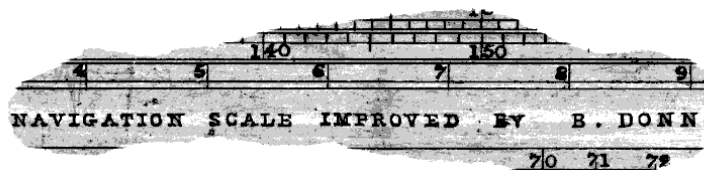


# The Navigation Scale, Improved by B. Donn<sup>1</sup>

Otto E. van Poelje



## Introduction

Maps and drawing instruments were the basic instruments of the sea navigator in the past, and they still exist today, even in our modern GPS-mapped world.

In ref. [13] the navigation rule was investigated, especially the plain-scale and the Gunter rule which were equipped with engraved scales for recurring navigational calculations. The Gunter rule not only used the logarithmic scales that Edmund Gunter had published in 1624, but contained many other specialized scales for drawing and calculating problems in navigation. Of the Gunters known today, the vast majority conform to the scale layout of the so-called Standard Gunter Rule. Still, there have been variations of that standard.

In the first place, some early variations are known from the 17<sup>th</sup> century, when the Standard Gunter Rule was not yet fully developed. But secondly, as we will describe in this article, a well-documented variant of the Gunter rule was developed between 1764 and 1772 by Benjamin Donn.

## Benjamin Donn

In the town of Bideford, Devon, a Mathematical School was run by George Donn in the mid-18<sup>th</sup> century.

Two of his sons, Abraham and Benjamin, were to become mathematicians, teaching in their father's private school. Here we will concentrate on Benjamin Donn (1729-1798) who lived and worked first in Bideford, and from 1764 in Bristol, see ref. [8] and [11]. In Bristol he established his own "Mathematical Academy". Compared to local grammar schools of that time, his curriculum was very progressive and extensive in diverse branches of engineering:

"Writing in the Usual Hands, Arithmetick, Algebra, Altimetry, Architecture, Astronomy with Theory of the Planets, Book-Keeping, Calculation of the Eclipses, Chances, Chronology, Conics, Decimals, Fluxions, Fortifications, Gauging, Geometry, Gunnery, Hydraulics, Hydrography, Hydrostatics, Levelling, Longimetry, Marine Architecture, Navigation, Shipbuilding, Mechanics, Mensuration, Optics, Perspective, Pneumatics, Surveying, Trigonometry, both Plane and Spheric."

We can see remnants of his teaching activities in the British Library: exercise books and teacher guides on decimal arithmetic, geometry, accountancy and logarithms. He even published tables, like the 7-decimal logarithms from 1 to 10,000 in his book "The British Mariner's Assistant . . .", see ref. [3]. In his 1758 book "Mathematical Essays", he describes himself as "*Teacher of the Mathematics and Natural Philosophy on Newtonian Principles*".

For the educated public he gave popular lectures on mathematics and science, and he published in the same vein, for example, several astronomical articles on eclipses and transits between moon, sun or Mercurius.

Bideford and Bristol were seaports where Donn must have taught mariners on the subjects of mathematics and astronomy as needed in navigation. This would explain the interest he took in the design of mathematical instruments. A number of articles from his hand have appeared, in the "Gentleman's Magazine" and the "Mathematical Repository", during the second half of the 18<sup>th</sup> century on subjects like a Davis' Quadrant, an Orrery, lunar and tidal instruments and an "Analemma", "Panorganon" or "Georganon" for solving "Problems of the Globe". In his 1796 book "An Essay in Mechanical Geometry", he informs the reader that

"...from 1766 to the present time I have invented mechanical aids to the most important propositions in Geometry, 50 schemes and models in card-paper, wood and metal."

Donn was active in designing, and also in selling his instruments at his Academy: the production of his designs he had delegated to instrument makers and engravers.

Benjamin Donn also was active in a different line of business: map-making. As a cartographer he acquired fame with his large scale (1 inch to the mile) county map of Devon in 1765, which won him the first prize instituted by the "Society of Arts". His very professional and accurate survey took him more than 5 years to complete and in his cartography he used innovative methods, for example the graphical display of some road aspects like hedges. He also produced maps of Bristol and surroundings.

About 1782 Donn changed his surname to Donne, the old family spelling, on the advice of friends.

<sup>1</sup>JOS Plus indicates that additional material for this article is available on our website [www.oughtred.org](http://www.oughtred.org).

