The *Spiegelboog* (mirror-staff): a reconstruction

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Introduction

At the end of the 16th century one of the principal instruments for celestial navigation at sea was the cross-staff (Fig. 1 A. The others were the mariner's astrolabe and the quadrant, but thanks to its accuracy (and price compared to the astrolabe) the cross-staff would eventually replace both instruments. The cross-staff is a wooden instrument consisting of a square staff and up to four sliding transoms or vanes. For each vane a scale was engraved on one of the sides of the staff. From the beginning the cross-staff was used for forward observations, so facing the sun. This meant that the navigator had to look into the sun with his naked eye or only protected by a small piece of coloured glass. Measurements were taken by holding the eye-end of the staff next to the eye (against the eye socket horizontally left or right of the eye or on the cheekbone below the eye[1]) and sliding the vane until the lower end 'touched' the horizon and the upper end 'touched' the celestial body. Then the corresponding scale on the staff was read, giving either the zenith angle or the altitude.

The cross-staff was first described in the early 14th century[2] and adapted for use at sea by the Portuguese in the early 16th century.[3] From 1595 onwards variations of the cross-staff were invented known in Dutch as the *hoekboog*, the back-staff, the *crommeboog*, the *knipboog*, the *kruisboog* and the *spiegelboog*.

might lead to confusion in this article. I will therefore refer to the instrument John Davis invented as back-staff and to the 17th century development as Davis Quadrant.

The main difference between the *hoekboog* and the Davis Quadrant was that the scales on a *hoekboog* were engraved on chords while on a Davis Quadrant they were engraved on circle segments. Usually the smaller chord of the *hoekboog* was engraved in 10 degrees intervals while the main chord was engraved down to 15 arc minutes.[7] The Davis Quadrant was usually engraved down to 5 arc minutes and thanks to its diagonal scale, which was engraved every 10 arc minutes and divided in 10 segments, the instrument could be read to one arc minute. The back-staff, *hoekboog* and Davis Quadrant had in common that they allowed navigators to take observations of the sun with their backs turned towards it by casting a shadow on a horizon-vane ('*H*' in Fig. 1) and therefore not blinding the eyes.

One of the last developments that originated from the cross-staff was the *spiegelboog*, a versatile navigational instrument (Fig. 2). The *spiegelboog* consisted of a square staff like the one on the cross-staff, a fixed transom at the eye-end with on it two vanes and a sliding horizon-vane on which a removable mirror was mounted (and therefore also called the mirror-vane). The transom was referred to as *kruis* (cross) and from now on I will use 'cross' to refer to it.

The upper vane on the cross is called 'shadow-vane', the lower one 'sight-vane'. They had fixed positions, enforced by brass pins, by which they can be pre-set at three different distances symmetrically from the staff along the cross. The sliding horizon-vane could then be used with or without the mirror for backward observations. Without the mirror the shadow of the shadow-vane was cast onto the horizon-vane, which had a rectangular hole through which the horizon was seen. With the mirror the celestial object was observed while it was seen over the shadow-vane. The shadow-vane had a square hole by which it could also be used as a transom for forward observations, similar to the use of the cross-staff.

As can be seen from the shape the *spiegelboog* clearly originates from the cross-staff. In his book *Seamans Secrets* John Davis not only described the back-staff as a development of the cross-staff, but also a cross-staff with a single transom on which two vanes were mounted (Fig. 3 B).[8] This cross-staff, complemented with a horizon-vane, can be found on the front page of the navigational book *Stiermans Gemack* written by Joost van Breen in 1662 (Fig. 3 C). Yet, this is not a *spiegelboog* because the staff protrudes from the transom which was not possible with a *spiegelboog*. The transom was modified, by closing the hole (by which it became the cross) and adding an adjustment screw. Finally a mirror was added in order to make it a *spiegelboog* (Fig. 3 D).

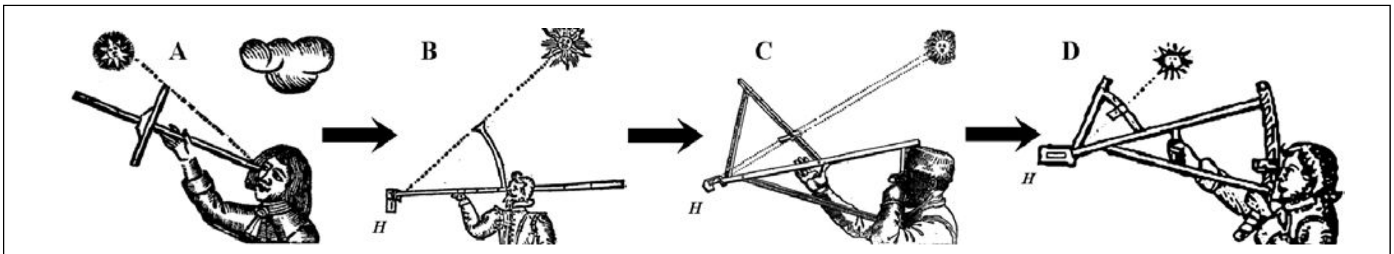


Fig. 1 *Evolution of the back-staff.*[4]

Little is known of the *crommeboog*, the *knipboog* and the *kruisboog*, most probably because they were not widely used. The *hoekboog* (Fig. 1 C) was a development based on the back-staff described by John Davis in 1595 in his book *Seamans Secrets* (Fig. 1 B). In the 17th century the *hoekboog*, cross-staff and astrolabe were regarded the instruments most suitable for taking observations at sea.[5] The *hoekboog* was probably not as widely used as the cross-staff, but in its later form as Davis Quadrant, developed in the mid 17th century, it was widespread (Fig. 1 D).[6]

