The Early Development of the Davis Quadrant

Nicolàs de Hilster

Introduction

By the end of the 17th century one of the most popular instruments for taking altitudes of the sun was the Davis quadrant (Fig. 1), of which it is generally accepted that it was fully developed by 1604.[1] Over the years during my research of early navigational instruments I found clues showing that 1604 was the start of its development rather than the end. The development went through several stages, relating to the frame, the scales and the vanes. In addition to that also the name of the instrument changed over time, not becoming 'Davis quadrant' until the last quarter of the 17th century. This article deals with the early development of the instrument and tries to provide evidence that the instrument was not fully developed until the 1670s. In addition to that the development of its name is looked at as well.

The Fully Developed Davis Quadrant

In its fully developed form the Davis quadrant is maybe best described by James Atkinson in 1715 (Fig. 2): '*The Form of it ... maybe of any Radius, or Length, between 18 Inches and 3 Feet; but the most general now made, are Quadrants of 26 Inches Radius, with one Arch 65 Degrees* [e-d], *the other 25* [g-F], *and a Glass* [lens] *in the Shadow-Vane* [B]. *The principal Parts are 3 Vanes* [A, B & C], *and 2 Arches* [e-d & g-F]*; on which Arches the Degrees both together make 90; from whence it hath the Denomination of a Quadrant. The Horizon-Vane* [A] *... respects the Horizon in Time of observing; that which gives the Shadow, is named the Shadow-Vane* [B]*; and that thro' which you are to look for both Shadow and Horizon, is termed the Sight-Vane* [C].'[2]

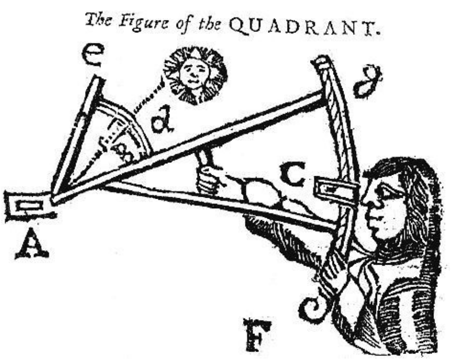

Fig. 2 *The Davis quadrant according to Atkinson.*

Fig. 1 *The Davis quadrant.*

He then continued describing both arcs: '*The lesser noted DE, is called the 60th Arch, because it did heretofore contain no more, but now it often contains 65, and sometimes 70 Degrees ... This little Arch is divided sometimes but to every 5 Degrees, and never less than every single Degree; its numbred* [sic] *from the upper end E, with 5, 10, 15, 20, &c. downwards to D, where it ends in the Line ADG (a Line in the middle of the longer Leg of the Quadrant) at 60, 65, or 70 Degrees ... The greater Arch GF, is called the 30 Arch; its of a large Radius, that it might contain the lesser Subdivisions of a Degree; and being of a competent Breadth, thereon are usually described 10 Concentrick Circles, intersected with 3 Diagonal Lines in each Degree; making each Intersection 2 m* [minutes]. *This Great Arch is divided on the Limb into Degrees by long Stroaks, each again subdivided into 6 equal parts by shorter Stroaks, each small division being 10 Minutes, and are numbred* [sic] *from the lower end F, with 5, 10, 15, &c. upwards to G, where it ends in Line ABG* [sic] *at 20, 25, 30 Degrees...*'[3]

Atkinson did not mention two parts: the 'normal' shadow vane and the cross-strut in the frame that served as a handle. The shadow vane he mentioned was equipped with a lens, the so called Flamsteed lens, used for observations under hazy or thinly clouded conditions. In addition to that a Davis quadrant would also have a shadow vane without a lens for observations in bright sunlight. Both the shadow vane and the cross-strut will be further explained below.

Observation Methods

According to Atkinson the '*... Instrument is rarely used otherwise than to observe the Sun's Meridian Altitude...*'.[4] The alternate use Atkinson referred to was perhaps the determination of longitude by lunar distance as described in a work printed for J. Wilford in 1726.[5] For measuring the sun's meridian altitude the shadow vane was set at a whole number of degrees, some 15-20 degrees lower than the expected zenith distance of the meridian passage of the sun. While standing with his back towards the sun – instruments used in this way were henceforth given the general name 'backstaff' – the observer would align the slit in the horizon vane with the horizon, while trying to coincide it with the upper edge of the shadow vane's shadow. This was done by tilting the frame and sliding it through the sight vane which was kept in front of the observer's eye. Once aligned he could then read off the scale along the sight vane in degrees and minutes (usually to the nearest 1, 2 or 5 arc minutes, depending on the interval of the graduations) and add the degrees of the shadow vane to it. The sum of these values gave him the zenith-distance of the sun.[6] This combined with values taken from a declination table for the date of observation, resulted in the observer's latitude. Observations were made of the sun's centre, its lower limb or upper limb, as mentioned by several period authors.[7]

Under hazy conditions the observer could replace the shadow vane by the lens vane. Now he would have a projected image of the sun cast onto the horizon vane instead of a shadow. To facilitate lower limb observations additional lines off-setted at half a sun's diameter distance were sometimes added to the 60-arc.

What's In a Name?

As we now know the instrument was named after John Davis, the inventor of the first two practicable backstaffs.[8] The instruments Davis invented are referred to as the '45 degree backstaff' (Fig. 3) and the '90 degree backstaff" (see Fig. 8).[9] Davis himself simply named each of them '*...Staffe...*'.[10] They did however not yet resemble the Davis quadrant as we know it today.

Assuming that the basic shape as shown in Figs 1 and 2 - two arcs attached to a central staff by means of two or three supporting struts - defines what a Davis quadrant is, the first positively identified occurrence is when George Waymouth depicts a diagram of it (Fig. 4) in his manuscript 'The Jewell

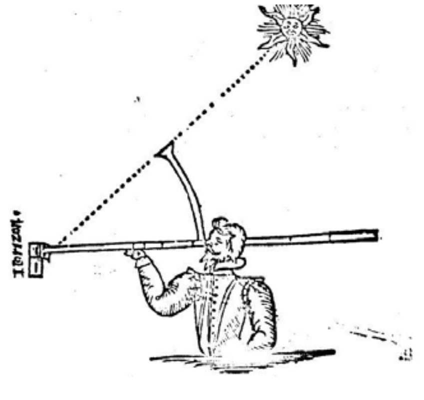

Fig. 3 *Davis' 45 degree backstaff.*

of Artes'[11], dedicated to James I of England, who reigned from 1603 until 1625. The manuscript included an account of Waymouth's voyage to the Hudson Strait in 1602, but not of his voyage to New England in 1605. It therefore can be dated to around 1604.[12] In his manuscript he refers to the instrument as a '*... cross-staff to observe the altitude of the sunne backe warde by her shadowe*'.

After Waymouth there is a gap of no less than 32 years until the instrument can be positively identified again, this time by its clear description given by Charles Saltonstall in his *The Navigator*, printed in 1636.[13] In it he spends a small chapter on the '*...Back-staffe*' of which he wrote that they were '*... projected of diverse formes and fashions...*' and that '*...they containe exactly a Quadrant, or fourth part of a Circle...;*'. He then wrote that '*... of all Backstaves, I hold the double Arched projection to be the best, and most usefull at Sea...*', positively identifying the Davis quadrant. He not only gave the name 'backstaff' to the instrument, but also tells us that backstaffs (or back-staves) are all quadrant types (so containing 90 degrees) and that other instruments existed bearing that same general name.