Only a few years before his death, under the patronage of James, Marquis of Salisbury, he was appointed the honorary title of “Master of Mechanics to his Majesty”.

This summary shows Benjamin Donn to have been a widely talented man, but for now we will focus on just one of his instrument designs: “The Navigation Scale, improved by B. Donn”.

### Method of Investigation

The Donn rule is even more scarce than the Gunter rule. Whereas more than 50 different Gunter rules (or pictures of rules) were available for the Gunter study in ref. [13] and [14], only six Donn-“Improved” Gunter rules could be found to form the basis of this study. These samples were all made of wood, and had lengths of two feet. The study really focused on scale design, and not on construction or manufacturing aspects. As it turns out, five out of the six Donn rules conform very well to Donn’s original description, the remaining one missing almost half of the Donn aspects like the name of Donn and all changes in the logarithmic scales. Therefore we will focus our inspection on the five rules with the name of Donn imprinted on the front. Two of the Donn rules under inspection had a Maker’s name imprinted, one being on the left side of the Ver. Sines scale, “Hall & Hawkes, London”, dating that rule to the period 1839-1842 according to ref. [9]. The other named rule carries the inscription “A. Ulrich

Danzig” in the middle of the top inch scale at the front side. This professional engraving appears to represent the maker, but it could also have been an owner’s name. Any information from the readers about an instrument maker in Poland with this name, will be welcome. The “Danzig” specimen is used in most of the pictures in this paper.

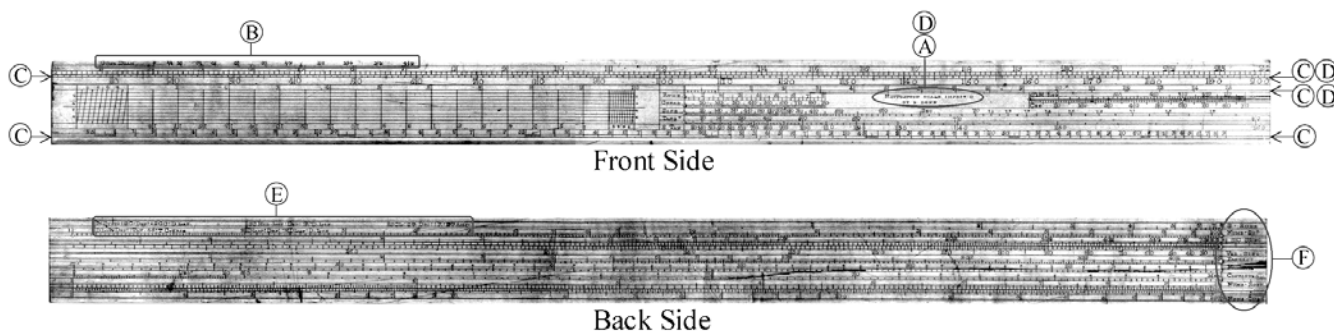
Fellow collectors kindly provided many pictures of their own specimens, either by scanning or by digital cameras.

Other sources for the study were Donn’s own description in ref. [2] and literature references like [7] and [10].

### Donn’s Improvements to the Gunter Scale

In Bristol, 1 Sept. 1772, a 12-page pamphlet by the hand of Donn was published, titled “The Description and Use of the Navigation Scale, As Improved in the Year 1772”, see ref. [2].

A transcript of this pamphlet is available as a JOS Plus feature on the website of the Oughtred Society at [www.oughtred.org](http://www.oughtred.org). In the introduction Donn explains how his experience over many years in teaching the use of the Gunter rule, has led him to design some improvements. He complains about the poor quality and low accuracy of many of the Gunter rules produced at that time. When Donn describes his improvements, he frequently makes the comparison with the “common Scales”, thereby meaning our “Standard Gunter Rule”.



The figure above shows the various areas where Donn has made his improvements on the front and the back side, numbered from A to F:

- A. The caption “Improved by B. Donn”
- B. Scale for Guns Diameter
- C. Extension of Equal Parts scales
- D. Changes in non-logarithmic scales
- E. Navigation formulae
- F. Changes in logarithmic scales

In the next sections we will treat each of these improvements in more depth. These changes are described as differences with the scales of the Standard Gunter Rule, which were extensively discussed in ref. [13].

