The Demi-cross: a reconstruction

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Introduction

In a previous article I described Master Thomas Hood's cross-staff, the first navigational instrument to use the shadow of an attached vane to measure the altitude of the sun without the need to look into it (Fig. 1).[1] That instrument was first described by Hood in 1590 in his *The use of the Two Mathematicall Instruments….*[2] Before his invention the sun's altitude was measured either with a mariner's cross-staff, a mariner's astrolabe, or a sea quadrant, although the latter was considered '*…an excellent Instrument upon the Shore,[…] but for a Seaman […] to no purpose…'*.[3]

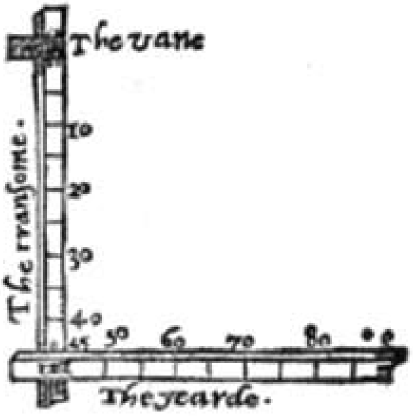

Fig. 1 *Master Hood's Cross-Staff.*

Fig. 2 *The mariner's cross-staff.*

Master Hood's staff was used for forward observations, similar to a mariner's cross-staff, by holding it next to the eye (Fig. 2), or by casting a shadow from an attached vane onto one of the scales. When used as a shadow-casting instrument the observer still faced the sun and held the instrument in front of him.

The method of forward observations changed around 1594, when Thomas Hariot[4] wrote his manuscript 'The Doctrine Of Nauticall Triangles Compendious' in which he further developed the idea of shadow casting instruments.[5] He not only used the principle of measuring the sun's altitude by a cast shadow, he also turned the observer so that he stood with his back towards the sun. This method of observing was the start of a new development in altitude measurement instruments called 'backstaffs' (or 'back-staves'), among which were the widespread Davis quadrant and the lesser known demi-cross.[6]

The main theme of the manuscript was the computation of meridional parts for drawing a Mercator chart, but on pages 31 and 32 he also discussed several navigational instruments. Present day authors have published on Hariot and the works he wrote, mainly discussing his live and mathematics. Only a few of them, among which E.G.R. Taylor (1953), D.W. Waters (1958), J.J. Roche (1981) and J.W. Shirley (1983), also discuss his navigational instruments.[7]

Historical Development

Hariot described three instruments for the backward observations, all of which showed features found on instruments that were developed in the following years. The first was based on a staff similar to Hood's design for the forward observation, but used in a backward manner, while the other two were quadrant types also for use with the back towards the sun.[8]

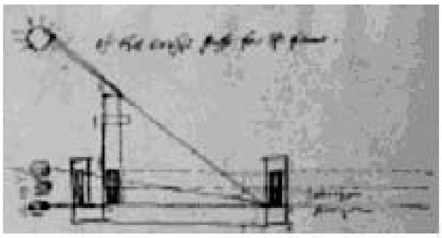

Fig. 3 *Hariot's original sketch 'of the crosse-staffe for the sunne'.*

The first instrument consisted of a staff, a sight vane, a shadow vane and a horizon vane (Fig. 3). Hariot wrote that *'The contriving must be aded* [sic] *that the horizon & the ~~shad~~ extreme of the shadow be in one line & then the observation may be perfecte.'*. Judging from the colour of the ink and thickness of the pen he continued this page at a later date by adding '*And that the staffe may be holden up right at the time of observation the vane which is next to the horizon must have a crosse vane whose edge must ~~muste~~ agree with the horizon, & with the shadow of the sunne upon the upright vane.*'.

Apparently Hariot was not too pleased with this design because his explanation (the part starting with '*And that the staffe...*') was struck through while below it he explained and drew two other – quadrant-type – instruments.

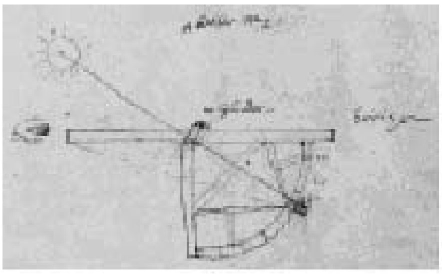

Fig. 4 *Hariot's original sketch of 'A better way…' to observe the sun backwards.*

The first of these two was titled '*A better way*', implying that it was more suitable for backward observations than the previous version of the instrument (Fig. 4). '*A better way*' had a 90-degree quadrant attached to the staff, a cylinder at the centre of the quadrant for casting a shadow and a '*… cursor or moveable vane so brode* [sic] *or broader than the Cylinder*' on the quadrant to catch the shadow cast by the cylinder. About the moveable vane Hariot wrote that *'The best is to have it just so big for the one halv* [sic] *as wilbe shadowed by the cylinder; the other half broder* [sic] *somewhat that the observer may se* [sic] *that the shadowe is in the middest; ~~shine~~ by shyning as much on the one side as the other'*. This way of projecting the shadow is of particular interest to the demi-cross, as will be explained below.

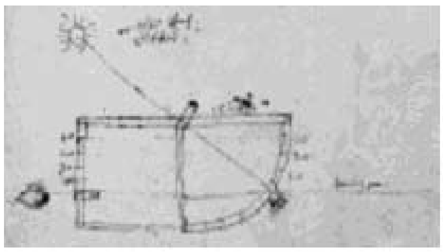

Fig. 5 *Hariot's original sketch of the 'or else thus better' version of the quadrant type instrument.*

Hariot must have thought that even this design could be improved, as below it an instrument entitled '*or else just better*', was drawn, this time using the same ink and pen (Fig. 5). This one also had a 90-degree quadrant attached to a staff. The eye-end of the staff was extended downwards to hold a sight vane. Again a cylinder was used to cast a shadow on a moveable vane. In this drawing the principle of shadow casting described with his first quadrant-type instrument – a movable vane with two different widths – is actually shown. The drawing also gives an indication of the size, as above the quadrant Hariot wrote *'18 inches'* (457 millimetres, probably the radius of the quadrant as the dimension is written between the cylinder and the arc). Where Hariot's first quadrant-type backstaff had the disadvantage that one had to look in two different directions to see the shadow and the horizon, with his improved version *'…the edge of the shadow & the horizon wilbe in one line'*. The fact that observations had to be made by adjusting two sliding vanes along two different scales must, however, have made this instrument cumbersome in use.

Hariot thought that both quadrant-type instruments were superior to his first, straight, version as '*…unto bothe these last wayes the shadow is perpendicular to the arche & vane, and allwayes of one bignesse because of the cylinder & therefore very commodeous which cannot be performed by strayte lined instruments*.'

The page ends with the remark that the instrument had to be made '*…to hold in the right hand excepte the observer be a sinister fellow*.'

It is unclear whether any of his instruments ever saw the light of day.[9] The section dealing with the last two versions seems to have been written in one go, as if the idea for the last instrument occurred to him while writing. In another manuscript, dating from 1595, Hariot wrote that there '*...are three instruments used at sea for taking of altitudes, The Astrolabe, The* [sea] *Ring & the* [cross-] *staffe.*'.[10] The use of these three instruments was described in detail, but no mention is made of backward observations or his instruments from his Doctrine.

It was probably Hariot who inspired John Davis to create his backstaffs[11], which he described in his *Seamans Secrets* in 1595.[12] The designs of Davis' instruments (and order in which he created them) clearly show similarities with Hariot's. Although collected in a manuscript, it did not mean that Davis was not able to gain knowledge of Hariot's ideas. Hariot and Davis had at least two mutual friends with interest in navigation; Dr. John Dee and Sir Walter Raleigh. Dee was in close and friendly touch with Hariot (who mentioned him twice in his manuscript)[13] and was Davis' teacher in science and navigation (he was Dee's last and most gifted pupil) as well as supporter of his voyages.[14] Raleigh was Hariot's inseparable friend for nearly 40 years[15] and Davis' friend and investor of his voyages.[16] That Davis and Hariot had knowledge of each others work in or after 1595 is evident as Davis wrote in that same year in his *Seamans Secrets* that *'...for Theorical Speculations and most cunning calculation, Mr Dee and Mr. Thomas Heriotts are hardly to be matched...'*[17], while Hariot listed Davis' work, among others, on the back of the final folio of his manuscript.[18]

Fig. 6 *John Davis' 45 degree backstaff.*

The first staff that Davis created was referred to as the '45 degree backstaff', as it was capable of altitude measurements only when '*…the sun not being more then 45 degrees above the Horizon…*' (Fig. 6).[19] Like Hariot's '*crosse-staffe for the sunne*' this consisted of a straight staff, a horizon vane and a sliding shadow vane, making the whole design almost identical, albeit with an arched shadow vane but without the sight vane.

