7–11 (photo after Struve 1930: Tafel IV)



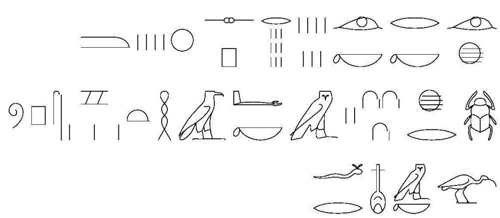
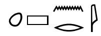


Fig. 3 Lines 12–14 (photo after Struve 1930: Tafel IV)

8) Take a ninth of 8;
ỉri.ḫr=k ⅑ n 8
9) result ⅔ + ⅙ + 1/18. Take
ḫpr.ḫr ⅔ ⅙ 1/18 ỉri.ḫr=k
10) the remainder of these 8 after (the subtraction of)
ỉri=k ḏꜣ.t n.t pꜣ 8 r-sꜣ
11) this ⅔ + ⅙ + 1/18; result 7 ⅑.
pꜣ ⅔ ⅙ 1/18 ḫpr.ḫr 7 ⅑
12) Recon with 7 ⅑ 4½ times;
ỉri.ḫr=k ỉri=k 7⅑ zp 4½
13) result 32. Behold, that is its surface.
ḫpr.ḫr 32 mk ꜣḥt=s pw
14) You have found rightly.
gmỉ=k nfr

Here the *nb.t* is taken as a hemisphere with a diameter of 4½ and a calculated semi--circumference of 7 ⅑, those measurements multiplied together to yield the area of its curved surface, 32. Some of the Egyptian terminology requires comment. A description of the mouth of the *nb.t* in lines 2–3 reads *nb.t m tp-r | r 4 ½ m ꜥḏ*, Struve reading *ꜥḏ* as the infinitive of the verb "to be whole" (1930: 162–163); in other words, the mouth or *tp-r* of the *nb.t* is "whole" or "preserved", *i.e.* the great circle of a hemisphere and not some smaller circle belonging to a lesser segment of a sphere. But *tp-r* – literally "front of the mouth" – is also used in Middle Egyptian mathematical papyri to refer to the bases of two-dimensional plane figures such as triangles and trapeziums, a fact not lost on other interpreters.[1] In line 6, the *nb.t* is described as being "half an *ỉ*[...]", the damaged word reconstructed by Struve as *ỉnr*, literally "stone", but suffixed with the egg sign to give it the meaning of "egg" or "eggshell"  (Struve 1930: 163–166).

The finding of the semicircumference of the *nb.t* requires some discussion. If a circle is enclosed in a square whose sides are equal to the diameter of the circle, there exists a ratio of the area of the circle to the area of the square, a circle-to-square area ratio. Now there is an inherent proportionality in these figures such that the circle-to-square perimeter ratio – the ratio of the circumference of the circle to the perimeter of the square – is also the same as the circle-to-square area ratio.[2] Problem 48 of the Rhind Mathematical Papyrus depicts a 9 × 9 square with an area of 81 in which is enclosed a circle (or a polygonal representation of a circle) with a diameter of 9 and an area of 64, giving a circle-to-square area ratio of 64/81. *If* the ancient Egyptians were cognisant of the equivalence of the area ratio and the perimeter ratio, they would have been able to calculate circumference by taking 64/81 of the perimeter of the square, which is equal to 4 times the circle's diameter. Since the ancient Egyptians didn't

1 Although modern mathematical convention shows geometric figures such as triangles and trapeziums standing on flat bases, drawings of these figures in Middle Egyptian papyri show relatively tall figures tipped sideways, their relatively narrow bases more or less vertically oriented. In that position, the sides of the figure resemble jaws, and the base resembles the "front of the mouth". In the case of a hemisphere, the "mouth" is quite obvious. For familiarity's sake, the plane figures depicted in upcoming fig. 2 are shown "standing" on their "bases".