### A. The caption “Navigation Scale Improved by B. Donn”

Already in 1764 Donn had asked instrument makers in London to produce Gunter rules with higher accuracy, and including some of his improvements. In the 1772 pamphlet [2], he reports that his original design had been pirated by other Makers:

“Several incorrect pirated Copies made in a very unworkmanlike Manner, and some with even the Diagonals drawn wrong, having been sold by some Makers in London and Bristol, and perhaps in some other Places, as my improved Scales; to prevent as much as possible my own Character from being injured thereby, and the Public from being imposed on, I hereby desire that any of the principal

Shops inclined to sell them, will apply to me to know with whom I have left the Pattern for the Trade, and to put under **Improved by B. Donn**, their own Names as Makers.”

This request to Makers has generally been met: most Donn rules can be recognized by this caption which is placed in the space that emerged by the removal of the Standard Gunter’s L and P scales (Equal Parts). Donn even mentioned by name a number of London Makers, who had been licensed to produce his improved rule:

“To prevent the Public being imposed on by the Sale of pirated Scales, it may be proper to acquaint them, that I have appointed the following Mathematical Instrument Makers, in LONDON, viz. Messrs. ADAMS, HEATH and WING, LINCOLN, MARTIN, NAIRNE, WATKINS and WHITFORD, to vend them, as they will not sell any without this Pamphlet, and their own Names as Makers stamped on the Scales; and consequently their own reputation will not permit them to sell any made in an inaccurate or nonwork-manlike Manner.”

Other Makers adopted his rule, even late in the 19<sup>th</sup> century. However, many surviving Donn rules—with his trademark caption—do not carry a Maker’s name.



All Donn rules under inspection had the Guns Diameter scale, at the top left side on the front, with pound values  $\frac{1}{2}$ , 1,  $1\frac{1}{2}$ , 2, 3, 4, 6, 9, 12, 18, 24, 32, 36 and 42 from left to right, but some were missing the values  $\frac{1}{2}$  and 36. All these values have brass pins inserted, suggesting the usage of dividers for measuring the gun’s bore. Note: all other brass pins in the Donn rules under inspection followed the regular design of the Standard Gunter Rule.

American rules in general have the inch scale numbered from right to left, in contrast to British rules, so the thoughtless copying of the guns diameter scale at the left of that inverted inch scale, did not result in a very practical gun scale. Only one of the Donn rules under inspection contained that unfortunate configuration, surprisingly the one from the British Maker! See ref. [12] for more information about observed practices in graduating inch scales left-to-right or right-to-left.

### C. Extension of Equal Parts scales

In the drawing rules called “plotting scales”, many Equal Parts (EP) scales are drawn to allow the use of more than one scale factor, which can be expressed in number of scale divisions per inch. The Standard Gunter Rule had only four factors of EP-scales:

All Donn rules under inspection have the caption “*Navigation Scale Improved by B. Donn*”, in one line or over two lines, sometimes with the dot after the “B” missing, or the “e” in “Improved”.

### B. Scale for Guns Diameter

This scale is added above the start of the 24-inch scale at the top left side of the front. For every guns diameter (“bore”) on the inch scale, the ball size could be read on the Guns scale in pounds (the usual identification of iron balls).

When the Donn rule was held before a gun to read a bore of 5.4” on the inch scale, the required ball weight of 18 pound was read on the guns diameter scale directly above the 5.3” value, showing a tolerance of 0.1”.

Donn added the thoughtful advice, that “. . . *it may be proper to hint, that the Weight of Powder for Service, is generally about half the Weight of the Shot.*”

Because of this guns scale, the casual observer might assume that the Donn rule is a military design. This is not the case because all other scales are non-military. It should be kept in mind that most commercial vessels at that time were equipped with guns, to fight pirates or to protect the King’s possessions.

In ref. [4], John Robertson describes around the same time a “Gunners Callipers” containing the same type of scale, and many more, where the bore measurement function is handled in an easier way by the calliper.