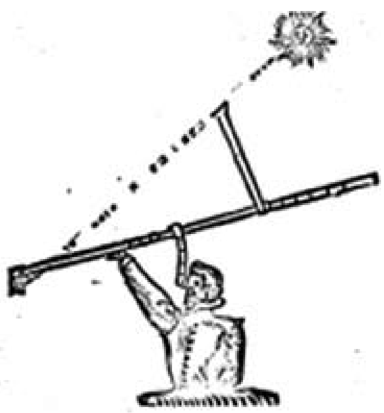

Fig. 7 *John Davis' 90 degree backstaff.*

Davis' second instrument was an improved version of his 45 degree backstaff and is referred to as the '90 degree backstaff', as this was capable of measuring altitudes up to 90 degrees (Fig. 7). Similar to Hariot, Davis added a graduated arc to improve his design. Here the arc would not be a quadrant, but a 25-degree section. The mayor difference with Hariot's instruments was, that Davis turned the quadrant around (the arc facing towards the observer) so that a horizon vane could be mounted in its centre and catch the shadow of a transom mounted on the staff. Hariot's design did cast a shadow from the centre of the quadrant towards the moveable vane, which in Davis' design became the sight vane. In this way Davis created a better instrument than Hariot as there was only one vane to move and only one location on the instrument to put ones attention to.

Both instruments actually materialised as, according to Davis, he used both instruments '*...under the sunne and under the climates...*'.[20] In 1614 the 90-degree version was described in Dutch period literature.[21]

The 90-degree backstaff would eventually evolve into the Davis quadrant and although Davis regarded the 90-degree backstaff superior to the 45-degree version, it did not mean the latter's further development stopped. In Holland it would evolve into another kind of backstaff, capable of measuring altitudes up to 90 degrees: the demi-cross.

The Dutch Connection

In 1598 three Dutch fleets sailed to the East Indies, two went through the Strait of Magellan, the other via the Cape of Good Hope. The last consisted of two ships, the *Leeuw* (Lion) and the *Leeuwin* (Lioness). Cornelis de Houtman in the *Leeuw* commanded the fleet, while his brother Frederick was skipper of the *Leeuwin*.[22] Captain John Davis was on board as pilot.[23] The voyage ended unfortunately for Cornelis de Houtman; he was killed in Aceh (Sumatera) in 1599.[24] The fleet returned to Holland in August 1600, leaving Frederick and 30 crew behind in captivity. Eventually Frederick re-

Fig. 8 *John Davis' 90 degree backstaff according to Metius.*

turned to Holland in 1602.[25]

In 1614 Adriaan Adriaansz. Metius published his *Nieuwe Geographische Onderwysinge…* (New Geographical Education).[26] On page 26 he wrote that he had recently met Governor Frederick de Houtman who showed him a staff very suitable to take the altitude of the sun backwards. On the same page Davis' 90-degree backstaff was shown in a different sketch than is known from Davis' own work (Fig. 8). So it was most probably Davis himself, through De Houtman, who introduced the 90-degree backstaff in the Netherlands and therefore most probably the 45-degree version as well.[27]

Davis' instruments might have been known in Holland even before De Houtman's return. In 1600 a book by Aelbert Haeyen was published, titled *Een Corte Onderrichtinge belanghende die kunst vander Zeevaert* (A short instruction concerning the Art of Navigation).[27a] Patented on December 17th, 1599, which was during the De Houtman's fleet's voyage, it mainly discussed two instruments: the variation compass and the mariner's cross-staff.

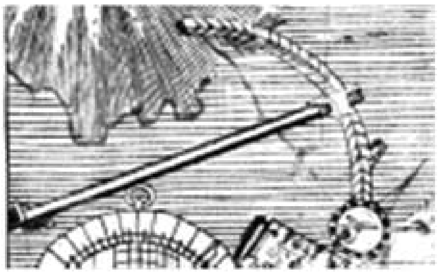

Fig. 9 *Edward Wright's mariner's bow.*

Although no direct indication is given that Haeyen was familiar with shadow-casting staffs, he did mention the *cromme boogh* (the curved staff) '*…diemen met schuyven moet regieren…*' (that has to be directed with vanes).[28] Haeyen wrote that the *cromme boogh* belonged to a master with a sound judgement who learned from his disciples, without naming the person in question or describing the instrument.[29] Up to today no research has ever revealed what the *cromme boogh* looked like, only that an instrument with the same name was patented in Holland on 13 September 1617, almost 18 years after Haeyen mentioned it.[30] The instrument that Haeyen described was used with multiple vanes (or at least he used the plural form of the word) and therefore could have been Davis' 90 degree backstaff as that was a staff with a curved part and two sliding vanes. A few pages before describing the instrument, Haeyen did mention several departing fleets in the years 1595 – 1598, but not specifically the

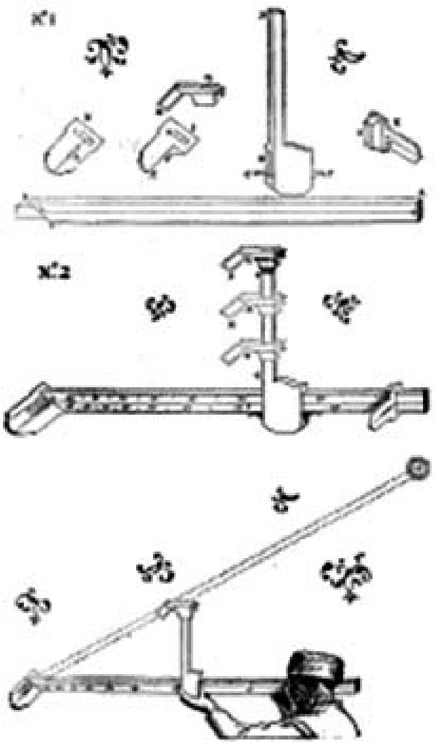

Fig. 10 *The earliest depictions of the demi-cross.*

one with Davis as pilot.[31] This leaves it unclear whether or not he knew Davis or his voyage with the De Houtmans. Alternately the instrument could have been a mariner's bow, as shown on the title page of the second edition of Edward Wright's *Certaine Errors in Navigation* in 1610, which was also curved and had two sliding vanes as well (Fig. 9).

Demi-cross

As mentioned, the 45-degree backstaff would evolve into another backstaff capable of measuring altitudes up to 90 degrees: the demi-cross. The earliest positive reference to the demi-cross so far can be found in a Dutch pilot book by Willem Jansz. Blaeu, *'t Derde Deel van 't Licht der Zeevaert* (The Third Part of The Fyrie Sea-Columne), printed in Amsterdam in 1621.[32] It contained three depictions of the instrument, with textual reference on how it had to be made (including dimensions), and how it worked (Fig. 10). This treatise would be copied and translated over and over in Dutch pilot books up to at least 1688.

In 1625 Blaeu depicted the instrument again, but now on the title page of *Tafelen van de Declinatie* ('Tables of the Declination'), printed in Amsterdam (Fig. 11).[33] It was depicted together with a mariner's astrolabe and a mariner's cross-staff. The prominent place on the title page is an indication of the significance of the demi-cross for Dutch navigation. The 1650 edition of

Fig. 11 *Blaeus* Tafelen van de Declinatie.

the same tables still carried the same title page. I have not been able to find works by other authors than Blaeu showing or describing the instrument in this 29-year period. It could therefore well be that it was Blaeu's own creation that was protected by a patent preventing others from showing it.

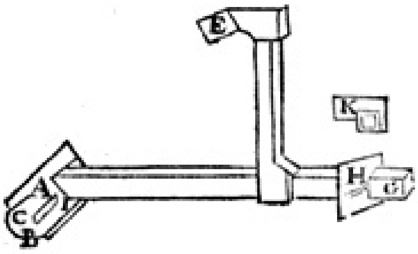

Fig. 12 *Dechales' Demi-Arbaleste.*

Claude Francois Millet Dechales was the first to give the instrument a name in literature: the *demi-arbaleste*, which he described in his *L'Art de Naviger…* (The Art of Navigation), in 1677.[34] The instrument is described in short and accompanied by a stylistic drawing (Fig. 12). Just as Blaeu's drawings it is semi three-dimensional. The shadow vane was not drawn completely as it lacks one horizontal line along the top of it. Dechales wrote that the instrument consisted of a staff with a half cross and had degree marks twice as big than those found on staffs with a normal cross.[35]

The English term 'demi-cross' can be found for the first time in Jonas Moore's *A New*

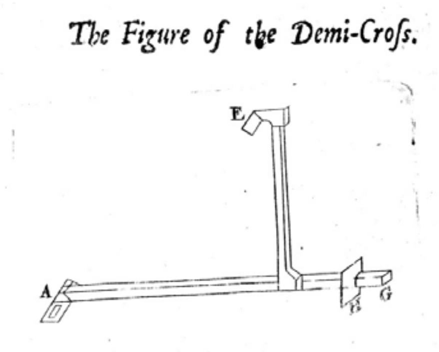

Fig. 13 *Moore's depiction of the demi-cross.*

ysteme Of The Mathematicks (London 1681).[36] He gives a short description, followed by an even more stylistic drawing than Dechales' (Fig. 13).[37] When comparing the images of Dechales and Moore it is apparent that Moore's version was derived from that by Dechales. It shows the instrument assembled almost in the same way, but less detailed and with a square sight vane. Along the top of the shadow vane the same line is missing and the capitals A, E, G and H are at the same locations.

As already said, a comprehensive description of how the demi-cross was made, including its dimensions and detailed drawings can be found in several editions of Dutch pilot books that appeared in Amsterdam between 1621–1688.[38] With so many Dutch works showing the instrument and non Dutch authors referring to it as being mainly used or described by them, the instrument seems to be a Dutch development based on Davis' 45 degree backstaff. I was however not able to find a Dutch name for the instrument in the works I examined. Instead, the instrument was introduced as '*…you may in good order finde the height of the Sunne by the shadow, in this manner: make a staff…*' and described in full detail.