2 This can easily be confirmed with pencil, paper, calculator, and the π approximation of one's choice.

use fractions such as 64/81 but rather worked with unit fractions, they would have made two successive reductions of the square's perimeter by ⅑ to obtain the same result as if by taking 64/81 of the square's perimeter. In order to calculate the semicircumference of a circle having a diameter of 4½, the diameter would be doubled to obtain the imaginary square's semiperimeter of 9 – that would be where the 9 comes from in line 5 – and then the 9 would be reduced by two successive reductions of ⅑ to obtain the semicircumference of 7⅑. This is the view articulated by Struve (1930: 178).

Peet found the grammatical structure of *nb.t m tp-r | r 4 ½ m ꜥḏ* problematic because *r* is typically used to introduce the second of two given dimensions. He resolved the issue by positing another dimension *ẖ* of the *nb.t* that had inadvertently been omitted by the scribe: *nb.t <n.t ẖ> m tp-r | r 4 ½ m ꜥḏ* (Peet 1931: 101). Thus the missing dimension was assigned to the *tp-r*, and the given dimension of 4½ was assigned to the *ꜥḏ*, which Peet understood to be the name given to the second dimension. The *nb.t* was *ẖ* in its *tp-r* by 4½ in its *ꜥḏ*. Peet understood the *i*[...] in line 6 to be some kind of round object, simply calling it a circle. By letting the restored dimension *ẖ* be 9, the *nb.t* could be understood to be a two-dimensional basket shape, a semicircle (Peet 1931: 103):

1) Example of working a semicircle.
2) If they say to you, A semicircle <of 9> in diameter
3) by 4½ in height, pray
4) let me know its area. You are to
5) take a ninth of 9, since a semicircle
6) is half a [circle]

There are no changes to the rest of the problem; 9 is reduced by ⅑ to 8, which is reduced by ⅑ to 7⅑, which is multiplied together with 4½ to obtain 32.

Although Peet notes that the 4½ corresponds to the radius of the semicircle and the 9 corresponds to the diameter, he doesn't explain the context of the mathematical operations performed upon the diameter. That context can be supplied in the light of the previously described circle-to-square ratios. In terms of the perimeter ratio, the diameter of 9 is also equal to one side of an imaginary 9 × 9 square; and performing the operations on a quarter perimeter of the square would yield the quarter circumference of its enclosed circle, which would equal the half-arc of its semicircle. Thus the 7⅑ in the problem is the half-arc of the semicircle. Seidenberg also understands the calculation of the half-arc of the semicircle as a function of perimeter ratio (Seidenberg 1972: 196).

The area ratio also affords a solution. If a 9 × 9 square enclosing a circle with a diameter of 9 is bisected from side to side, the half figure would be a semicircle enclosed in a rectangle measuring 4½ × 9. Shortening the length of the rectangle by two successive reductions of ⅑ yields a rectangle length of 7⅑ which when multiplied together with the rectangle height of 4½ gives an area of 32. Peet had misgivings about the semicircle interpretation, however, because it supplied two dimensions when only one was necessary (Peet 1931: 103, 106).

Peet offered a second interpretation which involved letting the missing dimension *x* be 4½ and taking the *nb.t* as a semicylinder – half the lateral area of a cylinder divided length wise – whose height and diameter were both 4½ (Peet 1931: 105):

1) Example of working out a semi-cylinder.
2) If they say to you, a semi-cylinder <of 4½> in diameter
3) by 4½ in height; pray
4) let me know its area. You are to
5) take a ninth of 9, since a semi-cylinder
6) is half of a [cylinder].

And again, there are no changes to the rest of the problem.

Peet tentatively restored the damaged word *i*[…] in line 6 as *ipt*, which he took as a grain measure container with a cylindrical shape, its semicylindrical form resembling the curve of a hemispherical basket when viewed endways (Peet 1931: 104–105). The mathematical operations involve the same application of the perimeter ratio as in the calculation of the semicircumference of the hemisphere with a diameter of 4½; here the calculated length of the semicircular arc of 7⅑ is multiplied together the given height of 4½ to obtain the area of 32.