- the two-foot-wide inch scale represented the 10:1 factor, as did one of the two diagonal scales (the one inch part)
- the other diagonal scale (half-inch) represented the factor 20:1
- the L- and P-scale had the factor 30:1 and 50:1, but on many rules these were drawn very inaccurately (the meaning of these scale factors must have been forgotten over time)

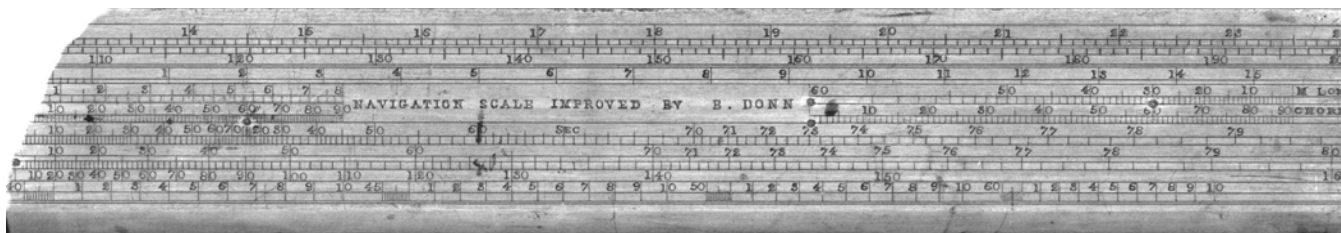
For a description of diagonal scales and finely divided “forerunners” on EP-scales, see ref. [14].

One first interesting addition by Donn was an EP-scale directly under the inch-scale on the top of the front side: this scale, from 0 to 200, represented decimal divisions of one foot. We might call these graduations “decifeet” and “centifeet”, but after all, they did not take hold in Anglo-Saxon measures.

Donn wanted to extend the number of EP-scales, to compete with the dedicated plotting scales. This was useful when working with maps of different scales. In an early design he even sacrificed the complete diagonal scale for a vertically arranged set of EP-scales (like on a plotting

scale). Eventually he managed to arrange horizontally—on the bottom line of the front side—not less than 7 EP scales, for the factors 25:1, 30:1 (replacing the L-scale), 35:1, 40:1, 45:1, 50:1 (replacing the P-scale) and 60:1. In addition, a 15:1 EP scale was put directly under the right-hand side of the decimal foot scale.

In total, Donn had managed to put ten EP-scales on his improved rule, for a full and elegantly arranged set of 10, 15, 20, 25, 30, 35, 40, 45, 50 and 60 to the inch respectively. All Donn rules under inspection contained the complete set of these Equal Parts scales.



### D. Changes in Non-Logarithmic Scales

With the additions of the caption and the 15:1 EP-scale on the right half of the front side, some scales of the Standard Gunter Rule had to go. The L- and P-scale, but also the LEA (a 20:1 EP-scale for leagues) had already moved to the range of EP-scales at the bottom and the diagonal scale respectively.

The only other scale in this space that had to give way to the Donn improvements, was the RUM scale related to the CHORD and the M.LONG scale at the very right side. This was no great loss as the M.LONG scale could just as well be used with only the CHORD scale.

All Donn rules under inspection contained these changes in non-logarithmic scales. The naming of these scales showed slight variations, not only in spelling but also the captions M.LONG and CHORD were placed either at the right side or at the left side of that pair of scales.

### E. Navigation formulae

On the back side of the Donn rule we see at the top left (in the less detailed lower part of the “Sines of Rhumbs” scale) a set of five formulae, to be used as *aides-mémoires* in the day-to-day work of navigators at sea.

The notation of these so-called “Canons” needs some explanation.

The first one,

$$R : \text{Dist} :: SC : \text{Dep.} :: SCC : D \text{ Lat.}$$

signifies:

“as Radius (R) is to the Distance (Dist) so is Sine of the Course (SC) to the Departure (Dep.), and so is Sine Complement of the Course (SCC) to the Difference of Latitude (D Lat).”

tation had already been laid in the late 1500s by François Viète and others, the common way to write formulae in Donn’s time, was still by equating “proportions”: this was very opportune for logarithmic scales because a proportion is represented by the scale distance between the two numbers in the proportion.

In today’s notation we would write:

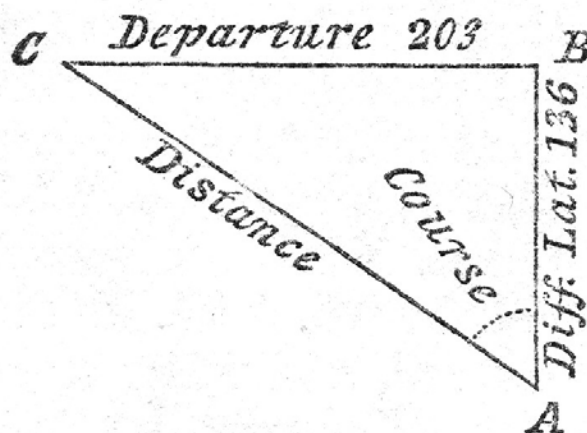
$$\frac{R}{\text{Dist}} = \frac{SC}{\text{Dep.}} = \frac{SCC}{D \text{ Lat.}}$$

or:

$$\text{Departure} = \text{Distance} * \sin (\text{Course})$$

$$\text{Difference of Latitude} = \text{Distance} * \cos (\text{Course})$$

This is the elementary formula in the rectangular triangle between distance A to C, “Departure” (= Difference in Longitude) and the Difference in Latitude.