Fig. 14 *The demi-cross (original in colour.)*

The most recent depiction of the instrument that I found, was also the only one in colour, on the title page of *Tome d'Atlas Avec Les Cartes Maritimes* by N. Sanson, A.H. Jaillot and P. Mortier, printed in 1693 (Fig. 14).[39] And although this title clearly indicates its French origin, it was printed in Amsterdam by Pieter Mortier. Besides the demi-cross it shows an astronomical astrolabe, a compass, a pair of dividers, a sounding lead, atlases, a globe and an armillary sphere.

In modern literature the demi-cross has been described by C.A. Davids, W.E. May and D.W. Waters, although very briefly.[40]

Use and Diffusion

The instrument has been shown and/or described in at least 17 books from a variety of authors spanning at least 72 years. Descriptions have been found in Dutch (7), English (6), French (3) and Italian (1) works from Dutch (13), English (2) and French (2) authors. Table 1 gives an overview of all period works – containing the instrument – that were used as reference for this article.

As can be seen from the last column, all works depicted the demi-cross (17); most had a textual description (14) and two-thirds also gave its dimensions.(11). De *Tafelen van de Declinatie* are two editions of the declination tables by Blaeu, both showing the same image on the title page (see Figure 11). The image found in Dudley's work shows an almost exact copy of one of the images found in the Dutch pilot books. It has to be noted that the Dutch pilot books all contain an almost exact (translated) copy of the text and images. These are also the only works that mention the dimensions of the instrument and hence have a 'D' in the 'Code' column.

Most works are from Dutch origin, which

Author	***Title***	**Year**	**Lang.***	**Code****
Willem Janszoon Blaeu	*'t Derde Deel van 't Licht der Zeevaert*	1621	NL/NL	ITD
Willem Janszoon Blaeu	*Tafelen van de declinatie*	1625	NL/NL	I
Willem Janszoon Blaeu	*Tafelen van de declinatie*	1650	NL/NL	I
Anthony Jacobsz.	*Loots-mans Zee-spiegel*	1652	NL/NL	ITD
Johannes Jansonius	*De Lichtende Columne ofte Zee-spiegel*	1652	NL/NL	ITD
Jacob Colom	*The Third Part Of The Fyrie Sea-Columne*	1655	NL/EN	ITD
Pieter Goos	*De Lichtende Columne ofte Zee-spiegel*	1657	NL/NL	ITD
Robert Dudley	*Arcano del Mare*	1661	EN/IT	IT
Pieter Goos	*The Lightning Columne, Or Sea-Mirrour*	1662	NL/EN	ITD
Jacob & Casparus Lootsman	*Le Grand & Nouveau Miroir Ou Flambeau De La Mer*	1666	NL/FR	ITD
Pieter Goos,	*The Lightning Columne, Or Sea-Mirrour*	1670	NL/EN	ITD
Jacob & Casparus Lootsman	*The Lightning Columne, Or Sea-Mirrour*	1676	NL/EN	ITD
Claude-François Millet Dechales	*L' art de naviger demontre par principes, et confirmé par plusieurs observations tirées de l'experience.*	1677	FR/FR	IT
Jacob & Casparus Lootsman	*Zee-spiegel ofte Lichtende Columne*	1679	NL/NL	ITD
Jonas Moore	*A New Systeme Of The Mathematicks*	1681	EN/EN	IT
Jacobus Robijn	*Sea Mirrour*	1688	NL/EN	ITD
Nicolas Sanson, Alexis Hubert Jaillot & Pieter Mortier	*Tome d'Atlas Avec Les Cartes Maritimes*	1693	FR/FR	I

* The language shows the author's nationality and the language of the book, so NL/FR means a Dutch author, French text.

** The code is an indication of what can be found in the corresponding work: I = Image, T = Text, D = Dimensions.

Table 1: Period works with reference to the demi-cross.

is an indication for its diffusion, at least within the Netherlands. Diffusion outside the Netherlands was slow. Davids tells us that although there was a prolific Dutch influence on nautical knowledge throughout north-eastern Europe in the 18th century, it was far less the case in the 17th century, which had all to do with the lack of understanding of the Dutch language.[41] In order to make the books accessible abroad they were translated, although that still did not guarantee they were read. Davids stresses that there is a difference between supply and consumption and that many sailors, even by the end of the 17th century, possessed no chart or pilot books at all.[42]

That knowledge about the instrument did spread outside the Netherlands to some degree is apparent as both Moore and Dechales described it in their works. Before describing the instrument Moore mentioned that '*... this instrument is sometimes used by the Dutch, but has been wholly neglected by the English...*'.[43] Dechales wrote that he had seen an image of the demi-cross in several Dutch pilot books, but he does not mention its actual use.[44] Apparently the instrument was mainly in use with (or at least described by) the Dutch.

Proof of its actual use on board of Dutch vessels is however hard to find. Davids examined a substantial amount of logbooks and sailor inventories from the period this instrument covers and lists the instruments he found. Of all angle measuring instruments known to have exist in that period only the mariner's cross-staff, quadrant and astrolabe were mentioned.[45] Perhaps future research of logbooks and other resources will reveal proof of its actual use at sea. So far all knowledge of the demi-cross comes from the books listed in Table 1. There is no physical evidence, as no demi-crosses (or parts of them) are known to have survived.

Materials

The only direct reference for materials is the mention of a steel or copper spring that was used in the cross in the Dutch versions of the pilot books, the English versions only mention '*...a copper fether steeled...*', indicating that a hardened copper spring was used.[46] Although copper is named, this would most probably have been brass as the words 'brass' and 'copper' were often used to refer to the same material, while brass is known to have been actually used for the metal parts of period navigational instruments.[47] About a part of the horizon vane it was written that one had to '*...make it very white...*'[48], an indication for the use of paint, although paper is known to have been used for this purpose as well.[49] It was probably whitened for a better visual contrast.[50] The shape of the vanes on the sketches indicate that they were made of wood, and not of brass. The thickness of the flat parts of the vanes and the size of the blocks with the holes to assemble the parts are much thicker than as shown in period literature for instruments that are known to have brass vanes. Assuming that both the staff and the vanes were indeed made of wood, most probably either pear wood (fruitwood) or boxwood would have been used for the vanes, and ebony, lignum vitae, redwood or pear wood for the staff as those were commonly in use in period mariner's cross-staffs and their vanes.[51]

Construction

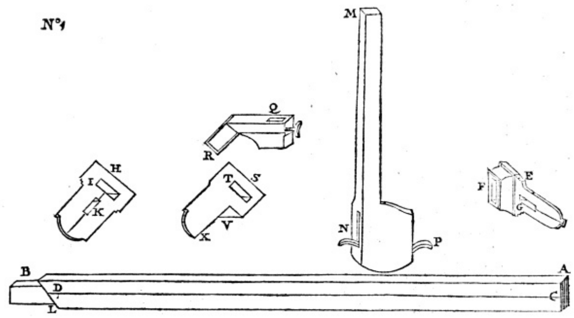

Fig. 15 *The demi-cross in parts.*

The Dutch pilot books show the instrument on three different sketches, which are roughly the same for all editions found so far. The first of them depicts all parts separately (see Fig. 15, which is from *Lootsmans Zee-spiegel,* a 1652 pilot book by A. Jacobsz.), the others how it was assembled and used (Fig. 10). The instrument consisted of a staff along which a cross (usually the word 'transom' is used for this part, but as all pilot books name it a cross I will from now on refer to it as that). Along the cross a movable shadow vane could slide and set at predefined positions. A horizon vane was mounted at one end, while a movable sight vane was slid on at the other end (Fig. 21).

The dimensions of the staff, cross and the shadow vane were only given in all versions of the Dutch pilot books in feet and inches, presumable Amsterdam feet (0.283m, divided in 11 inches of 25.7mm), Rijnlandse feet (0.314m, divided in 12 inches of 26.2mm) or *Wynroeyers* feet (0.289m, divided in 12 inches of 24.1mm) as these were commonly used in Holland.

The staff

The staff had to be '*...shaved even and smooth, halfe an inch thick, and 2 inches broad or more, (that it alwayes stand streight,)...*'.[52] So in contrast to the mariner's and Master Hood's cross-staff, which had a square cross-section, this one had a rectangular cross-section that was four times as broad as as thick. As can be seen on the sketches the staff had a narrower part, on which the horizon vane could slide (see Fig. 16). If mounted properly, the vane was flush with the diagonal wider part of the staff. The angle of line BL in the sketch is not given, but it had to be '*...not just but sloop or pendant as the rule of BDL doth shew...*'.[53] The angle however varies with different works and even between the sketches in the same pilot book (when comparing the vanes with the staff or the staves with each other). In the sketches the angle varies from about 40 to about 53 degrees. It probably was meant to be 45 degrees, the bisector of the maximum altitude measurable, or 41 degrees, the bisector of the maximum range measurable.