With but a couple of exceptions, subsequent treatments of Problem 10 have tended to fall into one of the three categories discussed above. Differences of opinion over just exactly what the *nb.t* is, what the *ꜥḏ* is, how lines 2–3 should be read, and how *i*[…] should be restored have kept the debate going. Here is how things stand at this writing (fig. 4): hemisphere (Struve

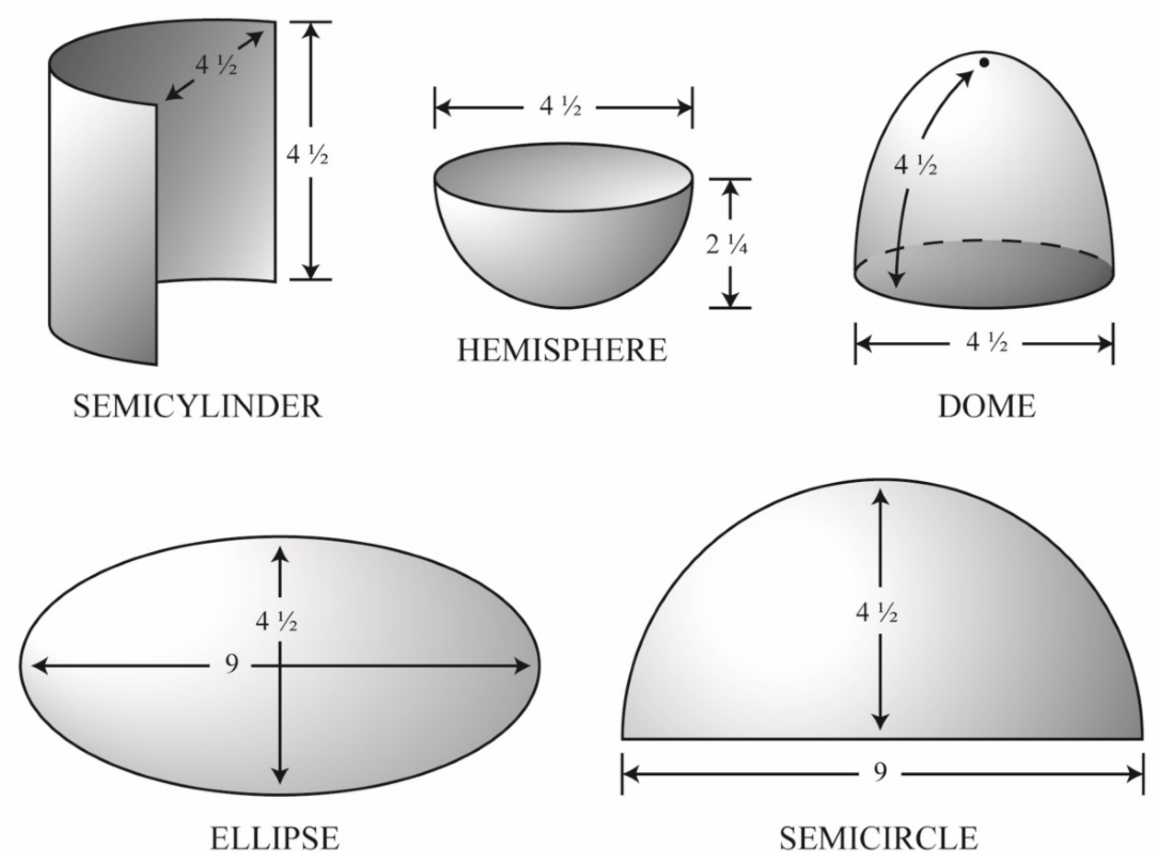


Fig. 4 Various interpretations of the *nb.t*; the hemisphere, semicylinder, and semicircle have been the most discussed

1930: 157–168; Gillings 1967; Gillings 1972: 194–201; Clagett 1999: 234; Cooper 2010; Michel 2012); semicircle (Peet 1931: 104–105; Smeur 1970: 268; Seidenberg 1972: 196; Friberg 2005: 77–81) and semicylinder (Peet 1931: 103–104; Hoffmann 1996; Miatello 2010; Miatello 2013: 67–70). Others (*e.g.* Neugebauer 1969: 136–137) suggested the *nb.t* might be a domed granary with a diameter of 4½ and an apex-to-circumference surface distance of 4½, its area being an approximation rather than an accurate calculation;[3] Schwela (2011) construed the *nb.t* as an ellipse with dimensions of 4½ and 9.