The later developed Davis Quadrant (which was also called 'English Quadrant') was - and still is - referred to as back-staff, which

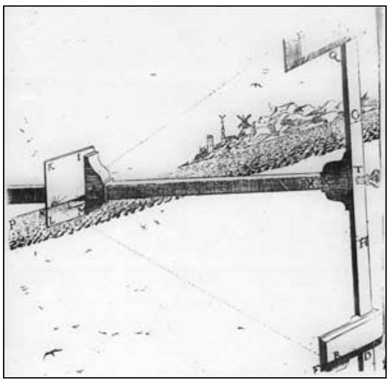


Fig. 2 *The spiegelboog, by courtesy of Leiden University Library.*

The *spiegelboog* had a number of advantages over the period instruments. Although it was possible with the back-staff to measure a bright sun backwards, measuring a weak sun was not until about 1670 when John Flamsteed introduced the lens in the shadow-vane.[10] By using a mirror, the *spiegelboog* made it possible to take a back sight of a weak sun in a hazy sky and in addition to that to take back sights of stars. The *spiegelboog* was the only navigational instrument with which star observations could be taken backwards before the invention of the octant in 1731. Furthermore the *spiegelboog* could be used without the mirror for taking back sights of a bright sun and for forward observations when the celestial body would be too low above the horizon to be measured backwards, in which case the observer's head would simply block the

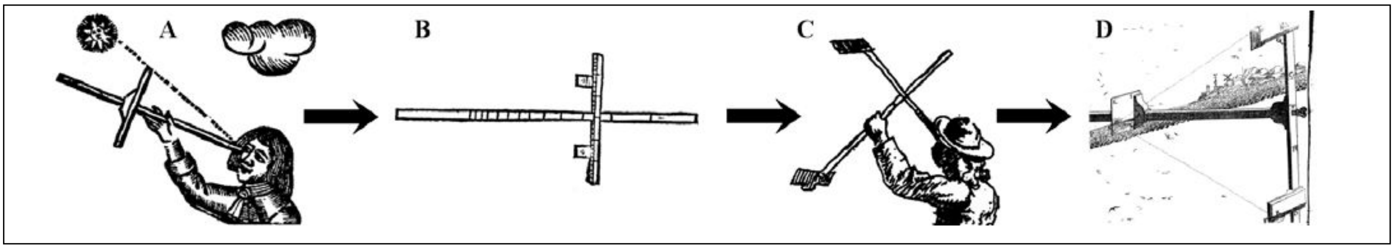


Fig. 3 *Evolution of the* spiegelboog.[9]

Fig. 4 *The author with the* spiegelboog *reconstruction set up for bright sun observations.*

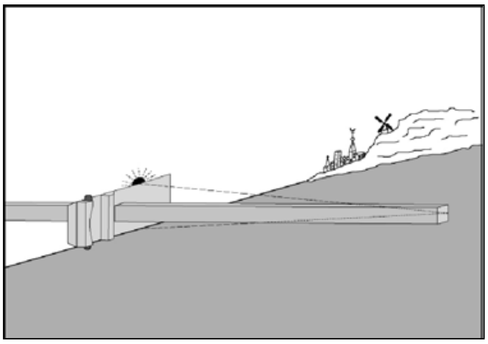


Fig. 5 *The shadow-vane in use as a transom (drawing by the author).*

sight on it.

Using the horizon-vane the instrument was held with the sight-vane just above the eye (Fig. 4). A brass aperture attached to the lower side of this vane (Fig. 17) forced the observer to look through a narrow slit between the lower edge of the sight-vane and the aperture towards the horizon hence improving the quality of the observations. When using the mirror on the horizon-vane the observer had to position the reflected image of the sun next to the horizon, therefore measuring the middle of the sun. As said the mirror was used for weak sun observations, but those who preferred to use the mirror at all times could do this with the aid of a piece of coloured glass as a protection for the eye. When used without the mirror the horizon-vane had to be positioned in a way that the upper edge of the hole in it would 'touch' the horizon while the upper edge of the shadow cast by the shadow-vane coincided. A horizontal line was drawn across the upper edge of the hole in the horizon-vane as an aid for this type of measurement. In order to get a proper observation the observer had to be sure that he would position the *spiegelboog* perpendicular to the horizon. When used with the mirror the observation had to be done as close to the left edge of the mirror as possible, while when using the *spiegelboog* without the mirror one had to be sure that the shadow of the cross coincided with the block on the mirror-vane through which the staff runs.

When the *spiegelboog* was used with the shadow-vane as a transom (Fig. 5) the *spiegelboog* was held next to the eye just as a normal cross-staff and observations were taken in the same way, but in contrary to the cross-staff the width of the vane served as a reference, not the length. So instead of holding the transom perpendicular to the horizon it was now held parallel to it, with the lower side 'touching' the horizon and the upper side 'touching' the celestial object.