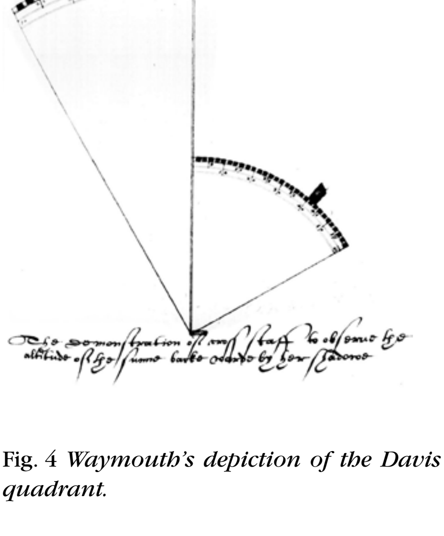

Fig. 4 *Waymouth's depiction of the Davis quadrant.*

Another seven years go by when the next positive reference to the instrument appears in a French work by Georges Fournier, printed in 1643.[14] He showed the instrument (Fig. 5), and wrote that the English used it, but no name was given.

Almost 20 years after Fournier, in 1662, Joost van Breen mentioned the instrument in his *Stiermans Gemack*. Chapter 13 of this work deals with the earliest reflecting navigational instrument – the *Spiegelboog* (mirror-staff) – which he patented in 1660.[15] In 1661 he took the instrument for a field test and compared it to a cross-staff and a 'peculiar English Quadrant'.[16]

A few years later, in 1665, Andrew Wakely showed the instrument in his *The Mariners-Compasse Rectified*, while naming it a '*Quadrant*'.[17] From now on the frequency by which the instrument appears increases considerably, starting with John Seller, who named it a '*Quadrant*' in 1669 (a name he used again in his 1672 and 1689 editions).[18] That same year Samuel Sturmy referred to it as '*Quadrant*' and as '*Back-staff*'.[19]

In 1677 the instrument reappears in a French work, this time by Claude François Millet Dechales, who named it a '*Quartier Anglais*' ('English Quadrant').[20]

Then in 1681 Jonas Moore had his work *A New Systeme Of The Mathematicks* printed. In it he devoted a chapter to '*...the common Sea Quadrant or Back-staff*'.[21] He opened the chapter writing that the '*...instrument ... was the contrivance of one Captain Davis, an English-man, and therefore is often called a Davis's Quadrant, but by the French the English Quadrant.*' As far as I could find this was the first time the instrument was actually named 'Davis quadrant', no less than 77 years after its first depiction in Waymouth's work, and 76 years after John Davis deceased.[22]

So over the years up to Moore's work the instrument had six different names; cross-staff, backstaff, quadrant, sea quadrant, English quadrant and finally Davis quadrant. Moore wrote that the term 'Davis quadrant' was '*...often...*' used, but the next year Peter Perkins wrote that it was '*... sometimes called Davis's Quadrant*',[23] while again four years later Daniel New-House wrote that it was '*...commonly called Davis's Quadrant*'.[24] In the years following, the instrument would mainly be named 'quadrant', 'sea quadrant', and 'English quadrant' or' Davis quadrant'.

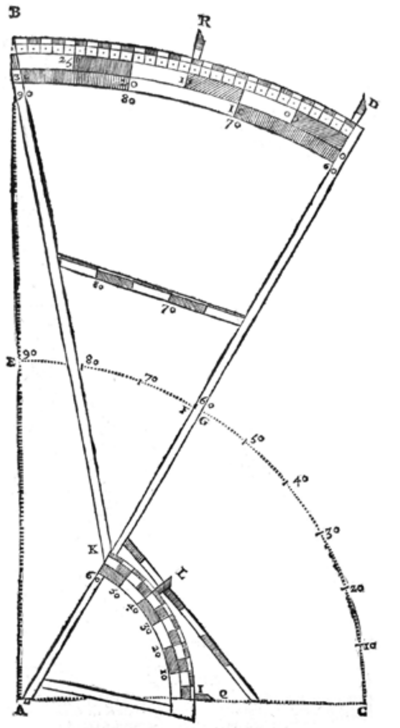

Fig. 5 *Fournier's Davis quadrant.*

From the second half of the 17th century onward the instrument started to appear in Dutch literature as well. It was named *Engels quadrant* (English quadrant), *haspel* (lit: reel), *haspelboog* (lit: reel-staff) or *hoekboog* (lit: angle-staff).25 The latter was however not uniquely used for the Davis quadrant, but also for another instrument used by the Dutch since 1623 and in English editions referred to as the 'Double Triangle' (Fig. 6, the shape of the *hoekboog* can also be seen in Fournier's drawing, see Fig. 5, but the instrument was not described or mentioned by him).[26]

The term 'backstaff' only reappeared in modern literature, causing considerable confusion at times being a general name for more than a dozen period instruments.

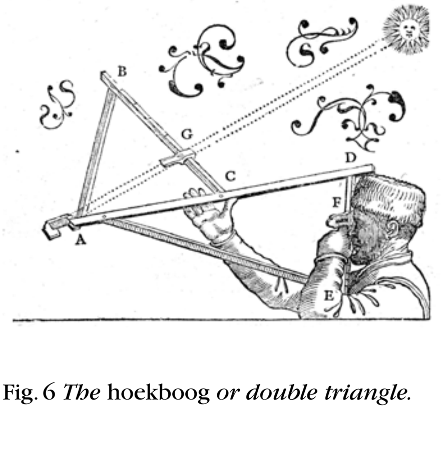

Fig. 6 *The* hoekboog *or double triangle.*

Fig. 7 *The sea or mariner's quadrant.*

Like the term backstaff, quadrant was also used for other instruments. Most popular-quadrants were the ones used for '*...dyalling, for the resolving of all proportions instrumentally, and for the ready finding the hour and azimuth universally...*' and which were variations on the one Edmund Gunter first described in 1624.[27] In shape these quadrants were, however, based on the mariner's quadrant, an altogether different instrument than the Davis quadrant (see Fig. 7). In the period the Davis quadrant evolved at least twelve books were written solely discussing these 'dyalling' quadrants, while the Davis quadrant was only mentioned in six books dealing with navigation in general.[28]

As a result it is risky to assume that a Davis quadrant is described in period literature when only the term backstaff, *hoekboog* or quadrant is used. In these cases one can only be sure that it was a Davis quadrant that the author really meant when the instrument is either depicted or described in enough detail (e.g. at least the two arcs are mentioned).

A good example for this is *The strange and dangerovs voyage of Captaine Thomas Iames*, published in 1633.[29] This work is mainly a discourse upon his journey into the South Sea in the years 1631-1632. He mentions several times that a quadrant was used for position finding. In one of these cases the latitude found was even given to the nearest arc minute: 58°-54'.[30] Based on these remarks, the nearest arc minute latitude and the fact that in 1595 Davis already regarded the mariner's quadrant '*... for a Seaman [...] to no purpose...*'[31] one is tempted to consider the quadrants mentioned to be Davis' Quadrants rather than a mariner's quadrant.