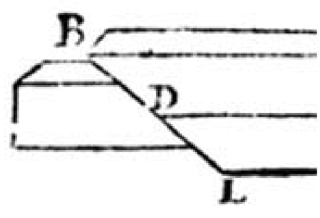

Fig. 16 *The horizon end of the staff.*

The cross

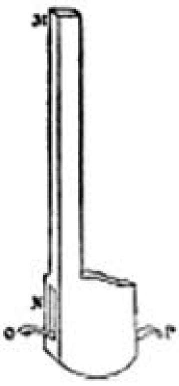

Fig. 17 *The cross.*

Sliding along the staff was '*...a crosse of a foot and a half, or two foot long ..., with a hole ... that is like a square line just on the foresaide staffe, whereby you may shove it a long to and fro...*' (Fig. 17).[54] The cross (sometimes also referred to as the *long* cross) is of an asymmetrical design and basically a large block with a square staff protruding from one corner. It carried the shadow vane and had to slide '*... softly and surely...*' along the staffe, which was accomplished by using '*...a copper fether* [sic] *steeled: which grindes under against the staffe, and holds it fast...*' (Colom translated this from the original Dutch text which mentioned 'a steel or copper feather').[55] This spring was an item not seen in navigational instruments before and had to keep the cross from wobbling and avoid forthcoming observational errors. That the demi-cross needed this spring and the mariner's cross-staff not is the consequence of its design. Mathematically seen the cross-staff measures the sum of two triangles; the one above and the one under the staff. When the cross of a mariner's cross-staff wobbles, the angle on one side between the staff and the cross increases, while it decreases at the opposite side. As long as the wobble remains small, these errors almost compensate each other. A demi-cross only measures one of these triangles, so any wobble is not compensated for and therefore directly affecting the observation.[56]

The shadow vane

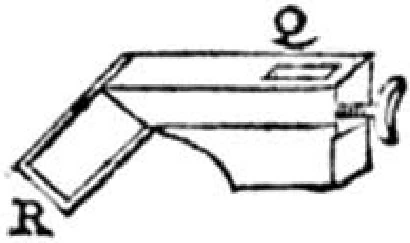

Fig. 18 *The shadow vane.*

On the cross a shadow vane (in the pilot books it is referred to as the little or small cross) was mounted (see Fig. 18). This vane had '*... a hole wherewith you moy* [sic] *put it on the long crosse ... and set it fast with a little screw..., so high and low as need requires...*'.[57] On the front end it had '*...a flatte eare , an inch, or an inch and a half broad...*' ('R' in Figure 18).[58] The ear of the shadow vane and the horizon vane should be made and mounted '*... that they make equall angles...*'.[59]

The horizon vanes

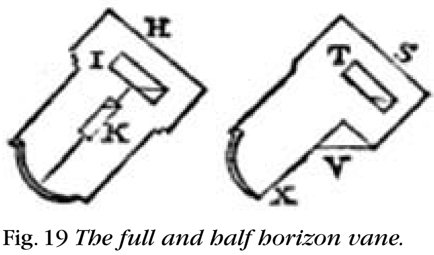

Fig. 19 *The full and half horizon vane.*

Two different horizon vanes were suggested for the staff: a half one and a full one with a slit in it (Fig. 19). The purpose of the difference however is not mentioned, but the reconstruction showed that it would allow the observer to take forward observations of the stars, a method more or less described by Dechales (see below). The slit in the full horizon vane was made at an angle parallel to the staff (see slit near K in Fig. 19) and thus only allows sights in that direction.

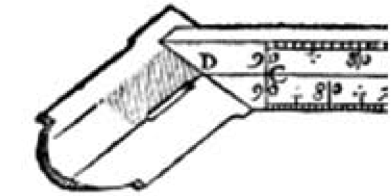

Fig. 20 *The full horizon vane with the shadow of the shadow vane.*

On the upper half of the horizon vane one had to '*...make two lines even wide upon the sloope...*' of which '*...one must goe mids through the little peep hole...the other so much higher as the little eare on the uppermost small shove is broad...*' and '*...you make it very white betwixt these 2 even-wide lines...*' (Fig. 20).[60] The '*...little eare on the uppermost small shove...*' is the ear of the shadow vane as described above. The parallel lines and the white area in-between served the same purpose as the moveable vane with two widths suggested by Hariot. Due to the diameter of the sun, the cast shadow will have a penumbra by which the width of the shadow will be disproportionate with the distance of the shadow vane to the horizon vane.[61] As the white area of the horizon vane and the ear of the shadow vane have the same width and always are parallel, the centre of the shadow should be cast onto the centre of the white area in order to get a proper observation. The white area helps the observer to centre the shadow within the two parallel lines, even when it is cast from the far end of the instrument. In this way the horizon vane works similar as Hariot's moveable vane with two widths.

The sight vane

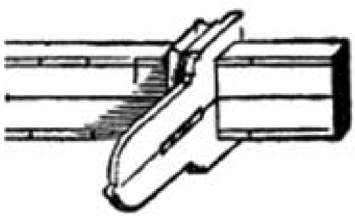

Fig. 21 *The sight vane.*

The last part of the instrument is the sight vane. It is '*...a little drawer ... with a hole ... which you may put on the staffe..., & shove there with along (like as you do with a trumpet) to and fro, also crosse wise or athwart there in a small peep hole made to loke* [sic] *through,...so that when that the little peep-hole comes then to stand just beside the mid-rule of the staffe..., neither higher nor lower.*' (Fig. 21).[62] The sight vane was to ensure that the instrument would point straight to the horizon. Peepholes are also known from Davis quadrants and octants, but although these were round and very small, the peephole of the demi-cross is rectangular in shape and is drawn as wide as the opening in the full horizon vane.

Scales

Just like period mariner's cross-staffs the demi-cross could have up to four scales engraved on the staff. Although the sketch with the assembled instrument only shows us 3 presets (and thus 3 scales), the part of the text that deals with the graduation tells us that the offset of the vane is first measured with the vane at the end of the half cross, then it is lowered '*...a third or fourth-part at your pleasure...*' before the next measurement is done.[63] The reader is cautioned to '*...not forget to make every time certaine markes on the long crosse, for to sett the small crosse to the marke which you please to use...*'.[64] In this way only graduating the first two scales was described and if you wanted to '*...make more reckonings upon the same staffe, sett then the uppermost small crosse more downeward and doe as is foresaid...*'. This process could thus be repeated three or four times, depending on the interval chosen. Each preset had its corresponding scale on the staff, which had space for two on both sides, so four in total. One may therefore assume that staffs have been made with four scales as well (I tried this on the reconstruction with success).

The scales of period mariner's cross-staffs were related to the length of the vanes - or rather half that length - and had the eye-end of the staff as the origin (180 degrees altitude, although the section from 180 – 90 degrees was never graduated). Due to the

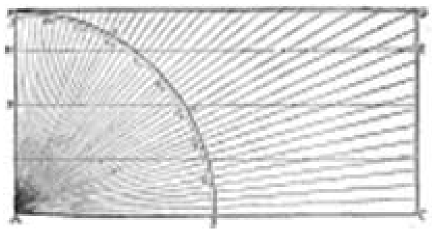

Fig. 22 *Constructing the scales of a demi-cross using the same method as cross-staffs were made.*

shape of the shadow vane the scales of the demi-cross had to be made with an offset, similar to those on the 45 degree Davis back-staff.[65] Thanks to its rectangular design the vane length and scale offset could be more easily determined than with Davis' design, which had an arced shadow vane.

The sketches show that the scales start at 90 degrees (see Fig. 20), which is confirmed by the accompanying text.[66]

The scales could be laid out using the same construction method as used with mariner's cross-staffs (Fig. 22), but the reader was also facilitated with a table that gave the ratio *'…for every degree or fourth-part of a degree…'*.[67] Using the table one could easily lay out the scales mathematically for every 15 minutes of arc. The height of the shadow vane above the centre of the staff had to be divided by 10000 and multiplied with the value in the table in order to get the distance from the start of the corresponding scale at the 0 degrees zenith distance mark. The table runs all the way from 0 to 90 degrees and was calculated accurately to what we would now call the 4th decimal (with an occasional rounding error). For 90 degrees the value *'Infinite'* (the Dutch pilot books give '*oneynd'lick*', Dutch for infinite) is given.[68]

Dimensions

As I used the *Wynroeyers* feet for my reconstruction I converted the feet and inches in this article accordingly. The instrument consisted of *'…a staffe, 3 or 4 foote long, so as you please, being shaved even and smooth, halfe an inch thick, and 2 inches broad or more (that it alwayes stand straight)…'*.[69] This means the length would have been at least 867 millimetres. The proposed thickness of half an inch (12mm) is similar to period cross-staffs, which were 12 – 14 millimetres.[70] With two inches (48mm) the proposed height was at least four times as much.

The cross was *'…a foote and a halfe, or two foot long...'* and the *'…flatte eare…'* (the shadow casting part) of the shadow vane had to be *'…an inch, or an inch and a half broad…'* (24 to 36mm).[71] How the length of the cross was defined is not mentioned, but it may be assumed that it was measured from the middle of the staff (the horizontal line running through 'C' in Fig. 23) as that would be the working distance of the cross. The overall length of the cross – so from the bottom of the block until the end of the protruding staff – should then be at least half the width of the staff (plus a bit extra for the spring) more in order to create the hole in the block that would allow it to be slid onto the staff. As previously described the two parallel lines on the horizon vane were the same distance apart as the width of the ear of the shadow vane, so 24mm to 36mm. The dimensions of the other parts of the demi-cross were not specified, but can be estimated from the drawings.

Signature, Marks and Decorations

As far as is known there are no surviving demi-crosses, or even parts of one. We have to rely on period works and similar instruments (cross-staffs) to get an idea of the way the instruments were marked, signed and decorated. What the scales might have looked like is shown in period works, although it has to be noted that these sketches do not show the scales in full detail (Fig. 23). As described in the paragraph on the scales, these were divided at quarter degree intervals. The sketches however only show us the whole degrees. According to the sketches the degree marks were laid out in a single row, with every 10 degrees stamped in with numbers and the 5 degree marks decorated with three points.