The *spiegelboog* was invented by the Dutchman Joost van Breen in 1660 and described by him in his navigational manual titled *Stiermans Gemack, Ofte een korte Beschryvinge vande Konst der Stierlieden* ('Helmsman's Ease, Or a Short Description of the Art of Helmsmans') (Fig. 6), that appeared in 's Gravenhage (The Hague), in 1662. *Stiermans Gemack* is in fact a course in navigation and covers all aspects as known in the mid-17th century. Chapter 13 starts with the patent he had on the instrument, and is followed by an eight-page explanation in seven propositions of the mirror, emphasising that this was a novelty. Then he continues to describe the shape of the instrument, including a full page semi-three dimensional drawing, followed by an elaborate description of its use as described above. The twenty pages chapter ends with the description and results of a trial he and two navigators did with the *spiegelboog* while comparing it to two contemporary instruments, the cross-staff and the Davis Quadrant (he calls it a peculiar English quadrant). It is this 13th chapter of his book that served as the main source for my research on the instrument.[11]

Patents

In 1660 Van Breen was given a patent for his 'newly invented cross-staff'[12] which he named *spiegelboog* after the mirror (*spiegel* in Dutch) that was the innovative part of the instrument. The use of a silvered glass mirror, 71 years before Hadley invented his double reflecting octant in 1731[13], made this the first navigational reflecting instrument. Between 1660 and 1731 only two other instruments using glass mirrors were invented, but never came into production. These were a single reflecting instrument by Robert Hooke in 1666 and a double reflecting instrument by Sir Isaac Newton in 1699.[14] Despite Van Breen's innovative step only few people know about its former existence, probably because most written sources on the instrument are in (period) Dutch and, as far as is known, not a single instrument survived.

In the 17th century the use of high quality glass mirrors was not common practice in the Low Countries. Although glass mirrors had been produced in Holland as early as the 14th century, these convex mirrors were made of forest glass, a thick and slightly greenish-tinted glass, that was blown into spheres and lined with lead[15] and therefor not suitable for an instrument like the *spiegelboog*. The invention of an alloy of quicksilver to produce mirrors, in Flanders, in 1500 and the invention of the use of soda to produce lighter and thinner glass by the 15th century Venetians resulted in the production of crystal glass mirrors in the 16th century.[16] By 1570 crystal glass mirrors were produced in Venice, Antwerp and Rouen.[17] The high quality of reflection of those new mirrors made them both wild-

STIERMANS
GEMACK,
Ofte een korte Beschryvinge vande
Konst der Stierlieden.
Daer in alle Voorstellen ('t sy deselve voorvallen in de Cromstreecx Rekeninge, ofte inde Clootse Werckstucken seer duydelijck ende gemackelijck (door toebereyde Tafelen, in klare getallen, sonder eenige calculatie werden opgelost, tot groote verlichtinge voor den Stierman inde dagelijckse practijcke, ende oock de aenkomende Leerlingen inde Rekenkonst niet wel ervaren synde, als mede voor die geene die de fondamenten der selver konst in 't korte soude trachten te begrypen.
Mitsgaders
De Beschrijvinge en 't gebruyck van een nieuwe geinventeerde Graetboog, daer mede men by nacht de Sterren van achteren mach schieten, en oock by dage de Son, schoon hy geen schaduwe en geeft, maer datmen hem alleen flaeuwelijck sien mag, tot groot gerijf voor den Zeeman.
Alles gecalculeert en geinventeert door
IOOST van BREEN van 's Gravenhage,
Liefhebber der vrye Konsten, eertyts by der zee gevaren hebbende, ende nu bedienende 't Equipagemeesterschap van hare Ed. Mog. ter Admiraliteyt in Zeelandt tot Middelburgh, ende mede Schips Tekger ende Wyntoeyer aldaer.
In 's Graven-Hage, gedruckt by Iohannes Rammazeyn,
Voor Ioost van Breen en Iohannes Tongerloo, Boeckverkooper in 's Gravenhage, 1662. Met Privilegie voor vijfthien Iaren.
Dese Boecken zijn by Ioost van Breen en Iohannes Tongerloo, met haer eygenhant onderteyckent.
Joost van Breen Johannes Tongerloo

Fig. 6 *Joost van Breen's title page of* Stiermans Gemack, *1662, collection of the Netherlands Maritime Museum, Amsterdam.*

ly popular and widely sanctioned.[18] For the puritan Thomas Salter, writing his *Mirrhor of Modestie* in 1579, the glass mirror is so negatively identified with worldly pride that it can in no wise evoke the celestial spheres, least of all in its glassy surface.[19] Eighty years later Van Breen put one on his *spiegelboog* in order to observe the stars for celestial navigation. Another five years later a patent on producing high quality (crystal) glass mirrors in the Low Countries was given for the period of 25 years to Dirck van Cattenburgh, merchant and citizen of Amsterdam.[20] The mirrors he produced were stated as being better on average than the best ones produced in Italy.[21]

Use and Diffusion

From literature, ship's logbooks and archives it is known that the *spiegelboog* was in use during at least 100 years, mainly in the Zeeland Chamber of the VOC (the Dutch East India Company). [22] Although it was not as widespread as the cross-staff, the *spiegelboog* was widely used among Dutch seafarers. In 1737 Dirk Kruik, examiner of the mates of the Rotterdam Chamber of the VOC, mentioned the *spiegelboog* as one of the suitable instruments for navigation.[23] It has been depicted on several versions of a printed illustration called *Het Volmaakte Schip* (The Perfect Ship).[24] Most of the versions of this print are in Dutch, but a French and a German version are known as well, which means that the instrument has been known abroad. More than a century after its invention and more than 40 years after the invention of the octant, the *spiegelboog* could still be purchased in 1777 at the Amsterdam firm of Van Keulen[25], map and instrument makers for more than two centuries.