That it was possible to take observations to the nearest arc minute was due to the type of quadrants that were on board.[32] James' discourse is followed by three appendices, the first of which is titled '*The Names of the severall Instruments, I provided and bought for this Voyage*', and contains a wide variety of navigational aids that were taken on board during his voyage.[33] In it we find '*A Quadrant of old seasoned Pearetree-wood, artificially made: and with all care possible divided with Diagonals, even to minutes. It was of foure foote (at least) Semidiameter.*' and '*A Quadrant of two foote Semid. Of like wood: and with like care projected.*' Apart from their diameter and the way they were divided this does not tell us too much about the type of quadrants they actually were.

On the same page, however, the quadrants are followed by a number of '*Staves for taking Altitudes and Distances in the heavens*'. Next to Gunter's cross-staff and three mariner's crossstaffs, '*Two of Master Davis Backe-staves: with like care made and devided* [sic]' are listed. The second part of the quoted sentence referred to the one above it, mentioning the three cross-staffs. According to James those were '*...projected after a new manner: and truly divided out of the Table of Tangents*'. As there is no need for tangents tables in dividing Davis Quadrants, which is done by bisecting, the '*Master Davis Backe-staves*' must have been of one of Davis' original designs – most probably his 45-degree version. From this it can be concluded that Davis' original designs were still in use around the start of the 1630s and that the quadrants mentioned must have been mariner's or – more likely – astronomical quadrants, and not Davis quadrants. That they were engraved with diagonals was not uncommon for this period as we will see below.

The Frame

As mentioned above the instrument was named after Captain John Davis. His second instrument (Fig. 8) contained 90 degrees and could thus, according to Saltonstall, be named a quadrant. Davis was probably influenced by Thomas Hariot and through him by Thomas Hood.[34] Davis' 90-degree backstaff is what would eventually evolve into the Davis quadrant.

The Davis quadrant was one of the many backstaffs that developed in the years following Davis' inventions.[35] As mentioned above the instrument was first depicted by George Waymouth in his 'The Jewell of Artes' (see Fig. 4).[36]

The main body or frame of the Davis quadrant was constructed using mortise and tenon joints.[37] This rather complex method of construction was new for navigational instruments and can be traced back to Hariot's proposed quadrant type backstaffs (Fig. 9), as constructing these without mortise and tenon joints would have been near to impossible. The use of mortise and tenon joints can be linked to period astronomical instruments, like the astronomical sextant used by Tycho Brahe, an instrument Hariot was familiar with.[38] The frame of the fully developed Davis quadrant consisted of two arcs, a central staff and three struts, all connected by above-mentioned method. The smallest strut was not only used as a handle, but also provided extra stiffness to the frame as described by the Dutch student in navigation Cornelis Janszoon Boombaar in his notes in 1728.[39]

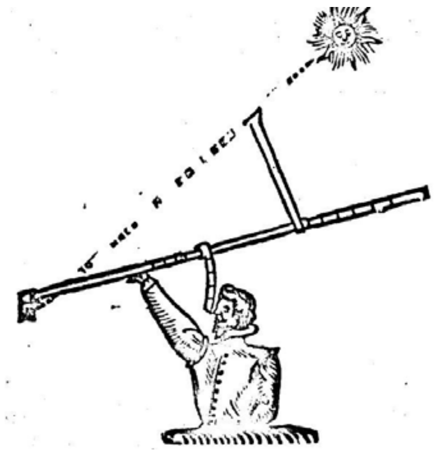

Fig. 8 *John Davis' 90 degree backstaff.*

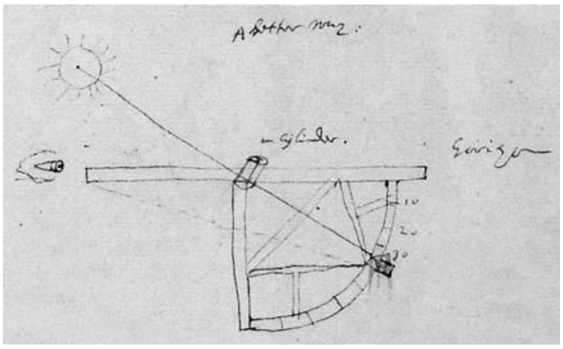

Fig. 9 *Hariot's proposed quadrant type backstaff.*

Waymouth's depiction of the Davis quadrant is – like the other instruments in his work – a diagram showing the basic principle of the instrument, rather than an actual instrument. In his depiction it did not yet have its cross-strut, while it is shown in Fournier's. It was, however, not uncommon

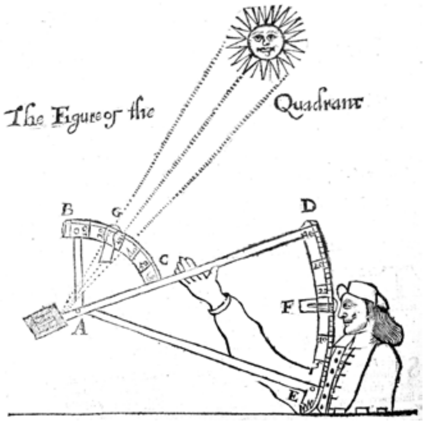

Fig. 10 *Davis quadrant without cross-strut as shown in his 1669* Mariners Magazine.

that the handle was omitted in drawings well into the 18th century, while all surviving Davis quadrants do have this cross-strut. A good example of this is a drawing in Samuel Sturmy's *Mariners Magazine* (London, 1669) where the handle lacks and the instrument is held by its central staff (Fig. 10). It is therefore unclear when exactly the cross-strut came into use, but it could have been after Waymouth.

The 30-degree Arc

A closer look at the 30-degree arc in Waymouth's manuscript, reveals that it is divided in ten, five and whole degrees only (Fig. 11). On itself this is quite normal and consonant with other period works regarding this and other instruments.[40] Usually this is the result of the scale at which the instrument is drawn, as showing all de divisions would in most cases clutter the drawing. The Davis quadrant in its fully developed form had, however, not only a finer divided scale, generally down to 5 arc minutes, but also an additional diagonal scale running along it.[41] This diagonal scale is also missing in the sketch, which of course could again be explained as above.

Different designs were applied to the diagonal scale of the Davis quadrants. They were made with '*... five, six, ten or twelve Concentrick Circles ... and between ... each*

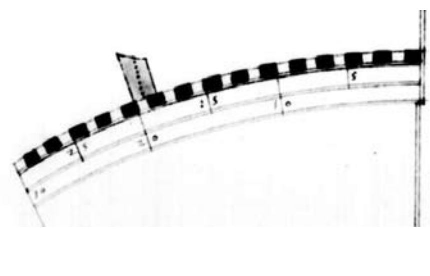

Fig. 11 *The 30 degree scale of Waymouth's Davis quadrant.*

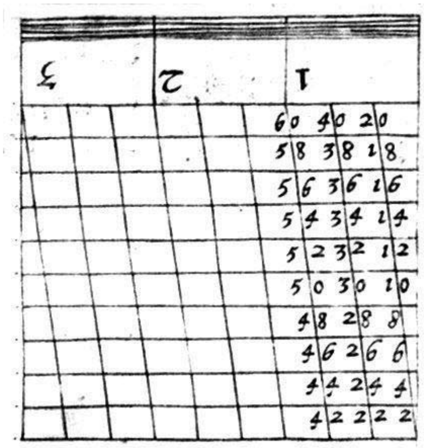

Fig. 12 *Moore's diagonal scale.*

Degree ... one, two, three, or more diagonal lines...' (Fig. 12 shows a diagonal scale from Moore's 1681 work).[42] The fully developed Davis quadrant would generally have six diagonals per degree. Each degree was in this way divided by the product of the number of diagonals per degree and the number of concentric circles. The example in Fig. 12 thus shows us a diagonal scale that divides each degree in 10 x 3 =30 parts, or 2 arc minutes.