It was stated early on that a case could be made for one of the earlier interpretations being the right one, and that interpretation is Peet's semicircle. The first point to be addressed is Peet's own misgivings about the semicircle because the problem gives two dimensions when only one is necessary, a point echoed by other interpreters as well.[4] The stumbling block here is the imposition of modern sensibilities upon ancient mathematics. In the modern world, every schoolchild learns πr^2, so when the area of a semicircle comes up, the reflexive response is to think one half πr^2. This wasn't the case in ancient mathematics, however; the Babylonians, for example, had three formulas for finding the area of a semicircle, none of them amounting to calculating the area of a circle and taking one half the result (Friberg 2005: 80).

The next step is an application of Occam's razor to pare away a problematic aspect of all the interpretations based on perimeter ratio. There is not in the entire corpus of Middle Egyptian mathematical texts a single example of a straightforward calculation of a circle's circumference.[5] Yet in interpretations of this problem, there are imputed calculations of semi-circumference and quarter circumference with no preamble whatsoever – no instruction that a partial circumference needs to be calculated, no mention of circumference at all, no mention that the 9 in line 5 would represent a doubling of the diameter of 4½ in the case of the hemisphere and the semicylinder. The spurious perimeter ratio business stripped away, the *only* remaining interpretation is that involving area ratio: the half figure of a circle with a diameter of 9 enclosed in a 9 × 9 square is a semicircle enclosed in a 4½ × 9 rectangle, and operating on the long side of the rectangle with two successive reductions of ⅑ shortens the length of the rectangle to 7 ⅑, leaving the rectangle with an area of 32.

Before relating the method behind the aforementioned area ratio calculation to the methods underlying the area calculation of other plane figures, additional remarks on terminology are in order. In the Demotic Mathematical Papyri, a segment cut from a circle by an inscribed triangle or square is called a *nby* or "basket" (Parker 1972: 44–48), and the basket glyph 𓎟 in the word *nb.t* looks just like one of the segments so depicted; so perhaps the *nb.t* may be more accurately described as a segment, which *is* defined by two dimensions. After the two dimensions of the segment are disclosed, it then becomes apparent that the segment is a semicircular segment, requiring a particular method of area calculation. Recent scholarship has offered a convincing reconstruction of the damaged word *i*[...] as *itn* 𓇳𓏏𓈖𓇋 (Michel 2012: 271), "sun" or "disk of sun"

3 The area is correct for the lateral area of a cone with a base of 4½ and a slant height of 4½ (see Neugebauer 1969: 137).

4 It apparently escaped Peet's notice that a semicircle is a special case of a circle segment, which *is* defined by two dimensions; other interpreters, however, have noted such (*e.g* Seidenberg 1972: 195).

5 Others have noted this as well (*e.g.* Smeur 1970: 265); and "the Egyptians did not 'calculate' the circumference of a circle" (Smeur 1970: 268, no. 76).

(Faulkner 1962: 33), this study opting for "disk" in the sense of a flat, circular shape.[6] The hieratic for *ꜥḏ* isn't perfectly clear, Struve reading it as being suffixed with the scroll sign  and having the meaning of the infinitive of "to be whole", Peet reading it as being suffixed with the canal sign  and perhaps having the meaning of "the strip of land bordering on the cultivation" (Peet 1931: 104, n. 3). This study reads the word as being suffixed with the canal sign and having the meaning of "edge" or "margin of cultivation" (Faulkner 1962: 51).