The reason that the *spiegelboog* was mainly used on the ships of the Zeeland Chamber of the VOC can be explained. Van Breen lived in Zeeland in the city of Middelburg[26], and had contact with the Directors of the VOC, the *Heren XVII*. In 1662 Van Breen was *Equipage ende Amonutie-meester* (an administrator of goods, supplies and ammunition for the vessels) of the Admiralty of Zeeland[27] and in 1665 he requested the *Heren XVII* to supply the ships on the route to Asia with his book and instrument. The latter was examined by Joan Blaeu, VOC chart maker and examiner of the mates of the Amsterdam Chamber of the VOC. The result of the examination was positive and in 1668 it was decided that the Chambers were allowed to provide the *spiegelboog* to their ships, if they wanted to.

In 1669 a conflict arose between the Zeeland Chamber and the same Joan Blaeu over the bill for navigational charts of 21,135 Dutch guilders for the year 1668 (almost enough to buy two 85-foot ships[28]). The Zeeland Chamber searched for an alternative supplier of charts and ended up with local chart makers Arent Roggeveen and Joost van Breen.[29] Before 1670 Roggeveen and Van Breen were appointed examiners of the mates of the Zeeland Chamber[30] (around this time Van Breen was appointed *Equipagemeester* of the Zeeland Chamber as well[31]). In 1670 the *Heren XVII* took the initiative to have a committee check the list of books, maps and instruments supplied to the ships for any improvements. This committee consisted of a number of captains, an external expert and the examiners of the mates of the Amsterdam and Zeeland Chamber[32], the latter being Van Breen. It was this same year that the use of the *spiegelboog* was strongly approved.[33]

According to the patent Van Breen had the exclusive right to produce the instruments for the first 15 years.[34] But did Van Breen produce them himself or did he only make a prototype just like Hadley did with the octant? Although Van Breen is not known as an instrument maker there are some indications that he did make the instruments or was at least closely involved in the process. In his book he states that he signed all the instruments himself on the upper edge of the mirror, by using a diamond. The horizon-vane too was signed by him, although the exact location leaves room for interpretation. Furthermore he writes about 'we' every time he refers to the persons that made the instruments. In addition to that Van Breen is known to have invented an instrument to 'copy all kind of objects' and a 'wagon that could be driven without being pulled' in 1657.[35] A 1753 auction catalogue of the library of the Middelburg doctor Gerardus de Wind included three *Circulus Astronomicus* signed 'J. van Breen'.[36]

But even if he were an instrument maker, would Van Breen have enough time to produce these instruments for all the Zeeland Chamber ships during these 15 years next to his functions at the VOC? Or would he have had a workshop or a department within the VOC that produced the instruments? Perhaps future research will reveal documents on this and until more evidence is found it will remain uncertain whether or not he did produce them himself. Uncertain too is whether or not a *spiegelboog* survived, as until now none, or even parts have been identified.

Why Make A Reconstruction?

The idea to make a reconstruction of the *spiegelboog* came to me after reading Mörzer Bruyns' conclusion in his book *The Cross-staff* in which he suggests '…a study (…) [of] the various staffs for navigation of which no examples survive'.[37] And apart from the fact that I wanted one for my collection of navigational instruments, people involved in researching navigational instruments, like archaeologists and curators, would like to see one as the reconstruction can tell them how the instrument worked and help to recognize parts when found.

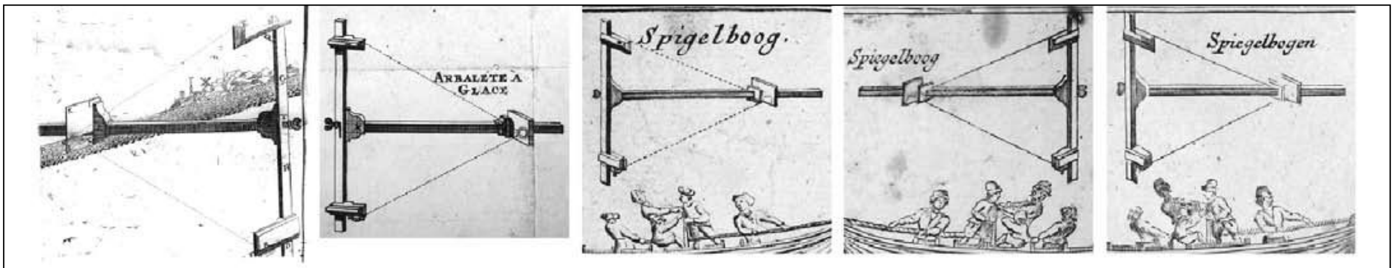
In addition to that a reconstruction can also serve in research on accuracy of early navigational instruments to give an idea on how accurate the positions were that were derived in those early days. In 1983 Forty wrote that 'it is surprisingly how little practical work appears to have been done on the accuracy of early instruments'.[38] This remark certainly was, and still is, justified. The importance of practical work can be understood from an article written in 1974 by Price and Muckelroy, who had their reservations about a part of a *hoekboog* found in the wreck of the Dutch VOC ship *Kennemerland*, because the graduation with 15 arc minutes intervals was less than they expected.[39] During my research on the *spiegelboog* a Dutch description of the *hoekboog* turned up confirming the graduation as found on that particular find.[40] Only a few publications on practical measurements are known ever since, like a recent one on the astrolabe.[41] Further on in this article a report is given on the *spiegelboog* in comparison to the cross-staff and Davis Quadrant, with measurements taken back in 1661 by Van Breen and in 2005 and 2006 by the author.