The explanation and context of this formula, and the four other ones, can be found in Bowditch, ref. [6], in the section on “Plane Sailing” and succeeding sections.

Although the foundations of our current algebraic no-

The other formulae are:

D Lat. : Dep. : : Tan. 45 : T Course	“as Difference of Latitude is to the Departure so is Tangent of 45 Degrees to the Tangent of the Course”
SC mid. Lat. : Dep : : R : D. Lon.	“as Sine Complement of middle Latitude is to the Departure, so is Radius 90 Degrees to the Difference of Longitude”
D Lat. : Dep : : MD Lat : D. Lon.	“as Difference of Latitude is to the Departure, so is Meridional Difference of Latitude to the Difference of Longitude”
SCL : S ☉ Dec : : R : SCL : S ☉ Amp.	“as Sine Complement of Latitude is to the Sine of the Sun’s Declination so is Radius or Sine of 90 Degrees to the Sine of the Sun’s Amplitude”

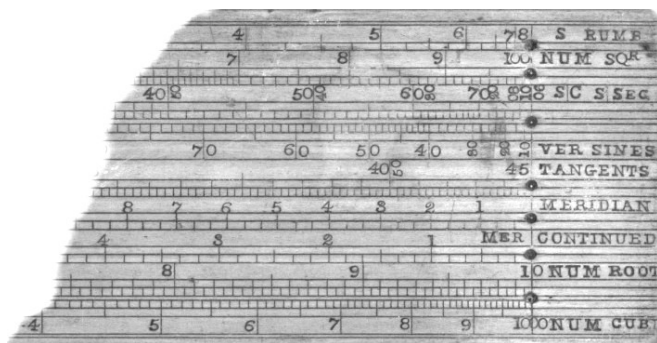


All Donn rules under inspection showed these five formulae, but many print errors were observed, like leaving out dots and colons: the makers obviously did not always understand the symbols for the equations of proportions.

**F. Changes in Logarithmic Scales**

The logarithmic scales on the back of the Donn rule have been changed from the Standard Gunter Rule into the following set:

S . RUMB		unchanged	Sine of Rhumbs
T . RUMB	Note 1)	REMOVED	Tangent of Rhumbs
NUMB . SQ <sup>R</sup>	Note 2)	NEW	Number “Square”, 2 decades: 1 - 100
S   C S   SEC	Note 3)	same as SIN, cosine added	Sine, Cosine, Secant
VER . SINE		unchanged	Versed Sine
TANGENT		unchanged	Tangent
MERIDIAN	Note 4)	RESCALED	Meridional increments
CONTINUED	Note 4)	NEW	Extension of Meridian scale
NUMB . ROOT	Note 2)	NEW	Number “Root”, 1 decade: 1 - 10
NUMB . CUBE	Note 2)	NEW	Number “Cube”, 3 decades: 1 - 1000
E * P	Note 4)	REMOVED	MERIDIAN uses small scale EQ. DEG.



Note 1)

The removal of T. RUMB must have been necessary to make space for new scales; there is already a TANGENT scale, and the choice to remove T. RUMB (instead of S. RUMB) indicates the priority that the sine function had for mariners.

Note 2)

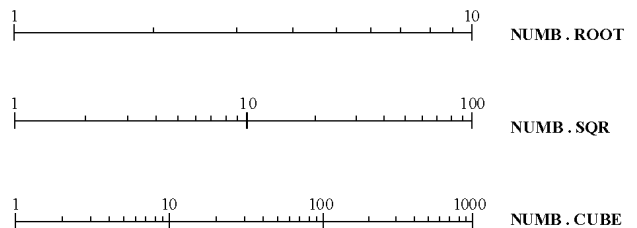
The standard Gunter rule had one single scale of numbers (NUMB). This scale was already in Edmund Gunter’s original design of the three lines NUMB, SIN and TAN.