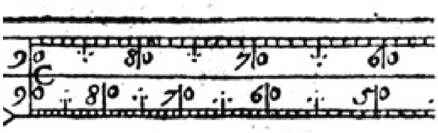

Fig. 23 *Detail of the scales according to Blaeu (1621). The 'C' on the left is not a part of the scale, but used as reference in the accompanying text.*

A wreck find from the *Kennemerland,* a Dutch VOC (the Dutch East India Company) vessel that sank off the coast of Shetland in the 17th century, shows us what the quarter degree intervals might have looked like. It concerns one of the scales of another early 17th century Dutch backstaff, the *hoekboog*. This scale, first described by R. Price and K. Muckelroy in 1974[72], shows the degrees laid out in two rows, the upper only divided for the whole degrees, while the lower had the degrees divided in two parts by a line, both of which were again divided in two parts by dots (Fig. 24). These intervals were typical for the *hoekboog* and are described in period literature.[73] As the demi-cross was divided in quarter degrees as well it might have looked quite similar.

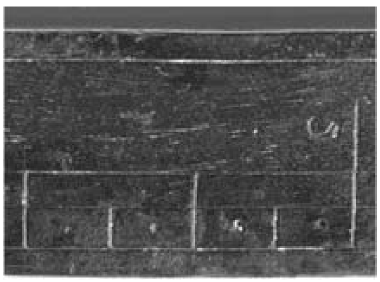

Fig. 24 *Detail of the Kennemerland* hoekboog *scale showing the divisions from 3 degrees (left) to 5 degrees (right) and their subdivisions.*

The protruding staff of the cross had to have '*...certaine markes...*', one for each scale engraved on the main staff of the instrument. These marks served as reference to set the shadow vane against, similar to the pins used on the cross of the *spiegelboog*.[74]

Any other decorations are not shown or mentioned in the works I investigated. We may assume that the instruments were signed just as most period mariner's cross-staffs, but how and where that was done on the demi-cross remains unclear. In addition to that the marks along the cross and the corresponding scales on the staff must have been marked with numbers in order to identify the scale that had to be read when a certain shadow vane setting was used. This method is known from surviving mariner's cross-staffs and from the *spiegelboog*, where the numbers were stamped in next to the eye-end of the staff.[75]

Using the Demi-cross

The second and third sketches in the Dutch Waggoners show how the instrument was used. The second depicts the different settings for the shadow vane (Fig. 25), while the third shows how it had to be held (Fig. 26).

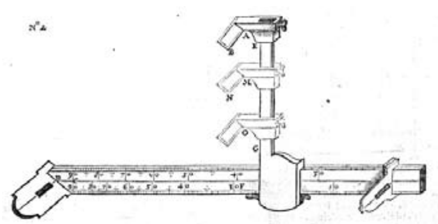

Fig. 25 *Three different settings of the shadow vane on the demi-cross.*

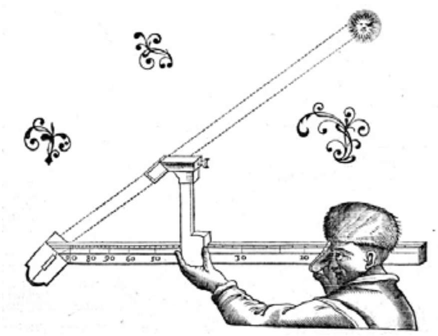

Fig. 26 *Using the demi-cross.*

With the demi-cross one had to look through the sight vane to the horizon vane and see the horizon through the latter while the shadow vane would cast a shadow on it, which could be accomplished by sliding the cross along the staff.

Dechales wrote that the instrument could be used for star observations, not using another horizon vane, but a half sight vane. One had to change the full sight vane (H, see Fig. 12) for a half sight vane (K), then put the horizon vane (A) next to the eye, look over the shadow vane (E) to the star and along the half sight vane (K) to the horizon.[76] From tests with the reconstruction it became evident that the full horizon vane would block sight towards the shadow vane. The instrument is only suitable for star observations when the half vane is placed at the end where the full horizon vane sits and subsequently used as a sight vane. It seems that the instrument was indeed used for forward observations as well, but that Dechales misunderstood the way this was done.

The Reconstruction

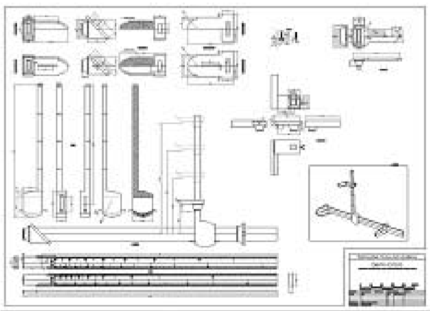

Fig. 27 *A modern drawing of the instrument made with CAD software.*

Just as with the *spiegelboog* and master Hood's cross-staff, I decided to build a reconstruction of the demi-cross, as that would give me a better feel of the instrument and allow me to take observations with it. I first made a technical drawing of the instrument as the basis for a real working object, then ordered the wood and started building the reconstruction. Materials used are ebony for the staff and pear wood for all other wooden parts. Brass was used for the spring and screw, while white paint was applied to the area between the parallel lines on the horizon vanes. Just as with my previous reconstructions, the wood was given a wax finish to prevent it from staining and to preserve the colours.

I made two reconstructions; one for my personal collection and one as a part of a navigational set made for a museum that is currently being built at the location of the former Dutch Trading Post in Hirado, Japan.[77] Apart from the serial numbers and signatures the two reconstructions are identical. Both bear the actual year of construction.

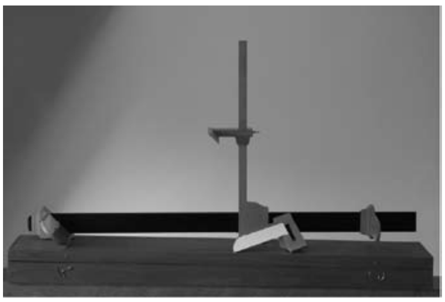

Fig. 28 *The reconstruction.*

Similar to with the *spiegelboog* I tried to find out if the drawings were to scale and determine the period measures used to build the instrument.[78] The drawings in the pilot books did, however, not show much consistency, so I decided to base the reconstruction on the same foot that was used for the *spiegelboog*, the *Wynroeyers* foot.

The length of the staff would have to be three or four feet (867mm or 1156mm). Assuming that this would be the length of the staff from the eye-end to the horizon vane (the working distance of the instrument), the staff was made about three inches longer for the narrower section that holds the horizon vane. I wanted to use ebony for the staff, which however is difficult to get in lengths above a metre. Therefore I decided to build the instrument based on the smaller dimensions given in the period literature, a three foot staff with a foot and a half cross. The length of the reconstruction became 937 mm, while the cross became 18¼ inch (440mm), which is slightly more than a foot and a half, in order to be able to stamp in a number above the uppermost mark on the cross that identifies its corresponding scale.

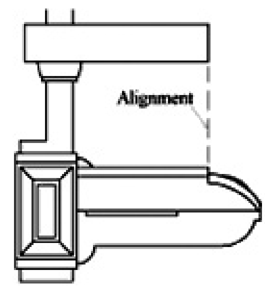

Fig. 29 *Alignment of the shadow vane.*

The lengths of the horizon and sight vanes were not given, but were estimated from the drawings, even though these are not very consistent. I made them seven inches long (168mm), by which they would protrude half a foot from the staff. The length of the shadow vane was chosen in a way that, when properly aligned with the sun, the end of its shadow would coincide with the corner of the upper straight edge of the horizon vane (Fig. 29). This resulted in a shadow vane of just over five inches (126mm).

As there was space for four scales on the staff I decided to give the shadow vane four settings on the cross and to divide the staff accordingly. Engraving scales 2 and 3 on one side of the instrument resulted in a staff very similar to what is shown in Fig. 25. Scales 1 and 4 where thus engraved on the other side. The scales were divided with the following intervals using the layout as described under *Signature, marks and decorations*:

	Interval (arcminutes)			
	300	60	30	15
Scale	Altitude range (degrees)			
1	-	-	-	90 - 27
2	-	-	90 - 80	80 - 21
3	-	90 - 80	80 - 50	50 - 15
4	90 - 80	80 - 40	40 - 30	30 - 8

Table 2: Scale division intervals.

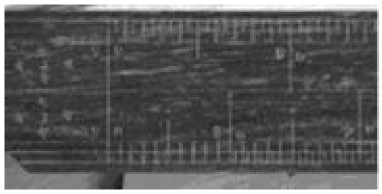

Fig. 30 *Scales 2 and 3 from the reconstruction.*

The construction of the scales was done mathematically and laid out using a specially built one metre long calliper with a 0.05 millimetre interval vernier . The engraving itself was done by hand using a sharp knife. The numbers were stamped in using modern handmade steel stamps with 17th century digits (Fig. 30).

Finally the instrument was signed *'N d H'* and dated on the upper side of the staff next to the horizon vane. The instrument number was stamped in at the eye-end of the staff. All vanes were marked with the same instrument number as on the staff. Signatures, dates and numbers were decorated with stars and sea horses (the latter being my instrument maker's mark).