As already mentioned no *spiegelboog* survived, but we cannot be 100% sure of that. Over the years the former curator of the Netherlands Maritime Museum in Amsterdam, Willem Mörzer Bruyns, tracked down as many as possible surviving cross-staffs. With his latest article on the cross-staff published in 2004 his count stopped at 124 staffs[42], but many are incomplete. A lot do not have the original vanes or no vanes at all. Some of them are just fragments of a staff. It is well possible that some of these incomplete staffs once were part of a *spiegelboog*, but as the staffs look quite identical it is hard to distinguish them. Making a reconstruction might solve this problem.

Contemporary Sources

As Van Breen describes the use of the *spiegelboog* in detail, his book proved to be invaluable in the research for this instrument as it contains both direct and indirect descriptions by which it has clues to virtually every aspect of the instrument. As described in the paragraph 'Use and diffusion' other contemporary sources tell us that it was used on board, that it was suitable for navigation and until when, by whom and at what price it was sold for.[43]

Van Breen's book also contains a detailed large size drawing (Fig. 7 A) of the instrument. The only other depictions that I have found so far are on several versions of *Het Volmaakte Schip* which date from between approximately 1688 and 1724 and that were published separately or in atlases like *De Nieuwe Groote Ligtende Zee-Fakkel* by Van Keulen in Amsterdam.[44] Fig. 7 shows the original drawing by Van Breen and the four different versions of *Het Volmaakte Schip*, of which I have found nine



A) Van Breen, 1662 B) Unknown, app. 1688 C) Mortier & Covens, app. 1700 D) Schenk, app. 1700 E) Homann, app. 1720

Fig. 7 *Depictions of the instrument.*[45]

examples. The most recent version of the print I could find was signed by Johann Baptist Homann, a German geographer and engraver in Nuremberg from 1702 until his death in 1724.

Although much smaller than the original by Van Breen, the *Het Volmaakte Schip* depictions are still interesting. By comparing the whole print and details, it is possible to determine how many different copper plates were used to produce the nine prints and in which order they have been copied.[46].One of those details is the block of the cross of the *spiegelboog* on which a 'X' was drawn. This 'X' was to ensure proper mounting of the cross on the staff (on which a 'X' was drawn as well). The original print by Van Breen shows this 'X' and so does the oldest print of *Het Volmaakte Schip* (Fig. 7 B).The original by Van Breen also shows the hole in the shadow-vane, which is deformed to a slit on print 'B' and still visible on print 'C', but print 'C' no longer shows the 'X'. The sight lines on the original and prints 'B' and 'C' are dashed, but on the last two prints they have become solid. The shape of the adjustment screw deteriorates over the versions and compared to all the other prints version 'E' is the least in quality in general.

So the quality and details of the prints deteriorates over the years, but on print 'C' a new detail is shown. On this version the aperture on the sight-vane has a small handle. It is known that the aperture was mounted in a way that it could be turned away behind the sight-vane. This handle was either an extra help to do this, or it was an interpretation error of the engraver while copying this from a previous, yet unknown, version of the print. If genuine, the handle indicates that the instrument was still developing over the years.

Validating The Drawing By Van Breen

As the article will get more technical from here on it will be necessary to introduce another definition in order to minimize confusion. On a cross-staff the vanes have different lengths, the so called 'vane lengths'. On a *spiegelboog* the 'vane length' is defined by the distance between the positions of the shadow and sight-vane on the cross. There

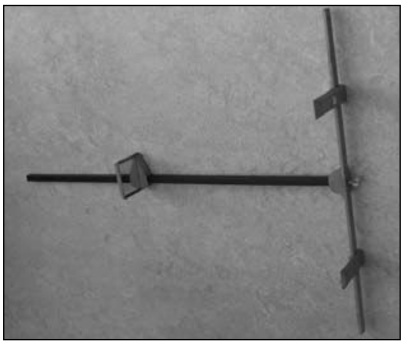


Fig. 8 *The reconstruction.*

are three different vane lengths, which are defined by the distance between brass locking pins. I will refer to these vane lengths as 'vane settings'.

The reconstruction (Fig. 8) looks like the drawing Van Breen made 350 years ago, but it was not that drawing that I relied on in the first place when I started my research on the instrument, because the drawing looks a bit odd with its strange perspective and slanted horizon.

So I examined his text and only used the drawing when it was referred to. One of the first indications of size and scale was the remark that the instrument could not be used when the altitude of the celestial body was below 10 to 12 degrees as the observer's head would block sight on it.This single remark told me that the staff would not have a scale for backward observations lower than 10 degrees and that, with the smallest vane setting, I should be able to see my own head in the mirror.

Measuring the height of my skull above my eyes I found approximately 110 millimetres.This is a direct indication for both the length of the staff and the distance of the smallest vane setting. In Van Breen's drawing I found 54 millimetres for the smallest vane setting, roughly half the size measured on my skull. Other measures in Van Breen's drawing, like the width of the staff of 13 millimetres as used in the 17th century[47], confirmed this 1:2 scale. Even the perspective was not arbitrary, but came out at a 1:3 scale, making the vanes similar in length to those found on Davis Quadrants.[48] So the drawing looks quite odd, but it is to scale.

Fig. 9 *Den Wynroeyer (Wine gauger).*

Another reason to believe that his drawing must have been to scale is his connection with Arent Jansz. Roggeveen, his associate chart maker.[49] If anyone should have been able to, or explain how to, create a scale drawing it must have been Roggeveen.