Turning over a few pages of Waymouth's manuscript we find two quadrants on successive pages; the first with a Nonius and the second with a diagonal scale, similar to the one described by James in 1633 (Fig. 13). Below the first can be read: '*The demonstration of a most exact quadrant to finde out the Degrees and minute of the sunnes altitude, found sundrie wayes.*', while below the other was written '*The demonstration of a most excellent quadrant to finde the Degrees and minute. it not so exact as the quadrante next before.*' Judging from the accompanying text, the Nonius scale was regarded to be the more accurate of the two.

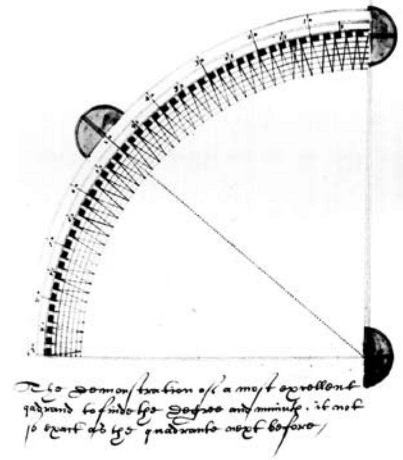

Fig. 13 *Moore's diagonal scale.*

Browsing through the rest of Waymouth's work other instruments with diagonal scales (8) and/or Nonius scales (6) can be found, among which the mariner's bow, another period navigational instrument (it is even shown twice, both times with a diagonal scale). The mariner's bow was an instrument similar to the Davis quadrant; both were intended for backward use at sea, while the mariner's bow was also intended for use on land, a method endorsed by the text below it: '*The demonstration of a most exact crosse staff to take the altitude of the sunne and starre ... both at sea and land*'. It was perhaps for the latter use – standing on *Terra Firma* – that it, in contrast to the Davis quadrant, incorporated a diagonal scale. We may therefore conclude that the Davis quadrant in Waymouth's time did not have a diagonal scale at all.

The absence of the diagonal scale not only applies to Waymouth's work. As mentioned before the first drawing after 1604 can be found in Fournier's work, printed in 1643 (see Fig. 5).[43] That image shows the 30-degree arc divided in ten, five and whole degrees by lines and in half degree intervals by dots (Fig. 14). This division is similar to what can be found on period instruments like the Dutch *hoekboog,* which had lines for the whole and half degrees and dots for the quarter degrees (Fig. 15).[44]

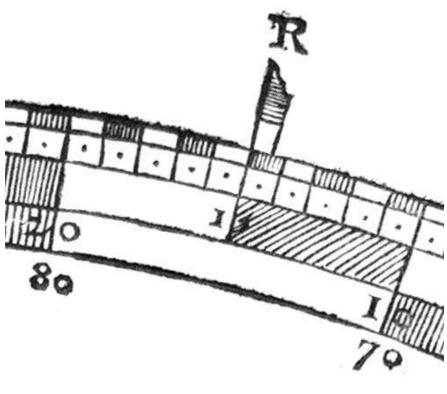

Fig. 14 *Detail of Fournier's 30 degree scale.*

About the arc Fournier wrote that it had to be made as '*…une partie de cercle de 30. degreez … que vous marquerez de degré, voir de minute en minute tant que faire se pourra.*' (…a part of an arch of 30 degrees … which one marks in degrees, even from minute to minute as many as is possible.). The latter could indicate that the scale was not divided using a diagonal scale but equidistantly (or rather equiangular) to a point that it became impossible to add any more divisions. Early Davis quadrants were as large as 30¾ inch, which would make one

Fig. 15 *Detail of the Kennemerland* hoekboog *scale showing the divisions from 3 degrees (left) to 5 degrees (right) and their subdivisions.*

arc minute just under a quarter of a millimetre.[45] Although that would be just too small for graduation[46], it is large enough to estimate single arc minutes on an equiangular scale divided at 5 arc minute intervals.[47]

It is not until 1669 that the first solid proof of the use of diagonal scales on Davis quadrants can be found in literature. In that year John Seller wrote that '*... possibly this manner of division may not be understood by every one that has occasion for this Instrument, for their sakes therefore have annexed this following Figure.*' (Fig. 16).[48]

The figure that follows shows a part of the diagonal scale and is accompanied by an explanation that takes a whole page. From this date onwards most other authors too describe or show Davis quadrants with diagonal scales, some authors, like Moore, again explaining the diagonal scales (see Fig. 12).[49]

The use of the diagonal scale possibly started a few years earlier. In 1662 the Dutchman Joost van Breen wrote in his *Stiermans Gemack* that the year before he used a '*... curieus Engels Quadrant...*' (...peculiar English quadrant…).[50] By using the adjective 'peculiar' Van Breen tells us that something on the instrument must have been new to him, even though he was familiar

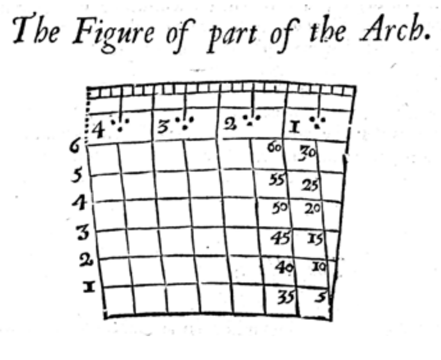

Fig. 16 *John Seller's diagonal scale.*

Fig. 17 *Skokloster decorations, left the undated Davis quadrant, right the 1661 cross-staff.*

with the basic shape of the instrument (he recognized it as an English quadrant, as mentioned above the term used on the continent to indicate a Davis quadrant). Being an administrator of goods, supplies and ammunition for the vessels of the Admiralty of Zeeland and the inventor of the first reflecting instrument for navigation, the *spiegelboog* (mirrorstaff), we may expect he was quite well aware of the instruments used around the North Sea at that time.[51] Perhaps it was the introduction of the diagonal scales on the instrument that made him use the adjective.