As previously mentioned, the bases of triangles and trapeziums are also called the *tp-r*, their height referred to as the *mryt* "bank" or "shore" (Faulkner 1962: 112).[7] Examples of calculating the area of triangles and trapeziums include Problems 51 and 52 in the Rhind Mathematical Papyrus. The methods are those still used today; half the base times the height gives the area of the triangle, and half the sum of the bases times the height gives the area of the trapezium. In these two examples, it is noted by the scribe that the operations are performed in order to obtain the "rectangle" or *ỉfd* of the figure (Peet 1923: 91, 94; Chace 1927: 92–93). This refers to the fact that the area of the triangle is equal to the area of a rectangle whose dimensions correspond to the height and half base of the triangle, and that the area of the trapezium is equal to the area of a rectangle whose dimensions correspond to the height and half sum of the bases of the trapezium. It was subsequently discovered, however, that what was being read as *ỉfd* or "rectangle" should have actually been read as *ỉfd-rmn* or "half a rectangle" (Galán 1990; Imhausen 2003: 251, 253). This mention of half rectangles implies whole rectangles whose dimensions would then correspond to the height and base of the triangle and to the height and sum of the bases of the trapezium-rectangles that could be imagined as enclosing the respective figures.

This points to a general method for setting up the calculation of the area of plane figures having a *tp-r*. The particular figure is visualised as being enclosed in a rectangle whose dimensions correspond to the height and base (*tp-r*) of the figure. The base of the rectangle is then operated upon in such a way so as to leave a smaller rectangle having the same area as the figure, the height of the rectangle remaining unchanged (fig. 5).[8] In the case of the triangle, the base of its enclosing rectangle is shortened by one half. In the case of the trapezium, the base of its enclosing rectangle is first extended by the length of the upper base, this sum of the bases length then shortened by one half. And in the case of the *nb.t*, the base of its enclosing rectangle is shortened by two successive reductions of ⅑.

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6 Michel herself opts for "sun" in the sense of a spherical body rather than "disk of sun" as a flat, circular shape. This note presents an opportune time to correct a misconception concerning Neugebauer's purported take on *ỉtn*. In no less than three recent papers on this problem, Neugebauer is said to have reconstructed *ỉ*[…] as *ỉtn*. In reality, Neugebauer pointed out that although some readers of the problem might take *ỉ*[…] as *ỉtn*, he himself had his doubts, finally concluding: "So ist also die Ergänzung *ỉtn* mit Sicherheit auszuschließen." (Neugebauer 1969: 133) This study finds Michel's detailed reconstruction of the damaged word more persuasive than Neugebauer's objections.

7 Middle Egyptian geometry problems abound in agrarian imagery. The area of the *nb.t* is its *ꜣḥ.t*, literally "field" or "arable land" (Faulkner 1962: 4). It is not surprising, then, that words describing boundaries of plots of acreage – "bank", "shore", "edge", "margin of cultivation"– would be used to describe the dimensions of geometric figures.

8 The trapezium and triangle are shown as right-angle figures as a visual aid for conceptualizing the method described; the method gives the same result for isosceles and scalene figures as well.