Local Measures That Define The Instrument Dimensios

In Zeeland two of the old local measures used are the '*Goesse Voet*'[50], named after the city of Goes which is near to Middelburg where Van Breen lived, and the '*Wynroeyers Voet*'.[51] They both measure about 289 millimetres and being a *Wynroeyer*[52] (Fig. 9, Wine Gauger, a civil servant who measures the contents of wine barrels in order to determine the amount of tax due), Van Breen must have been familiar with this measure. One *Goesse Voet* was divided in 12 *duim*, making a *duim* about 24 millimetres. Multiplied by four and a half this gives 108 millimetres, exactly twice the measure found for the smallest vane setting in Van Breen's drawing. In this way quite some measures in Van Breen's drawing can be found that could easily be made using this 24-millimetre *duim*, by dividing it in halves, quarters etc.

The Instrument Dimensions

As the drawing by Van Breen does not show the complete instrument, the length of the staff needs to be estimated. With the 108

Fig. 10 *The upper end of the cross of the reconstruction showing one of the pins and the corresponding scale number.*

millimetres found for the smallest vane setting the length can be calculated, assuming that the staff would not have a corresponding scale beyond 10 degrees. The length (*L*) of the staff can be calculated from half the vane length (*b*) and half the smallest angle (α):

$$L_{staff} = \frac{b}{\tan(\alpha)} = \frac{54}{\tan(5)} = \frac{54}{0.0875} = 617.2mm$$

Although a bit short this size still fits well within sizes given for cross-staffs in contemporary navigational manuals shortly after the invention of the *spiegelboog*.[53] These 617 millimetres are the minimum required to get a 10-degree reading, but you need a bit more length in order to keep the mirror-vane on the staff instead of falling off at 10 degrees. The ebony I ordered came at 742 millimetres in length and I decided not to shorten it for this reason

The length of the cross had to be estimated as well. Just like the staff the cross is not shown completely in Van Breen's drawing. From research on cross-staffs it is known that the largest vane was usually smaller than the length of the staff. For many of surviving cross-staffs the ratio of the four vanes and the staff is 1 : 2 : 4 : 6 : 9[54], meaning that the largest vane would measure 66% of the staff. In Van Breen's drawing only the two smallest vane settings on the cross are shown (these make the second and third 'vane' of the *spiegelboog* as the shadow-vane is the first when used as a transom). The largest of the two is triple the size (324 millimetres) of the smallest. So instead of having a 2 : 4 ratio Van Breen shows a 2 : 6 ratio for these two vane settings. Assuming a 2 : 6 : 10 ratio for the third vane setting not only gives a nice equally divided cross, but also makes the cross almost two *Goesse Voet*. In addition to that a 2 : 6 : 12 ratio would make the cross too long (648 millimetres), while a 2 : 6 : 8 ratio would not add much to the capabilities of the instrument as the scales of the two largest vane settings would then have too much overlap. As the cross has small pins to give the vanes a fixed position along it, it has to be a bit longer than this 5 x 108 millimetres. When two *Goesse Voet* long, it not only holds the pins for the largest vane setting but also gives the ends nice proportions as can be seen in Fig. 10.

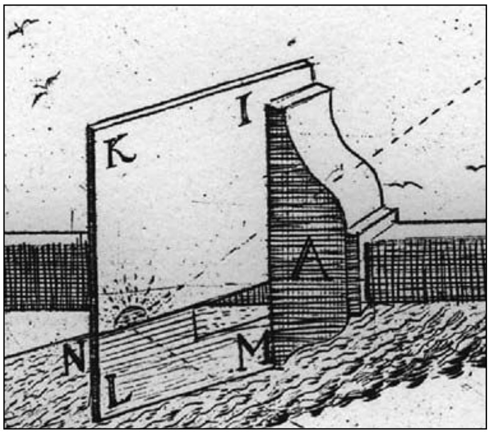


Fig. 12 *The mirror-vane according to Van Breen, by courtesy of Leiden University Library.*

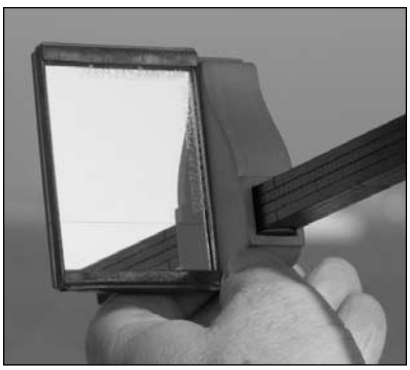


Fig. 11 *The mirror-vane of the reconstruction with the mirror attached.*

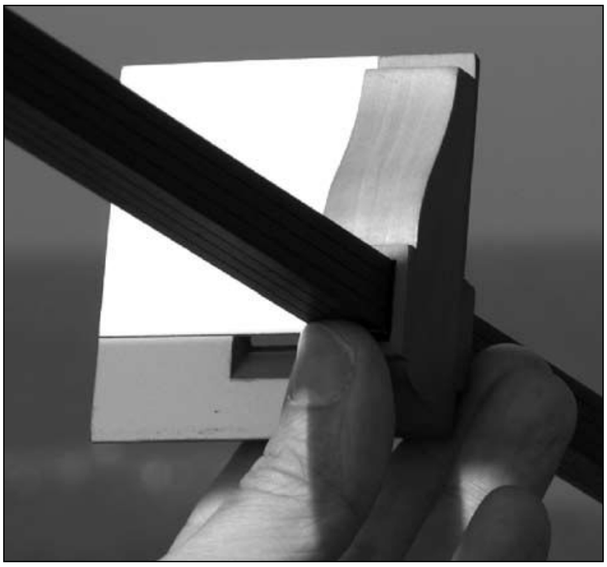


Fig. 13 *The mirror-vane of the reconstruction with the mirror removed.*

The Mirror-vane

One part of the drawing however proved not to be an accurate depiction of what Van Breen made. In retrospective it is not surprising that this concerns the mirror-vane (Fig. 11). As Van Breen had the privilege for 15 years, he might have been not too keen in sharing his invention other than by selling it, and was therefore reluctant to show the mirror-vane in great detail in a book. But as one could purchase the instrument in order to make a copy, a more plausible reason why he simplified his drawing of the mirror-vane was an economical one: he wanted to explain the whole instrument using one drawing only, although the mirror-vane has two different functions.