The original NUMB scale by Gunter was a two-decade

logarithmic scale, in the first place to cover a range of 0.01 to 1.0 for the SIN and TAN function, and secondly to prevent results in a calculation from overflowing outside the NUMB scale.

Donn added a 1-decade scale, called NUMB. ROOT, and a 3-decade scale, called NUMB. CUBE.

For consistency he renamed the old NUMB scale into “NUMB. SQR”.



On these three scales one could not only multiply and divide, but also handle squares and cubes, and square and cube roots.

This naming of the three NUMB scales can be confusing, as the named function is related to only one of the other two scales. Also the renaming of the original

NUMB scale into “NUMB SQR” makes it less intuitive that this still is the scale which corresponds with the sine and tangent scales.

Note 3)

The SINE scale itself is unchanged, running from lower than  $1^\circ$  to  $90^\circ$ , but the complementary angles are imprinted vertically, next to each tenfold of a degree value. This allows reading of cosine values, hence the scale indication:

S | C S | SEC

where “C S” stands for CoSine, and SEC for Secant. Donn claimed that his sine scale effectively contained the secant function too, because when used with the NUM scale the cosine function can be changed into the secant version by using the reciprocal of the cosine value on the NUM scale: this means the distance on the cosine scale between the tips of the dividers should be extended the “other” way on the NUM scale.

What Donn was actually saying by this reasoning, was: *rewrite the secant in your formula into  $1/\cosine$ , so you can use the sine & cosine scale.*

Note 4)

The original Meridian scale on the Standard Gunter Rule was a single scale, designed to range from latitude  $0^\circ$  to about  $86^\circ$ . The adjacent E\*P scale gave the increase in vertical scale on a Mercator map, while the P-scale on the front gave the vertical distance in sea miles between two latitudes.

Donn considered the precision of the original Meridian scale insufficient, so he decided to provide two successive MER scales, calling the first one “Meridian” ( $0^\circ$  to  $60^\circ$ ) and the second one “Continued” ( $60^\circ$  to  $80^\circ$ , so his highest limit was lower than in the Standard Gunter Rule—which would only affect Polar explorers).

To the extreme left of the Continued Meridian scale, a small separate scale is inserted, “Equator Degree”, representing the horizontal map distance of 10 degrees on the equator. This scale is used to determine the vertical map distance between any two latitudes measured on the Meridional scale. In the Danzig rule this small scale is abbreviated to EQ<sup>L</sup> DEG (Equatorial Degree). In the standard Gunter rule this small scale was the extreme right part of the E\*P scale adjacent to the MER scale.

Donn’s meridional distances in equatorial sea miles have to be read on the 20:1 Equal Parts table in the diagonals scale (half-inches) on the front side. For example, the distance between latitude  $20^\circ$  and  $30^\circ$  can be read on the diagonals scale to represent a vertical distance of 663 equatorial sea miles. On the EQ<sup>L</sup> DEG scale it shows to be “waxed” to 11.05 Equator Degrees.

All Donn rules under inspection contained the described changes in logarithmic scales, with many variations in spelling of the abbreviated scale names (NUM or NUMB, VER SINES or VERSED SINES etc).

## Conclusions

How important are Donn’s improvements?

To answer that question, we should realize that before Donn there was no satisfactory single description of the Standard Gunter Rule. Bion’s description in Ch. VII of ref. [1] was the best of his time, but he concentrated more on construction than on usage.

The first significance of Donn’s improvements is that he described them clearly in his 1772 pamphlet.

Only some 100 years later, a very complete description of the Donn-improved Gunter rule was written by Captain Ludwig Jerrmann in Hamburg, see ref. [8], but the language restricted his publication to a German-reading public.

Some of Donn’s changes were definitely of lesser importance, or just informative (like the memory-aid formulae).

He clearly was a master in reorganizing the “real estate” of the two Gunter faces by leaving out some, and adding other scales. The addition of the caption with his name was important enough for him to move out the L- and P-scale: and the effect was that makers indeed did use this caption, so the Donn became a standard in itself as the inspection of the five Donn rules suggests.

The most striking improvement is the inclusion of the cube and the root scale, bringing the Donn rule in that respect to the level of the basic Rietz scales of more than a century later.

But these scales were not new. Already in 1645, Edmund Wingate had described the one-decade and three-decade number scales as additions to Gunter’s original lines. And Thomas Everard described in 1684 his “sliding rule” for the gauging profession, which also contained one-decade, two-decade and three-decade scales, see Plate III of Bion’s book [1] or the instrument made by Carver (London Science Museum).