There is even proof of even earlier use of diagonal scales on Davis quadrants. In the Wrangel/Brahe collection at the Skokloster Slott (Sweden) several navigational instruments can be found.[52] Next to three Dutch astrolabes it contains a mariner's bow, a cross-staff and a Davis quadrant. Although the Davis quadrant is not dated, from the decorations (*fleur-de-lis*) it is apparent that it was not only made in the same workshop, but also by the same maker as the cross-staff in that same collection. Not only the stamps used for both of them are identical, they were also stamped in using the same pattern (three out of the four *fleur-de-lis* are stamped in parallel or perpendicular to the frame and slightly out of line which each other, the fourth at an angle, see Fig.17). With the cross-staff being dated 1661 and assuming that the Davis quadrant was made around the same time, this makes this Davis quadrant the oldest surviving example known to date.[53] The diagonal scale found on it is of the type as shown in Fig. 12. The cross-staff has been identified as being possibly English, which would make the Davis quadrant English as well.[54] An introduction of the diagonal scale around 1660 would also explain why no older examples survive, as these would soon have been replaced by this modern and seemingly more accurate version of the instrument.

Fournier wrote that the Davis quadrant was covered by a shroud of mystery and not without reason.[55] If up to the application of diagonal scales, Davis quadrants were indeed divided in 5 arc minute intervals, it would potentially have been a very competitive instrument. Its main Dutch competitors, the *hoekboog* and the demi-cross were divided down to 15 arc minute intervals[56], while period cross-staffs of the first half of the 17th century had graduations at a minimum of 30 arc minute intervals and 10 arc minutes during the second half.[57] The 5 arc minute intervals on cross-staffs were not accomplished before the turn of the century[58], but by then Davis quadrants, equipped with diagonal scales, could already be read down to one arc minute.[59] That, however, was far beyond the instrument's real accuracy of about 12 arc minutes[60], something that was not realized until the second quarter of the 18th century.[61] Still, this seemingly unparalleled high accuracy, combined with its easy way to use[62], must have contributed to its worldwide success.

Division Method

In contrast to other period instruments it is not explained in contemporary literature how the diagonals were engraved on the arc. The most obvious method is by original division, but in 1988 Deborah Warner showed that they were produced in large numbers, up to several hundreds and possibly more than a thousand per instrument maker.[63] It therefore would be more logical if some sort of 'dividing engine' would have been used in the process even though real dividing engines - like the ones by Ramsden from the end of the 18th century - were not yet invented.

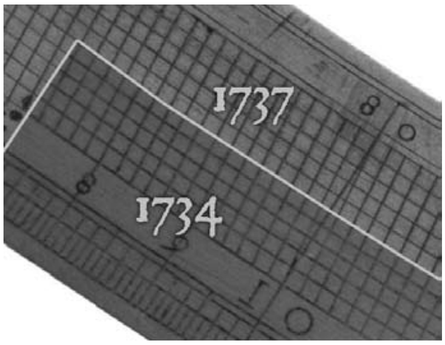

Fig. 18 *Superimposing two diagonal scales by W. Garner.*

In the collection of the National Maritime Museum in Greenwich, London, there are two Davis quadrants by Will Garner, dated 1734 and 1737. When superimposing the diagonal scales onto each other the resemblance between the two becomes clear, both showing deviations at the same positions along the scales (Fig. 18). The devia-

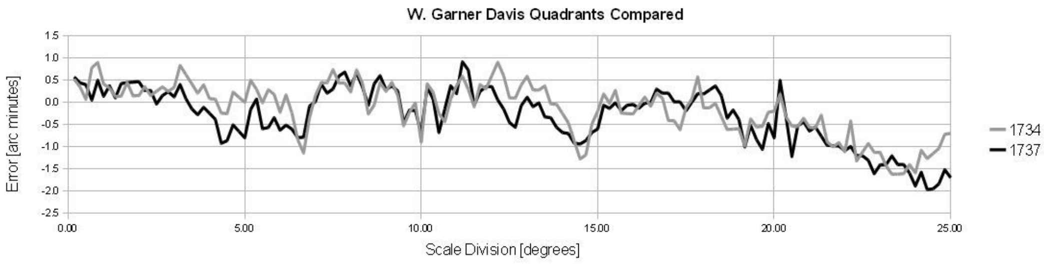

Fig. 19 *Diagonal scale errors in W. Garner Davis quadrants (graph by the author).*

tions can also be measured and compared mathematically. In this way I found an 83% correlation between the two instruments (Fig. 19), which is a good indication some mechanical aids was used in the process.[64]

Based on the surviving Davis quadrants in America, listed by Warner, I contacted various individuals and institutions in an attempt to bring together more matching pairs of Davis quadrants for above comparison (e.g. two instruments by the same maker, with the same type of diagonal scale and made within a few years of each other).[65] Although about one third responded to my request - with a total of eight instruments - I was not able to get together two instruments by the same maker with the same type of diagonal scales. When comparing three of the Davis quadrants that I made myself (for which I used of a simple dividing aid) I found 70% correlation between the first and second and 85% correlation between the second and third, while correlation between instruments of different makers always remained below 60%.[66] Further research might give more insight in the use of dividing aids in the production of these instruments.

The 60-degree Arc

The Davis quadrant was made to measure the sun's altitude by casting a shadow from the shadow vane onto the horizon vane. It was the upper edge of the shadow vane that served as reference. This method worked in full sunshine, but under hazy or thinly clouded conditions the shadow would not be distinctive enough to align it properly with the horizon vane. In 1681 Moore wrote that this problem was solved by incorporating a '*...lens or double convex glass...*' into the shadow vane.[67] Using this lens it became possible to show an image of the sun, rather than a shadow, on the horizon vane.

Having the image of the sun available, measuring the sun's upper or lower limb wassignificantly easier than when using the shadow vane. As said before additional lines offsetted at half a sun's diameter distance were sometimes added to the 60-arc to facilitate lower limb observations and although so far no written evidence on them has been found we may assume that these lines were introduced shortly after the introduction of the lens vane. The additional lines are mainly found on English instruments, although two non-English are known showing them as well; one by Anthony Lamb from New York dated 1747 (he was of English origin though) and one by the Dutch firm Van Keulen dated 1777.[68]

Lens Vane

According to Moore the lens vane '*... was the contrivance of ingenious Mr. Flamsted*[sic].'[69] In 2009 Anthony Turner explained that the Flamsteed lens probably was the result of combined effort by three people; Robert Hooke, Edmund Halley and John Flamsteed.[70] Although Turner already explained the origin of the Flamsteed lens very well, I would still like to add some details, for which I need to go back to the original sources. One of the quotes Turner used was a paragraph in Hooke's posthumous work, claiming the invention of the Flamsteed lens to be of his own:

'*The Instrument which I shew'd the Society, some Years before the Sickness, by making use of a Telescope-glass, instead of the small hole or slit of the Shadow-vane of a Back-staff, but was not made use of 'till about ten Years after, and yet now it meets with general approbation, and is of continual use, and pretended to be the invention of another, tho' my shewing thereof was Printed in the History of the Royal Society.*'[71]

The History of the Royal Society, written by Thomas Sprat in 1667, indeed printed the demonstration of a device he made:

'*A new kind of Back-staff for taking the Suns altitude by the Shadow, and Horizon: which is so contriv'd, that though the shadow be at three foot distance, or as much more as is desir'd, yet there shall not be the least Penumbra: and the shadow may be easily distinguish'd to the fourth part of a minute.*'[72]

Turner already remarked that '*...it seems curious that Sprat speaks only of shadows and not of the bright spot of light...*' and that '*...the length of the shadows... seems to imply an instrument altogether different from the traditional back-staff...*'.[73] In order to avoid further confusion it needs to be noted that although Turner used the term 'traditional back-staff', what he really meant was the Davis quadrant.[74]

Sprat mentioned a shadow at three feet distance. The largest dimension found in period literature for a Davis quadrant was three feet, which meant that the Flamsteed lens – which was mounted on the lesser radius 60 degree arc – would be much closer to the shadow vane than this distance. From period drawings the ratio between the radii of the 30-degree arc and the 60-degree arc can be estimated at about 2:1 - 3:1, while surviving instruments show a 1:3 ratio. With a maximum semi-diameter of 3 feet for the 30-degree arc, the 60-degree arc would be 1½ feet at most (surviving examples generally show radii of less than one foot). Even at 1½ foot distance the ¼ arc minute penumbra given by Sprat would only be 0.00003 metres wide (three hundredths of a millimetre).The penumbra would only be '*...easily distinguish'd...*' when it was at 3 or 4 feet distance, as it would then be approximately 0.1 millimetre.