In the drawing (Fig. 12) a mirror-vane can be seen with a clear reflection of the shadow-vane and the sun. Also a rectangular hole is shown, through which the staff can be seen. Reading Van Breen's book it becomes clear that the hole is in the vane, and not in the mirror. This means that what is shown in the drawing is the combined use of the mirror-vane with and without the mirror. When the mirror is in place, observations had to be taken as close to the left edge of the mirror as possible, but when used without the mirror (for bright sun observations using shadows) observations had to be taken on the right side of the hole in the mirror-vane (this is when the shadow of the cross would coincide with the block on the horizon-vane, just as Van Breen described). The first time Van Breen mentioned the hole in the mirror-vane is when he explained that the mirror can be removed, after he had explained the use of the instrument with the mirror in place. He wrote that once you remove the mirror you will have the mirror-vane covered with paper with a hole in it. This remark clearly tells us that the mirror had neither a hole nor a clear part in it. Also the remark that mirror observations had to be taken as close as possible to the left edge indicates that there was no clear part or hole in the mirror as otherwise he would have suggested to take the readings closer to the block.

The paper on the surface behind the mirror of the mirror-vane (Fig. 13) probably served to get a better contrast when measuring a bright sun by casting shadows, for that same reason bone or ivory was used in the horizon-vane of cross-staffs.[55] A line was drawn on the paper over the whole width of the vane, along the upper side of the hole in it. This was the reference line on which the shadow of the shadow-vane and the horizon should coincide.

Fig. 14 *The mirror of the reconstruction as seen from the rear.*

Van Breen does not describe how the mirror was attached to the vane. The only clues he gives are the remarks that the mirror can be *slid onto* and *taken from* the mirror-vane, so that the clamping mechanism appears to be on the mirror, and not on the vane because in that case the mirror had to be *slid into* and *taken out off* the mirror-vane. From the 1650s cross-staffs were fitted with the so-called Dutch Shoe or aperture disk.[56] These also slid onto the vane, so I designed the clamping mechanism of the mirror accordingly, by adding a copper frame to the mirror (Fig. 14) that would hold the mirror-vane from below and above.[57] Seen from the front, the frame is built in the same way as on early octants, allowing the observer to take readings as close to the mirror's edge as possible, just as described by Van Breen.

He also writes that removing the mirror should not be done too often as it might damage the silvered layer. This tells us that the back of the mirror was not protected by the frame that holds it, but only by the mirror-vane.

For night-time observations the observer had to carry a light or candle in order to set the mirror-vane roughly to the proper altitude. When no light was available the mirror-vane could be set by observing the star in a forward manner first, with a reversed instrument, e.g. by looking over the shadow-vane from the mirror-vane. Then the observer could turn around and observe the celestial body in a backward manner.

The Shadow-vane

The shadow-vane (Fig.15) was not only used to cast shadows when measuring a bright sun, but also as the reference when observing celestial bodies with the mirror and for forward observations when the celestial body's altitude was below 10 degrees. For backward observations the vane was clamped on the cross using a brass spring (Fig. 16 shows the brass spring and the nail that holds it), by which it could slide along the upper half of the cross, similar to the vanes of Davis Quadrants. Small brass pins in the cross were used to ensure fixed positions of the shadow-vane at all times.

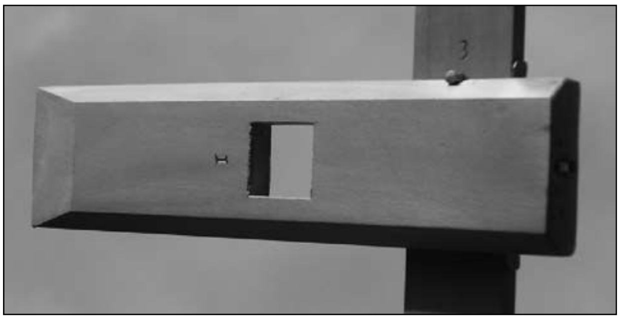


Fig. 15 *The shadow-vane of the reconstruction on the cross.*

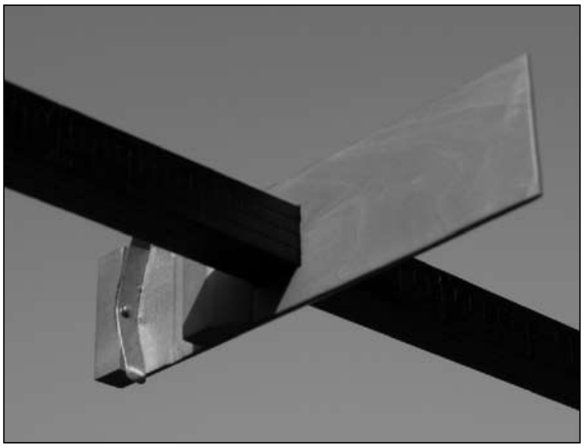


Fig. 16 *The shadow-vane of the reconstruction in use as a transom.*

A square hole in the shadow-vane allowed it to slide over the staff like a transom of a cross-staff. This was used for forward observations when the celestial body would come below 10 to 12 degrees. When using it in this way the width, not the length, of the vane was used as reference (Fig. 5).