It is surprising that Donn’s design is rarely mentioned in the many books and articles that have been published on the history of slide rules since his time: apart from his own pamphlet, only references [7] and [10] mention Donn and his improvements of the Gunter rule, while reference [10] has an additional reference to a slide rule book by Albert Rohrberg addressing this subject.

Only a few years after Donn finished his improvements, the book “Gunter lines, as improved by John Robertson” was published posthumously by his friend William Mountaine, see ref. [5]. Robertson, like Donn, complained about the cheap and inaccurate Gunter rules of his time. His main improvements included an increase in length to 30 inches, a real “slider” and a brass “index”, although some scales still required the use of dividers. Robertson’s extension of Equal Parts scales, and the splitting of the meridional scale in two parts, shows some resemblance to Donn’s improvements. Would Donn and Robertson have known of each other’s designs?

Donn's improvements of the Gunter rule were quite valuable, but certainly not as revolutionary as Gunter's original scales, nor as innovative as Robertson's design.

The sea navigators, however, liked the Gunters and the Donn improvements well enough to keep the rules in production, even into the early 20<sup>th</sup> century.

### Acknowledgments

Many fellow collectors have contributed to this paper by providing information and pictures of their own Donn rules, or with references, remarks and suggestions. Especially I would like to thank Jim Bready, John Byrne, Ed Chamberlain, Dieter von Jezierski, Whitman Richards and Werner Rudowski for their valuable contributions.

### Literature, References, and Notes

[1] Bion, M., Stone, E., *The Construction and Principal Uses of Mathematical Instruments*, 1709. Facsimile reprint of the 1759 version by Astragal Press, NJ, 1995; the 1759 edition is translated from French into English and supplemented greatly by E. Stone.

[2] Donn, B., *The Description and Use of the Navigation Scale, As improved in the Year, 1772*, Bristol, Mathematical Academy, 1772. A transcript of this pamphlet is available as a **JOS Plus** feature on the website of the Oughtred Society at [www.oughtred.org](http://www.oughtred.org). One of the extant pamphlets can be found in the British Library under nr. 966105.

[3] Donn, B., *The Brittish Mariner's Assistant, containing 40 tables . . .*, London, 1774.

[4] Robertson, John, *A Treatise of Mathematical Instruments, as are usually put into a Portable Box*, London, 1775, facsimile reprint by The Invisible College Press, Woodbridge, Virginia, 2002.

[5] Mountaine, W., *A Description of the Lines drawn*

*on Gunter's Scale, as Improved by Mr. John Robertson*, London, 1778.

[6] Bowditch, N., *The New American Practical Navigator*, New York, Blunt, and other publishers, 1802 through late 20<sup>th</sup> century.

[7] Jerrmann, L., *Die Gunterscale*, Hamburg, 1888. This book of almost 100 pages gives a very extensive description of the Gunter/Donn rule. There are 42 detailed examples from the author's sea navigation practice. The introduction gives the history of the rule, but also some very practical hints for using the dividers on the rule.

[8] Ravenhill, W.L.D., "Benjamin Donn, 1729-98 – Mapmaker and Master of Mechanics", *Transactions of the Devonshire Association for the Advancement of Science Literature and Art*, XCVII, Plymouth, The Association, pp.179-193, 1965. This is the most extensive biography of Donn, from which most others are derived. It has an extensive list of publications by Donn, but the Gunter improvements are missing, both in the text and in the references.

[9] Clifton, G., *Directory of British Scientific Instrument Makers 1550-1851*, London, Zwemmer/National Maritime Museum, 1995, p.123.

[10] Jezierski, D. von, *Slide Rules, A Journey Through Three Centuries*, Astragal Press, 2000, p.4-5, 92-93, 100.

[11] Oxford *Dictionary of National Biography*, Benjamin Donn's biography, London, OUP, 2002.

[12] Stanley, Ph.E., *Source Book for Rule Collectors*, Astragal Press, 2003, p.156.

[13] Poelje, O.E. van, "Gunter Rules in Navigation", *Journal of the Oughtred Society*, 13:1, 2004, pp.11-22.

[14] Poelje, O.E. van, "Diagonals and Transversals: Magnifying the Scale", *Journal of the Oughtred Society*, 13:2, 2004, pp.22-28.