As mentioned before the name backstaff stood for a variety of instruments, the Davis quadrant only being one of them. The only known backstaffs that would fit Hooke's dimensions were John Davis' original 45- and 90-degree backstaffs or the Dutch demi-cross.[75] It is therefore unlikely that it was a Davis quadrant that Hooke modified.

In order to prove that it could indeed have been a shadow that was projected I made a simple set-up with a shadow vane and a lens (Fig. 20). With the shadow vane (in this case a folded piece of cardboard) in the lenses focal point (on the side of the sun) it is indeed possible to cast a sharp shadow on the horizon vane, even at four feet distance (see Fig. 21, which shows a sharp upside-down shadow cast - or rather projected - at 2 feet distance). Technically it would have been no problem to create a

Fig. 20 *Hooke's possible lens set-up.*

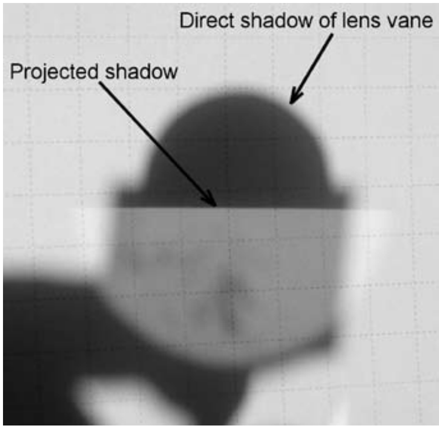

Fig. 21 *Projecting a shadow.*

backstaff on this principle, which in theory could be as accurate as a modern sextant. The method, however, had one downside; any change in the alignment of the shadow/lens vane with the horizon vane would be magnified proportionally with the lenses optical magnification.[76] Because of this Hooke's projection method must have been impracticable on early wooden instruments, as these tended to warp and bend easily. In addition to that, this set-up is useless at a projection distance close to the focal length of the lens. The idea to use a lens was however born and finally resulted in the set-up we know now.

Who finally made the change to projecting the sun's image instead of a shadow remains unclear. As Turner showed us the implementation of the Flamsteed lens was credited to both Halley and Flamsteed. Turner stresses however that Halley perhaps only implemented what he learned from Hooke and/or Flamsteed. He may even have tried Hooke's method close to the lenses focal point to discover that projecting the sun rather than a shadow was a better method. What we do know is that Hooke made his invention between about 1660 and 1665 and that - in its final form as

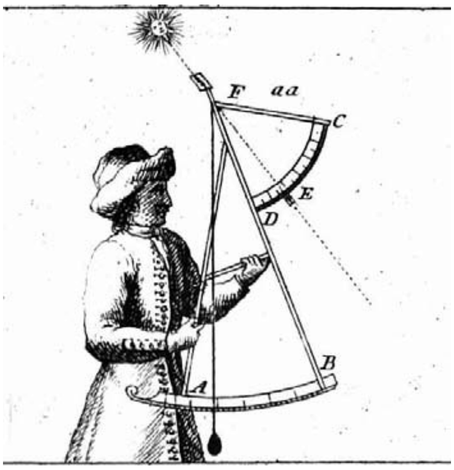

Fig. 22 *Albrizzi's plumb bob method.*

Flamsteed lens - it was not generally used until ten years later.

It is at this point that I regard the Davis quadrant to be fully developed. The only further development known was the addition of artificial horizons by John Elton in 1731 and Charles Leigh in 1736.[77] The addition by Elton changed the layout of the instrument considerably. The 60-degree arc was replaced by a non-graduated chord and the artificial horizon was added, making it impossible to use the instrument as a 'normal' Davis quadrant.[78] We therefore may regard Elton's invention as an altogether new instrument based on the Davis quadrant, rather than one with an accessory. Alternatively the use of a plumb bob as an artificial horizon (or rather vertical) has been shown by Girolamo Albrizzi in 1715 (Fig. 22).[79]

Conclusion

In the 17th century the Davis quadrant became one of the most popular instruments for taking the altitude of the sun at sea. In contrast to what is generally accepted, the instrument went through several stages of further developments since it was first depicted in 1604. Taking place throughout the 17th century those developments related to the scales, the frame, the vanes and even to its name. The 1604 depiction already showed the form as we know it from surviving examples, but lacked the centre strut that was first depicted in 1643, served as a handle and supplied additional stiffness to the frame. The larger radius 30-degree arc was originally divided in an equiangular fashion, probably at 10 or 5 arc minutes intervals, while diagonal scales were introduced around 1660 making direct arc minute readings possible (even though these were beyond the instrument's accuracy). The oldest known surviving Davis quadrant dates from around 1661 and already shows these diagonal scales, while two other instruments show signs of mechanical division for them despite being produced well before the introduction of proper circular dividing engines. The lens vane for observations under hazy or thinly clouded conditions was introduced in the following five years and resulted in additional lines for lower limb observations on the 60 arc. Finally the name 'Davis quadrant' was introduced around 1680, about three quarters of a century after its first depiction and after Captain John Davis - whom the instrument was named after - deceased.

Acknowledgements

This paper was originally presented at the 'A Sense of Direction, New Researches in the History of Navigation' conference at the National Maritime Museum (NMM) in Greenwich, London on Friday 7 May 2010.

I am very grateful to R. Dunn (curator of navigation at the NMM) for supplying information on their Will Garner Davis quadrants in their collection. Despite failing to bring together matching pairs of Davis quadrants I am still very much indebted to the Adler Planetarium in Chicago, Ill, the Connecticut Historical Society in Hartford, Ct, the Mariners' Museum in Newport News, Va, the National Maritime Museum, Greenwich, London, the New Bedford Whaling Museum in New Bedford, Ct, and to Ron Johnson for their generous co-operation in my research. Furthermore, I also wish to thank B. Kylsberg, Museum Curator of Paintings, Weapons and Tools, and I. Olovsson, Museum Curator of Textiles, of the Skokloster Slott in Skokloster, Sweden, for allowing me to study several navigational instruments in their collection. I am indebted to D. Wildeman, curator of Navigation and Library Collections, and Information Officer A. van Oortwijn of the Netherlands Maritime Museum in Amsterdam for allowing me to study several works in their library, despite being closed to the public for renovation. Finally I wish to thank W.F.J. Mörzer Bruyns for commenting on this article and the conversations we had on this and other period instruments.