Field Test

On November 5th, 2007 three experienced navigators (Nico Duijn, Jan Jonker and Jaap Ypma) joined me in a field test in IJmuiden, The Netherlands (52°27'29.4,N, 4°32'17.7,E). They all had experience with my previous reconstructions of 17th and 18th century navigational instruments as they had joined me in 2005 for field tests with, among other instruments, a *spiegelboog* (mirror-staff), a Davis quadrant and a mariner's cross-staff.[79]

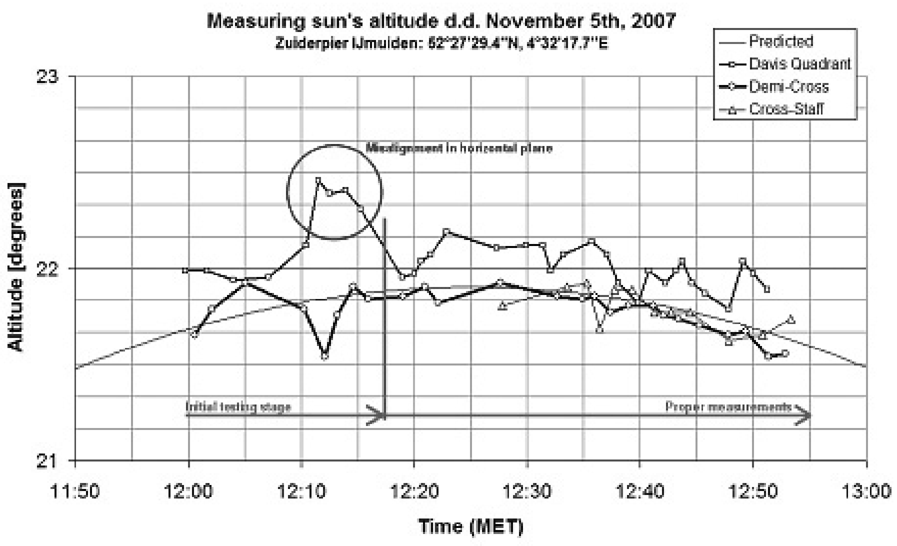

Fig. 31 *Results of the field test.*

This time we had the demi-cross, Master Hood's cross-staff, a Davis quadrant and a cross-staff at our disposal. How Master Hood's cross-staff performed can be found in my previous article[80], while the mariner's cross-staff and Davis quadrant are discussed in my *spiegelboog* article.[81] The Davis quadrant and the mariner's cross-staff were newer copies than the ones used in the previous field test. While on Terra Firma we collected data during a one hour-period around the meridian passage of the sun, trying to shoot the sun's centre. We first had to get used to the instruments, which resulted in some irregular data during the first 15 minutes. After this 'initial testing stage' the data became much more consistent while the measuring interval became shorter over time. In between observations the instruments were reset by sliding away the vane or cross, forcing us to take a completely new observation instead of adjusting the previous one.

All collected data was corrected for refraction, dip and parallax, and compared to the theoretical altitude of the sun (Fig. 31).

When considering the data after the first 15 minutes, the demi-cross showed an average error of -2.6 arc minutes with a 2.3 arc minutes standard deviation (1σ, 68%). The Davis quadrant had an average error of +10.5 arc minutes with a 5.1 arc minute standard deviation, and the mariner's cross-staff had an average error of -0.8 arc minutes with a 4.8 arc minutes standard deviation.

As can be seen from figure 31 and above statistical values both the mariner's cross-staff and the demi-cross performed quite well. It has to be said that the mariner's cross-staff was used in a configuration not available until the mid-18th century and therefore performing much better than an early 17th century version would have done.[82]

The Davis quadrant was checked for instrumental errors, but none could be found explaining the average error. Previous measurements with another Davis quadrant also showed this positive deviation in altitude measurements[83], and from period literature it is known that the Davis quadrant was not regarded to be better than 12 arc minutes or 6 arc minutes at the most.[84]

In order to explain the average error of the Davis quadrant, we have to go back to Hariot's quadrant type instruments. As described, Hariot used a cylinder to cast a shadow on a vane with two widths, allowing the observer to centre the shadow on it. This ensured that the penumbra, the space of partial illumination caused by the sun's diameter, did not negatively influence the observations. With the Davis quadrant only the upper edge of the shadow vane casts a shadow on the horizon vane (see Fig. 32, 1). Using the mariner's cross-staff in the way we did, not the shadow, but the slit of sunlight within it is used as reference (see Fig. 32, 2, the slit of sunlight should be projected on the horizontal protruding edge of the horizon vane, here it is slightly low).[85] The demi-cross uses both edges of the shadow vane to cast a shadow within the whitened area of the horizon vane (see Fig. 32, 3).

Both the slit of sunlight of the mariner's cross-staff and the shadow of the demi-cross can easily be centred on the horizon vane, while with the Davis quadrant one has to estimate what the centre of the penumbra is (or the upper or lower edge of it when one wants to measure the lower or upper limb of the sun). As the shadow vane of the Davis quadrant is not always parallel to the

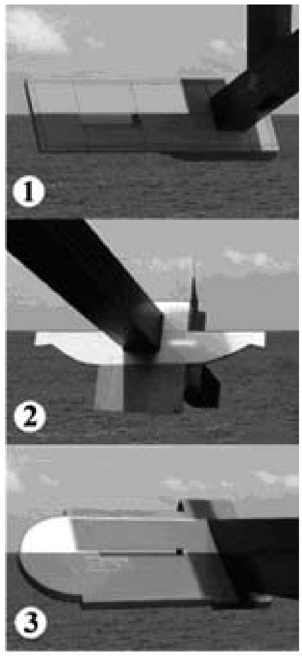

Fig. 32 *Different types of shadow casting.*

horizon vane, the width of the shadow will change with the altitude measured. For this reason only one edge of the shadow can be used, an error source already recognized by Dechales in 1677.[86] The human interpretation of the penumbra is such that one tends to raise the shadow too much, increasing the altitude observed. With the demi-cross the shadow, even when cast at three foot distance, is quite easy to centre on that whitened area.

From our tests it became apparent that due to its smaller size, lesser weight and its shape the Davis quadrant was easier to use than the twice as big demi-cross. This also resulted in a higher repetition rate for the Davis quadrant. During the one hour trial we managed to take 33 observations with the Davis quadrant versus 25 with the demi-cross.

Conclusion

The addition of a shadow vane to a cross-staff by Thomas Hood initiated a development of shadow casting instruments at the end of the 16th century. Thomas Hariot was probably the first to improve Hood's design and also initiated the backward measuring method. It was John Davis who perfected the backstaff initiating the development of a wide range of backsight instruments, among which Davis quadrant and the demi-cross. When in good condition the demi-cross performs almost as well as a mariner's cross-staff would do more than a century later. Although a better performing instrument (at least on Terra Firma), the demi-cross did not become as popular and widely spread as the Davis quadrant. A reason may be the fact that the demi-cross is less easy to handle than the Davis quadrant and more susceptible to warping and bending (causing observational errors) than the sturdy frame of a Davis quadrant.[87]

Acknowledgements

I am very grateful to D. Wildeman, curator of Navigation and Library Collections and A. Oortwijn, Information Officer of the Netherlands Maritime Museum in Amsterdam and to S. de Meer, Curator of Cartography and Ron Brand, librarian of the Maritime Museum Rotterdam, for allowing me to study their collections, even though the Netherlands Maritime Museum was closed for renovation during my research. Many thanks to C.A. Davids for digging into his archives for me and to Lord Egremont for allowing me to have a digital copy of Hariot's manuscript. I also wish to express my gratitude to all those who granted me permission to reproduce images from their collections and to publish them in this article. Especially appreciated is the assistance by Tommy Watt, curator of the Shetland Museum and Archives, who has been so kind to take pictures and measurements of the *hoekboog* scale in his collection, to let me study that same part and the *Kennemerland* archives at a later visit and to let me use one of his pictures of the *hoekboog* scale for this article. Finally I wish to thank W.F.J. Mörzer Bruyns for commenting on the reconstruction and this paper and for the discussions we had on this instrument and period navigational instruments in general.

For this subject see also:

www.dehilster.info.

List of Image References

Fig. 1: M. Blundeville, *His Exercises* (London, 1594), p. 315, collection Rotterdam Maritime Museum.

Fig. 2: J. Moore, *A New Systeme Of The Mathematicks*, (London, 1681), p. 238, Collection Netherlands Maritime Museum, Amsterdam.

Fig. 3: 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. 4: 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. 5: 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. 6: J. Davis, *Seaman's Secrets*, (London, 1657), From http://www.mcallen.lib.tx.us/books/seasecr/bk_staf2.gif, last accessed January 16th, 2008.

Fig. 7: J. Davis, *Seaman's Secrets*, (London, 1657), From http://www.mcallen.lib.tx.us/books/seasecr/bk_staf3.gif, last accessed January 16th, 2008.

Fig. 8: A.A. Metius, *Nieuwe Geographische Ondervvysing, Waer in ghehandelt werdt de beschryvinghe ende afmetinghe des Aertsche Globe / ende van zijn ghebryck : midtsgaders een grondelijcke onderwysinge vande principale puncten der Zeevaert : inhoudende sonderlinghe nieuwe ghepractiseerde Instrumenten / konstighe practijcken / diversche noodtlijcke Regulen / die alle Pilooten ende Stuerluyden behooren te verstaen*, (Amsterdam, 1621). Collection Netherlands Maritime Museum, Amsterdam.