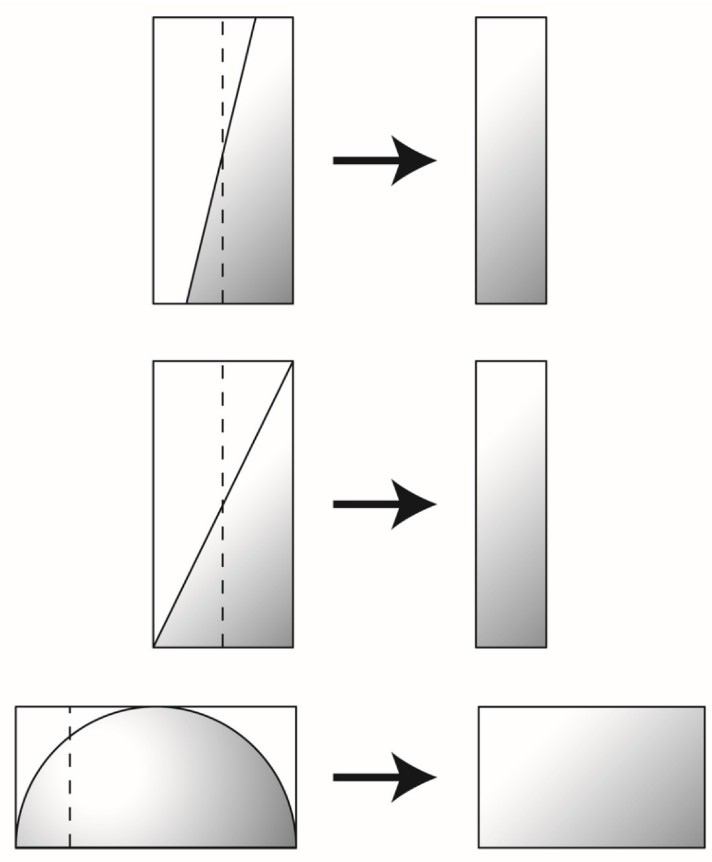

Fig. 5 Illustration of a method of area calculation in which a figure is visualized as being enclosed in a rectangle, the base of the rectangle operated upon in such a way as to reduce the area of the rectangle to the area of the enclosed figure

The crucial beginning lines of the problem may therefore be rendered as follows:

1) Method of calculating a segment:
   tp n ỉr.t nb.t
2) If said to you, a segment <of 9> in base
   mỉ ḏd n=k nb.t <n.t 9> m tp-r
3) by 4 ½ in height, pray
   r 4 ½ m ꜥḏ ḥꜣ
4) let me know its area.
   dỉ=k rḫ=ỉ ꜣḥ.t=s ỉrỉ.ḫr=k
5) Take ⅑ of 9 because the segment
   ỉrỉ=k ⅑ n 9 ḥr-ntt ỉr nb.t
6) is half a [circle]
   gs pw n ỉ[tn]

The paradigmatic circle area problems in the Rhind Mathematical Papyrus (41, 43, and 50) all involve circles with a diameter of 9, the problem solver instructed to take away ⅑ of the diameter of 9 as the first step in calculating the area. The instructions in line 5 above to "take

⅑ of 9" seem to presuppose familiarity with the paradigmatic circle area problems and reinforce the supposition that the *nb.t* is indeed "half a *circle*".[9]

In conclusion, although Problem 10 has continued to challenge its interpreters, many of the interpretations are predicated upon the supposition that Middle Egyptian mathematicians had a working knowledge of the circle-to-square perimeter ratio and were able to calculate the circumference of a circle in spite of the fact that there are no straightforward examples of such in the Middle Egyptian mathematical texts. This study presents a case that the *nb.t* is a segment of a circle, which is defined by two dimensions, the disclosure of the dimensions indicating that the segment is a semicircular segment whose area can be calculated by an application of the circle-to-square area ratio. Like triangles and trapeziums, a segment has a base called a *tp-r* and lends itself to a method of calculation in which a figure is envisioned as being enclosed in a rectangle whose dimensions correspond to those of the enclosed figure, the base of the rectangle operated upon in such a way as to reduce the area of the rectangle to the area of the enclosed figure. Peet deserves credit for first accurately describing the shape of the *nb.t* as being semicircular.

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9 In these area problems, once ⅑ is taken away from the diameter of 9 leaving 8, the 8 is squared to obtain the area of 64, half of which is the *nb.t* area of 32. This operation can be visualized as a circle with a diameter of 9 enclosed in a 9 × 9 square, the square then shrinking in size to an 8 × 8 square and squeezing the area of the circle into the area of the smaller square. One half of that square bisected from side to side is a 4 × 8 rectangle with the same area as the *nb.t*. So why did they *not* use this method to calculate the area of the *nb.t*? It's because the *nb.t* has a *tp-r*, and when the area of figures with a *tp-r* are calculated, the *tp-r* is operated on while the other dimension remains the same. In the example above considered as a half figure, a 4½ × 9 rectangle enclosing a semicircle has *both* sides operated on to reduce it to a 4 × 8 rectangle. In the "orthodox" method, only the long side of the rectangle – corresponding to the *tp-r* – is operated on to produce a 4½ × 7 ⅑ rectangle, the dimension of 4½ left as is.

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