Image References

Fig. 1: J. Seller, *Practical Navigation: Or, An Introduction to the Whole Art: Containing many useful Geometrical Definitions and Problems : The Doctrine of Plain and Spherical Triangles : [...] sundry useful Problems in Astronomy : The Use of Instruments [...] Useful Tables [...] Also a Table of 10000 Logarithms, and of the Log : Sines, Tangents, and Secants. The third Edition.*, (London, 1689), collection Netherlands

Maritime Museum, Amsterdam, the Netherlands (inv. no. S.4793(704)).

Fig. 2: J. Atkinson, *Epitome of the Art of Navigation, or a Short and Easy Methodical Way to become a Compleat Navigator. Containing Practical Geometry ... Trigonometry ... with its uses in Navigation ...*, (Dublin, 1715), © British Library Board. All Rights Reserved (Shelfmark 8803.aa.23).

Fig. 3: J. Davis, *Seaman's Secrets*, (London, 1657), From http://www.mcallen.lib.tx.us/books/seasecr/bk_staf2.gif, last accessed November 10th, 2009.

Fig. 4: G. Waymouth, 'The Jewell of Artes', (1604), © British Library Board. All Rights Reserved (Shelfmark 19889).

Fig. 5: G. Fournier, *Hydrographie contenant la théorie et la practique de toutes les parties de la navigation*, (Paris, 1643), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. A.1051).

Fig. 6: W. Jsz. Blaeu, *The sea-mirror; containing a briefe instruction in the art of navigation; and a description of the seas and coasts of the easterne, northerne and westerne navigation; collected and compiled together out of the discoveries of many ... sea-men* (Amsterdam, 1625), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. A.0120).

Fig. 7: J. Moxon, *A Tutor to Astronomie and Geographie : or an Easie and speedy way to know the Use of both the Globes, Coelestial and Terrestrial : whereunto is added the Antient Poetical Stories of the Stars : shewing Reasons why the several shapes and forms are pictured on the Coelestial Globe : as also a Discourse of the Antiquity, Progress and Augmentation of Astronomie*, (London, 1659), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. S.4793(165)[nr 0001]).

Fig. 8: Davis, *Seaman's Secrets*, From http://www.mcallen.lib.tx.us/books/seasecr/bk_staf3.gif, last accessed November 10th, 2009.

Fig. 9: T. Hariot, *The Doctrine of Nauticall Triangles Compendious*, (1594), p. 31. By kind permission of Lord Egremont (ref. Petworth House Archives HMC 241/6b).

Fig. 10: S. Sturmy, *The mariners magazine; or, Sturmy's mathematical and practical arts; containing the description and use of scales; ... the art of navigation ...; together with a discourse of the practick part of navigation ...*, (London, 1669), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. A.1024).

Fig. 11: Waymouth, 'The Jewell of Artes', © British Library Board. All Rights Reserved (Shelfmark 19889).

Fig. 12: J. Moore, *A New Systeme Of The Mathematicks: the Second Volume: Containing: I. Astronomical Tables, with Tables of Logarithms, Natural and Artificial Sines and Tangents, and Versed Sines, & c.: II. A New Geography, or a Description of the most Eminent Countries and Coasts of the World, with Maps of them, and Tables of their Latitude and Longitude*, (London, 1681), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv .no. S.4793(688)).

Fig. 13: Waymouth, 'The Jewell of Artes', © British Library Board. All Rights Reserved (Shelfmark 19889).

Fig. 14: Fournier, *Hydrographie...*, collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. A.1051).

Fig. 15: Picture by T. Watt, Shetland Museum, Lerwick, Shetland.

Fig. 16: Seller, *Practical Navigation...*, collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. S.4793(704)).

Fig. 17: Pictures by the author.

Fig. 18: Pictures by R. Dunn, National Maritime Museum, Greenwich, UK.

Fig. 19: Graph by the author.

Fig. 20: Picture by the author.

Fig. 21: Picture by the author.

Fig. 22: A. Albrizzi, *Introduzione all Arte Nautica per uso de Piloti, e Capitani di Nave, e per il Migliore Servizio de Commandanti Sopra il Mare.*, (Venetia, 1715), collection Netherlands Maritime Museum, Amsterdam, the Netherlands (inv. no. S.0187 [nr 1228]).

Notes and References

1. D.W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, (London, 1958), p. 258, n. 2.

2. J. Atkinson, *Epitome of the Art of Navigation: or a Short and Easy Methodical Way to become a Compleat Navigator*, (Dublin, 1715), pp. 3-4 of chapter 'The Description and use of Instruments most useful in Navigation'.

3. Atkinson, *Epitome...* (note 2), p. 4 of chapter 'The Description...'.

4. *Ibid.*

5. J. Wilford, *A Sailor's Proposal for Finding his Longitude by the Moon*, (London, 1726), p. 23.

6. The zenith-distance was in fact the sum of three figures as the observed angle needed to be corrected for dip – the correction for the height of the observer above the sea surface.

7. Atkinson, *Epitome...*(note 2), pp. 4-5 of chapter 'The Description...'.

8. N. de Hilster, 'The Demi-cross: A Reconstruction', *The Bulletin of the Scientific Instrument Society,* No. 105 (2010), p.31.

9. See note 8.

10. A. Hastings Markham, *The Voyages and Works of John Davis*, The Navigator, (London, 1880), pp.330-337.

11. G. Waymouth, 'The Jewell of Artes', f. 26.

12. From e-mail correspondence with Arnold Hunt (Curator of Historical Manuscripts, British Library).

13. C. Saltonstall, *The Navigator*, (London, 1636), pp. 121-124.

14. G. Fournier, *Hydrographie contenant la théorie et la practique*, (Paris, 1643), pp. 493-495.

15. N. de Hilster, 'The *Spiegelboog* (mirror-staff): A Reconstruction', *The Bulletin of the Scientific Instrument Society*, No. 90 (September 2006), pp. 6-16.

16. J. van Breen, *Stiermans Gemack, Ofte een korte Beschryvinge vande Konst der Stierlieden*, ('s Gravenhage, 1662), p. 20 of chapter 13.

17. A. Wakely, *The Mariners-compasse Rectified*, (London, 1665), pp. 206-217.

18. J. Seller, *Practical Navigation*, (London, 1669), pp. 207-212.

19. S. Sturmy, *The Mariners Magazine*, (London, 1669), pp. 85-92.

20. C.F.M. Dechales, *L'Art de de Naviger demontre par principes, & confirmé par plusieurs observations tirées de l'experience*, (Paris, 1677), pp. 70-71.

21. J. Moore, *A New Systeme Of The Mathematicks*, (London, 1681), pp. 248-250.

22. E.G.R. Taylor, *The Mathematical Practitioners of Tudor & Stuart England, 1485 – 1714*, (Cambridge, 1967), p. 178.

23. P. Perkins, *The Seaman's Tutor, Explaining Geometry, Cosmography and Trigonomotry*, (London, 1682), pp. 185-189. English Libary shelf-mark C 126 e 11.