Fig. 9: E. Wright, *Certaine Errors in Navigation*, (London, 1657), titlepage, collection Netherlands Maritime Museum, Amsterdam (inv. no. S.4793(812)). Although this titlepage is taken from an edition 47 years after the second it is similar. Also see: D.W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, (London, 1958), p. 313v.

Fig. 10: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621), pages 11, 12 & 15 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 11: W.J. Blaeu, *Tafelen van de Declinatie* (Amsterdam, 1625), title page, collection Netherlands Maritime Museum, Amsterdam (inv.no. S.4793(250)).

Fig. 12: F.M.C. Dechales, *L'Art de de Naviger, Demontre par Principes & confirmé par plusieurs observations titées de l'experience* (Paris, 1677), p. 65-66, collection Maritime Museum Rotterdam (inv.no. BWAE340).

Fig. 13: J. Moore, *A New Systeme Of The Mathematicks* (London, 1681), p. 244, collection Netherlands Maritime Museum, Amsterdam (inv.no S.4793(688)).

Fig. 14: S. Sanson, Ch.H.A. Jaillot & P. Mortier. *Tome d'Atlas Avec Les Cartes Maritimes*, 1693, collection Maritime Museum, Rotterdam, inv. No.: Atlas60, Title page.

Fig. 15: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 1 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 16: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621), page 11 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 17: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621), page 11 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 18: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 1 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 19: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 1 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 20: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621), page 12 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 21: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621), page 12 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 22: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 2 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 23: W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert'*, (Amsterdam, 1621), page 12 from chapter *'van het gebrvyck deses boecks'* (of the use of this book), collection Leiden University Library.

Fig. 24: Picture by T. Watt, Shetland Museum, Lerwick, Shetland.

Fig. 25: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 1 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 26: A. Jacobsz. Loots-mans Zee-spiegel, 1652, (inv. no. WAE123), page 3 of chapter 24 of section *'Korte onderrightingh in de konst der zee-vaert'*, collection Rotterdam Maritime Museum.

Fig. 27: Screendump by the author.

Fig. 28: Picture by the author.

Fig. 29: Drawing by the author.

Fig. 30: Picture by the author.

Fig. 31: Graph by the author.

Fig. 32: Pictures by A.A. Twisk (1) and the author (2 & 3).

Notes and References

1. N. de Hilster, 'Master Hood's cross-staff: a reconstruction', *Bulletin of the Scientific Instrument Society*, No. 101 (2009), p.10-17.

2. T. Hood, *The use of the Two Mathematicall Instruments, the Crosse-Staffe (differing from that in common use with the mariners:) And the Jacobs Staffe: set forth Dialogue wise in two Treatises: the one most commodious for the Mariner, the other profitable for the Surveyor to take the length, height, depth or breadth of anything measurable.*, (London, 1590).

3. J. Davis, *Seamans Secrets*, (London, 1607), in: A. Hastings Markham, *The Voyages and Works of John Davis, The Navigator*. Works Issued by The Hakluyt Society No.

LIX, (London, 1880), p. 334. Two editions of this book have been examined: the 1607 edition and the 1657 edition available on the Internet from http://www.mcallen.lib.tx.us/books/seasecr/dseasec0.htm, last accessed January 16th, 2008.

4. Hariot's name was spelled in many ways, like 'Hariote', 'Hariots', 'Harriot', 'Harriots', 'Harriott', 'Harriotte', 'Harriotts', 'Harryot', 'Heriott', 'Herriott' and 'Herytt' or in Latin 'Hariotum' 'Hariotus', 'Harrioti', 'Harrioto' and 'Harriotus'.The spelling I use originates from Henry Stevens who was the first to write a biography on Hariot (H. Stevens, *Thomas Hariot, the Mathematician, the Philosopher, and the Scholar*, (London 1900)). Most other spellings can be found as quotations of period letters and works in this work.

5.T. Hariot,'The Doctrine of Nauticall Triangles Compendious',(1594).This manuscript belongs to the Petworth collection owned by Lord Egremont (ref. Petworth House Archives HMC 241/6b) who kindly permitted to have it digitized for my research.

6.The word 'backstaff' is a general term and was derived from the fact that the observer would stand with its back towards the sun. Next to the Davis quadrant and demi-cross the following backstaffs existed: Davis' 45 degree backstaff, Davis' 90 degree backstaff, the *hoekboog ,* the backstaff-quadrant, the plough and Gunters bow. As a response to this development the cross-staff was modified, by which it could serve as a backstaff as well, a modification that would eventually lead to the *spiegelboog* (mirror-staff) that could be used with a mirror or by casting shadows (see: N. de Hilster,'The *Spiegelboog* (Mirror-staff): a reconstruction', in: *Bulletin of the Scientific Instrument Society, No. 90* (2006), p.6.).

7. A wide range of publications on Hariot and his work exist, a bibliography of secondary sources published since 1974 can be found in R. Fox (ed.), *Thomas Harriot, An Elizabethan Man of Science*, (Aldershot, Burlington, 2000), pp. 298-303. A second list with works from before 1974 can be found in J.W. Shirley, *Thomas Harriot, Renaissance Scientist* (Oxford, 1974), pp. 166-174. In addition to these, other works relating to Hariot used for this article are: J.V. Pepper, 'Harriot's Calculation of the Meridional Parts as Logarithmic Tangents', in: *Journal Archive for History of Exact Sciences,* 4, No. 5 (1968). David B. Quinn and John W. Shirley,'A Contemporary List of Hariot References', in: *Renaissance Quarterly*, **22,** No. 1 (Spring, 1969). J.J. Roche,'Harriot's 'Regiment of the Sun' and Its Background in Sixteenth-Century Navigation', *The British Journal for the History of Science*, **14,** No. 3 (Nov., 1981). J.W. Shirley, *Thomas Harriot, A Biography*, (Oxford, 1983). H. Stevens, *Thomas Hariot* (2004 [Ebook 5171]). E.G.R. Taylor,'The Doctrine Of Nauticall Triangles Compendious, I – Thomas Hariot's Manuscript', in: *The Journal Of The Institute Of Navigation ,* **6** (1953). D.W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, (London, 1958).

8. Hariot, 'The Doctrine of Nauticall Triangles Compendious', p. 31.

9. Shirley, *Thomas Harriot, A Biography*, p. 92.

10.T. Hariot, BL Add. MS 6788, fos. 485-9.

11. Taylor, 'The Doctrine Of Nauticall Triangles Compendious...', pp. 134-135.

12. Davis, *Seaman's Secrets*, (London, 1595), pp. 330-334.

13. Taylor,'The Doctrine Of Nauticall Triangles Compendious...', p. 133.

14. Waters, *The Art of Navigation...*, pp. 180.

15. Stevens, *Thomas Hariot*, p. 111**.**

16.Waters, *The Art of Navigation...*, pp. 180, 547, 584.

17. Davis, *Seamans Secrets*, p. 234.

18. Hariot, *The Doctrine of Nauticall Triangles Compendious*, folio 22. Quinn and Shirley,'A Contemporary List of Hariot References', p. 15. Taylor did not mention the bibliography, most probably because at that time it was not yet an integral part of Hariot's manuscript. In her *Doctrine of Nautical Triangles Compendious* she mentioned that Hariot's manuscript consisted of 21 folios. Two years after her article was published the manuscript was bound by Hugh Wyndham, 4th Baron Leconfield, and since then consists of 22 folios, the last of which contains the bibliography. Quinn and Shirley concluded that the bibliography dated from around 1603, but that the value of that indication was not great. When considering the handwriting, inks and pens that were used the bibliography shows remarkable resemblance with other parts of Hariot's manuscript, which were dated positively before 1596 or even 1594 by Taylor, and seems to have been built up over the period he was writing it.

19. Davis, *Seamans Secrets*, p. 330.

20. *Idem,* p. 333.

21. A.A. Metius, *Nieuwe Geographische Ondervvysinge, Waer in ghehandelt werdt de beschryvinghe ende afmetinghe des Aertsche Globe / ende van zijn ghebryck : midtsgaders een grondelijcke onderwysinge vande principale puncten der Zeevaert : inhoudende sonderlinghe nieuwe ghepractiseerde Instrumenten / konstighe practijcken / diversche noodtlijcke Regulen / die alle Pilooten ende Stuerluyden behooren te verstaen*, (Amsterdam, 1621), p. 26. One copy of this book (the 1621 edition, inv.no BWAE340) has been examined in the collection of the Maritime Museum Rotterdam. The 1614 edition is discussed in C.A. Davids' *Zeewezen en Wetenschap, De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 and 1815* (Amsterdam/Dieren, 1986) on page 122 where he refers to the same text and image.

22. F. de Houtman, *Cort Verhael van Frederik de Houtman* (Gouda, 1880), in: W.S. Unger, *De Oudste Reizen van de Zeeuwen naar Oost-Indië*. Werken uitgegeven door de Linschoten-Vereeniging, LI ('s Gravenhage, 1948), p. 64.

23. Waters, *The Art of Navigation...*, p. 232.

24. Houtman, *Cort Verhael van Frederik de Houtman*, p. 77.

25. V.D. Roeper, G.J.D. Wildeman, *Ontdekkingsreizen van Nederlanders (1590-1650)* (Utrecht/Antwerpen, 1993), p. 64.

26. Metius, *Nieuwe Geographische Ondervvysinge....*, p. 26.

27. David's, *Zeewezen en Wetenschap*, pp. 122-123.

27a. A. Haeyen, *Een Corte Onderrichtinge belanghende die kunst vander Zeevaert*, (Amsterdam, 1600). One edition in the Koninklijke Bibliotheek (Royal Library) in The Hague of this book has been examined. It is known as shelfmark 1701 D 20 and is bound together with Simon Stevin's *De Havenvinding* (Haven Finding Art) of 1599 to which it is a response.

28. *Idem*, p. 24.

29. *Ibid.*

30. G. Doorman, *Octrooien voor uitvindingen in de Nederlanden uit de 16e – 18e eeuw* ('s Gravenhage, 1940), G162, p. 136.

31. Haeyen, *Een Corte Onderrichtinge...*, pp. 21-22. The 1598 fleets mentioned by Haeyen departured from the river Meuse (one fleet), which is in the mid-west of the Netherlands, and from the island of Texel in the north (two fleets), while De Houtman and Davis sailed either from Flushing or from Middelburg, which both are towns in Zeeland in the south-west. Also see: W.S. Unger (ed.), *De Oudste Reizen van de Zeeuwen naar Oost-Indië, 1598 – 1604*, ('s-Gravenhage, 1948), pp. 41, 227.

32. W.J. Blaeu, *'t derde deel van 't Licht der Zee-vaert*, (Amsterdam, 1621). Three editions of this book have been examined: two at the Netherlands Maritime Museum in Amsterdam (inv.no. S.1496 and S.2856, both dated 1620) and one at the Leiden University Library, (inv.no. COLLBN Atlas 617, dated 1621). Only the latter showed the demi-cross, while the other showed an astrolabe, a cross-staff and a nocturnal. The English translation of the title is taken from the 1655 edition by Jacob Colom. In his *Zeewezen en Wetenschap. De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 and 1815* (Amsterdam/Dieren, 1986) Davids wrote that the demi-cross was a modified cross-staff and that it could be found in Blaeu's 1620 pilot book, but that was Blaeu actually dated 1621.

33. Two copies of this book have been examined in the collection of the Netherlands Maritime Museum, Amsterdam: the 1625

(inv. no. S.4793(250)) and 1650 (inv. no. A.0750) edition both printed in Amsterdam by Willem Jansz. Blaeu.

34. F.M.C. Dechales, *L' Art de Naviger demontre par principes, et confirmé par plusieurs observations tirées de l'experience.*, (Paris, 1677). One version of this book has been examined in the collection of the Maritime Museum, Rotterdam (inv. No. BWAE340).

35. Dechales, *L'Art de Naviger...*, p. 66.

36. J. Moore, *A New Systeme Of The Mathematicks* (London, 1681), p. 243.

37. *Ibid*, pp. 243-244.

38. Eleven versions of these pilot books have been examined: the 1621 (inv. no. Atlas 617) edition by Willem Jansz. Blaeu, the 1652 (inv. no. WAE123) edition by Anthony Jacobsz., the 1652 (inv. no. WAE089) edition by Jan Jansz., the 1652 (inv. no. WAE083) edition by Pieter Goos, the 1655 (inv. no. Atlas18) edition by Jacob Colom, the 1657 (inv. no. WAE080) edition by Pieter Goos, the 1666 (inv. no. Atlas44) edition by Jacob and Casparus Lootsman, the 1670 (inv. no. WAE086) edition by Pieter Goos, the 1676 (inv. no. WAE101) edition by Jacob and Casparus Lootsman, the 1679 (inv. no. WAE98) edition by Jacob and Casparus Lootsman and an edition by Jacobus Robijn from 1688 (inv. no. Atlas 70). Except for the 1621 edition, which is in the collection of the Leiden University Library, all are in the collection of the Maritime Museum Rotterdam, The Netherlands.

39. N. Sanson, A.H. Jaillot, P. Mortier, *Tome d'Atlas; Avec Les Cartes Maritimes ... Romanus de Hooghe J.U.D. et Com. Reg. tab: hanc suis D. dedit auct. et inv. 1693. ... A Amsterdam Chez Pierre Mortier* (Amsterdam, 1693), title page.

40. Davids, *Zeewezen en Wetenschap*, p. 122, Waters, *The Art of Navigation*, plate LXXI, W.E. May, *A History of Marine Navigation*, (New York, 1973), pp. 127-128.

41. C.A. Davids, 'On the Diffusion of Nautical Knowledge from the Netherlands to North-Eastern Europe, 1550-1850', in: W.G. Heeres et. al. (eds), *From Dunkirk to Danzig, Shipping and Trade in the North Sea and the Baltic 1350-1850*, (Hilversum, 1988), p. 224, 225.

42. *Ibid*.

43. Moore, *A New Systeme Of The Mathematicks*, p. 243.

44. Dechales, *L'Art de Naviger...*, p. 66.

45. Davids, *Zeewezen en Wetenschap*, pp. 120-128, 165-177.

46. J. Lootsman, *Zee-spiegel ofte Lichtende Columne*, (Amsterdam, 1679), p. 17.

47. Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.16-n. 57.

48. Colom, *The Third Part Of The Fyrie Sea-Columne*, (Amsterdam, 1655), sixth page of *A Briefe Sommarie of this Booke.*

49. Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.10.

50. W.F.J. Mörzer Bruyns, *The Cross-Staff, History and Development of a Navigational Instrument* (Zutphen: Vereeniging Nederlandsch Historisch Scheepvaart Museum, 1994), p. 40.

51. *Idem,* p. 35.

52. Colom, *The Third Part Of The Fyrie Sea-Columne*, fourth page of *A Briefe Sommarie of this Booke.*

53. *Idem*, fifth page of *A Briefe Sommarie of this Booke.*

54. *Ibid.*

55. *Ibid.*

56. It can be calculated that the wobble induced error of a cross-staff stays below 1 arc minute if the wobble remains less than 1.5 degrees, which compares to a 1 millimetre play between the staff and cross. The demi-cross exceeds this value as soon as the wobble exceeds 0.02 degrees, which compares to only 0.03 millimetre play between the staff and the cross. From experience I know that in order to slide smoothly a 0.1 millimetre play is about the minimum required.

57. Colom, *The Third Part Of The Fyrie Sea-Columne*, fifth page of *A Briefe Sommarie of this Booke.*

58. *Ibid.*

59. P. Goos, *The Lightning Columne, Or Sea-Mirrour*, (Amsterdam, 1662), p. 6 of *A short introduction, in the art of navigation*. Although most English quotes are from Colom's 1655 English edition. I give this reference as the text in Colom's work contains several spelling and translational errors in this part.

60. Colom, *The Third Part Of The Fyrie Sea-Columne*, sixth page of *A Briefe Sommarie of this Booke.*

61. For this reason Hariot thought that one had to use a quadrant to keep the distance between the vanes equal in order to get a proper observation, as the shadow would then be '*...alwayes of one bignesse...*'.

62. Colom, *The Third Part Of The Fyrie Sea-Columne*, fourth and fifth page of *A Briefe Sommarie of this Booke.*

63. *Idem*, sixth page of *A Briefe Sommarie of this Booke.*

64. *Ibid.*

65. Davis, *The Seamans Secrets*, pp. 330-331

66. Colom, *The Third Part Of The Fyrie Sea-Columne*, sixth page of *A Briefe Sommarie of this Booke.*

67. *Idem*, seventh page of *A Briefe Sommarie of this Booke.*

68. *Idem*, eighth page of *A Briefe Sommarie of this Booke.*

69. *Idem*, fourth page of *A Briefe Sommarie of this Booke.*

70. Mörzer Bruyns, *The Cross-Staff,* p. 102.

71. Colom, *The Third Part Of The Fyrie Sea-Columne*, fifth page of *A Briefe Sommarie of this Booke.*

72. R. Price, K. Muckelroy, 'The Kennemerland', *The Journal of Nautical Archaeology*, **6**-3 (1974), p. 210.

73. Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.8.

74. *Idem,* p.10.

75. Mörzer Bruyns, *The Cross-Staff*, p. 36. N. de Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.12.

76. Dechales, *L'Art de Naviger...*, p. 66.

77. This set comprises of a demi-cross, a cross-staff, a chip log with sand glass and a traverse board.

78. Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.9.

79. *Idem,* p.14.

80. Hilster, 'Master Hood's cross-staff...', pp. 14-15.

81. Hilster, 'The *Spiegelboog* (Mirror-staff)...', pp.13-14.

82. The mariner's cross-staff was used in a backward manner according to the Dutch fashion, with two Dutch shoes attached to the vane.

83. Hilster, 'The *Spiegelboog* (Mirror-staff)...', p.14.

84. May, *A History of Marine Navigation*, p. 23

85. The slit of sunlight is produced by an aperture disk that is slid onto the end of the vane and therefore is not representing the edge of the vane, but the centre of the actual opening between the aperture disc and the vane. This introduces a small error in the instrument as the vane will become slightly longer.

86. Dechales, *L'Art de Naviger...*, p. 71.

87. Both the demi-cross and the mariner's cross-staff have a main body made of a single piece of wood and therefore are susceptible to warping. The observations of the mariner's cross-staff are however less affected by warping than those of the demi-cross. The warp induced error is proportional with the perpendicular distance between the staff and the point on the shadow vane where the measurement is taken. Using a mariner's cross-staff the measurement is taken directly next to the staff. With a demi-cross any warping of the staff will cause the large protruding vanes to misalign, introducing observational errors as a result.

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