24. D. New-House, *The whole Art of Navigation*, (London, 1686), pp. 258-260. National Maritime Museum inv.no. B2860.

25. Breen, *Stiermans Gemack...*(note 16), p. 20 of chapter 13. C.J. Vooght, *De Zeemans Weghwyser*, (Amsterdam, 1706), pp. 37-38, 330. C.J. Boombaar, 'Onderwijs Der Zeevaert ofte de Konst der stuurluijden Int Jaer 1727',

1727, f61r.

26. N. de Hilster, 'The *Hoekboog*: a reconstruction', *The Bulletin of the Scientific Instrument Society,* No. 108 (2011), p. 21.

27. T.R. Adams, D.W. Waters, *English Maritime Books Printed Before 1801*, (Providence/Greenwich, 1995), pp. 332-335.

28. *Ibid.*

29. T. James, *The strange and dangerovs voyage of Captaine Thomas Iames, in his intended Discouery of the Northwest Passage into the South Sea : wherein the Miseries indvred both Going, Wintering, Returning; and the Rarities obserued, both Philosophical and Mathematicall are related in this Iournall of it*, (London, 1633).

30. *Ibid.*, p. 20.

31. See note 8.

32. Another explanation for single arc minute latitudes is the use of declination tables with arc minute accuracy as the latitude is the sum of the zenith distance and declination.

33. James, *The strange and dangerovs voyage...* (note 29), appendix directly following p. 120.

34. See note 8.

35. *Ibid.*

36. Waymouth, 'The Jewell of Artes' (note 11), f. 26.

37. A 1970 research project of the National Maritime Museum resulted in a technical drawing (NMM REF. No. S-119), showing the construction of the instrument in detail.

38. J.W. Shirley, *Thomas Harriot, A Biography*, (Oxford, 1983), p.92.

39. C.J. Boombaar, 'Onderwijs Der Zeevaert ofte de Konst der stuurluijden Int Jaer 1727', 1727, f61r. In this Dutch manuscript (NSA inv. no. S.1386 (E-0341)) – which is largely based on works by period authors – several instruments are described, among which the cross-staff, *spiegelboog* and Davis quadrant. Of the latter Boombaar states that this beam is "...een Staender tot & stijvinge des Boogs of ook den hant aan te houden" (... a beam to stiffen the Davis quadrant or also to hold it in the hand...).The text is accompanied by two coloured drawings and is dated by the author 1728.

40. See note 8.

41. See note 37.

42. Moore, *A New Systeme Of The Mathematicks* (note 21), p. 248. As a matter of fact one extra concentric circle was added, as the first and last concentric circle represent the same concentric interval, one diagonal interval apart.

43. Fournier, *Hydrographie...* (note 14), pp. 493-495.

44. See note 8, figure 24. Also see: R. Price, K. Muckelroy, 'The Kennemerland', *The Journal of Nautical Archaeology*, **6**.3 (1974), p. 210.

45. D.J. Warner, 'Davis' Quadrants in America', *Rittenhouse*, **3**, No. 1 (1988), p. 34.

46. See note 8.

47. From field tests with the smaller 18th century Davis quadrant it became apparent that they are easily read to 2 arc minutes without using the diagonal scale at all.

48. Seller, *Practical Navigation* (note 18), p. 209.

49. Moore, *A New Systeme Of The Mathematicks* (note 21), pp. 248-249.

50. Breen, *Stiermans Gemack...* (note 16), p. 20 of chapter 13.

51. Hilster, 'The *Spiegelboog...*' (note 15), p. 8.

52. A. Losman, I. Sigurdsson, 'Äldre Vetenskapliga Instrument på Skokloster', *Skoklosterstudier utgivna av Skoklosters Slott*, No. 10 (1975), pp. 89, 91.

53. Warner, 'Davis' Quadrants...' (note 45), p. 25. Warner lists 57 Davis quadrants, the oldest of which (and the only from the 17th century) dates from 1676.

54. W.F.J. Mörzer Bruyns, *The Cross-Staff, History and Development of a Navigational Instrument* (Zutphen: Vereeniging Nederlandsch Historisch Scheepvaart Museum, 1994), pp. 48-49.

55. Fournier, *Hydrographie...* (note 14), p. 493.

56. See note 8.

57. Mörzer Bruyns, *The Cross-Staff...* (note 54), p. 43.

58. *Ibid.*

59. Hilster, 'The *Spiegelboog...*' (note 15), p. 6.

60. W.E. May, *A History of Marine Navigation*, (New York, 1973), p. 23.

61. As from 1731 the Davis quadrant was no longer provided to the vessels of the Dutch VOC because of its inaccuracy, while the use of the octant was not officially approved until 1748. See Mörzer Bruyns, *The Cross-staff...*, p. 16. Also see W. Maitland, *An Essay towards the improvement of navigation, chiefly with respect to the instruments used at sea*, (London, 1750), pp. 35-36.

62. See note 8.

63. Warner, 'Davis' Quadrants…' (note 45), p.26.

64. As the research was done using photographs only the relative errors within five degree sections along the scale could be determined. The graph therefore shows five of these sections and not the absolute errors along the whole scale.

65. Warner, 'Davis' Quadrants...' (note 45), *passim.*

66. In total 45 correlations were calculated between 10 scales, one of which was not of an actual instrument, but randomly generated. The latter never generated a correlation over 20% when comparing to an actual instrument.

67. Moore, *A New Systeme Of The Mathematicks* (note 21), p. 250.

68. With thanks to W.F.J. Mörzer Bruyns for pointing me to this Van Keulen Davis Quadrant, which is known as object no. 9199 in Museum Boerhaave. For the Anthony Lamb Davis Quadrant see: W.F.J. Mörzer Bruyns, 'Navigating Instruments Acquired by the Peabody Essex Museum after 1963', *Rittenhouse*, **23**, No. 70 (2009), pp. 67 & 85.

69. *Ibid.* A year later Perkins added a literal copy of this paragraph to his work, see Perkins, *The Seaman's Tutor...* (note 23), p. 188.

70. A. Turner, 'Who Invented the Flamsteed Lens?', *The Bulletin of the Scientific Instrument Society,* No. 96 (March 2008), pp. 32-33.

71. R. Waller, *The Posthumous Works of Robert Hooke*, (London, 1705), p. 557.

72. T. Sprat, *The History of the Royal-Society of London For the Improving of Natural Knowledge*, (London, 1667), p. 246.

73. Turner, 'Who Invented the Flamsteed Lens?' (note 70), p. 32.

74. From correspondence between Turner and the author on November 2nd, 2008.

75. See note 8.

76. The Flamsteed lens needs alignment as well, but only with the edge of the lens-vane, which is much easier achieved and is not affected by any play in the instrument's construction.

77. *Philosophical Transactions,* **37**, No. 423, (1731-32), pp. 273-279.

78. Later editions of the instrument had their diagonal scales replaced by a Nonius. See inv. no. NAV0039 of the National Maritime Museum, Greenwich, UK.

79. G. Albrizzi, *Introduzione all Arte Nautica : per uso de Piloti, e Capitani di Nave, e per il migliore servizio de commandanti sopra il mare*, (1715), figure 37 and pp. 98-99.

Author's address:
Charlotte de Bourbonstraat 1
1901TK Castricum, The Netherlands
e-mail: info@dehilster.info