The Sight-vane

The sight-vane (Fig. 17) was similar to the shadow-vane, but a bit shorter and instead of a hole the sight-vane had a brass aperture with a narrow slit through which the horizon and horizon-vane could be seen. The aperture could be turned away to make it easier to locate the object of observation. Once found the aperture was returned to its position for the observation, ensuring a more accurate observation.

For the sight-vane also three brass pins were available to slide it against, ensuring fixed positions for it as well.

Graduation

In his book Van Breen clearly describes that the staff was graduated on all four sides. The first side, numbered 1, was used in combination with the shadow-vane for forward observations, just like a cross-staff. The other three sides, numbered 2, 3 and 4, were used in combination with the mirror-vane for backward observations with or without the mirror. The number 2 scale was used in combination with the smallest vane setting, number 3 with the middle one and number 4 with the largest.

Van Breen does not say at what intervals the scales were graduated, but from surviving period cross-staffs it is known that they were graduated to 10 arc-minutes.[58] The scales were most probably stamped with digits for both altitude and zenith distance as was usual on period cross-staffs.[59] He does mention that as long as the scales allowed for it the smallest vane setting should be used. So for some reason the scales could not be read all the way towards the cross or eye-end. This could either mean that the scales were not fully engraved towards the eye-end, or that, with exception of side four, for larger altitudes only the whole 10 degree marks were engraved. Both ways of engraving are known from surviving cross-staffs next to fully engraved scales. The reconstruction has fully engraved scales starting at 90 degrees altitude on all sides.

Materials Used For The Reconstruction

The woods chosen for the reconstruction are pear wood for the cross and vanes and ebony for the staff as these were commonly used in contemporary cross-staffs.[60] Van Breen does not mention the materials he used, but mentions that when the staff was warped one could straighten it by wetting and twisting it by hand and let it dry in the sun while holding it. Tests done with a warped ebony staff in my workshop revealed that this does not work with ebony, even when applying mechanical force for several hours, so it might be that Van Breen used a different kind of wood for the staff.

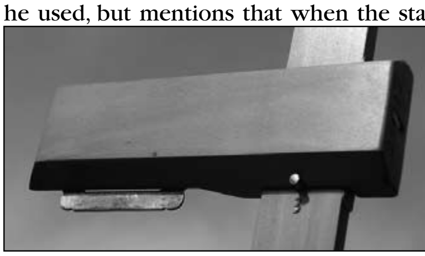


Fig. 17 *The sight-vane of the reconstruction with the aperture at pin number 3.*

The mirror of the reconstruction is made of modern 4 millimetres thick mirror glass

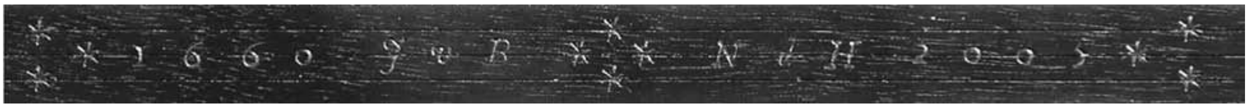


Fig. 18: *The signature on the reconstruction.*

and in thickness similar to mirrors found on octants and sextants. Although Van Breen does not mention the actual thickness he does mention that this can vary. At that time silvered glass mirrors could be made as thin as just under two millimetres as an archaeological find from the wreck of the Royal ship *Kronan* in Sweden revealed.[61]

For the mirror-frame and the aperture copper is used, but most probably Van Breen used brass like other instrument makers did on octants and sextants. In his book Van Breen mentioned copper as material for the aperture, but copper and brass were often used as a word for the same material. From aperture disks and springs found on original cross-staffs and Davis Quadrants it is known that they were made of brass. The other metal parts on the *spiegelboog* reconstruction (springs, pins and adjustment screw) are made of brass.

Finally, like on the original, paper is glued behind the mirror on the mirror-vane for higher contrast.

Signature, Marks And Decorations

As described above, Van Breen signed his instruments on at least two different places: on the mirror and on the wood behind the mirror. The manner in which he did this can be derived from his books. Along the upper edge of the mirror he engraved his name as *'Joos van Breen'* by using a diamond. On the wood behind the mirror he would sign the instrument as:

JOOS van BREEN,

voor

JOHANNIS TONGERLOO

Stiermans Gemack itself too was signed by Van Breen, and by Johannis Tongerloo, the publisher. On the book and the instrument he spelled his first name without the 't'. It can therefore be expected that Van Breen signed his staffs similarly, although it is known that period cross-staff makers not always signed their staffs the way they wrote their imprints in their books.[62]

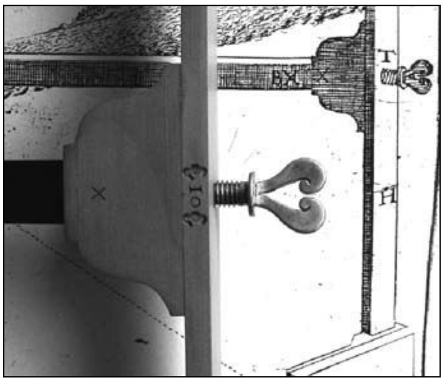


Fig. 19 *The adjustment screw, left the reconstruction, right according to Van Breen.*

Van Breen mentions that he marked the cross and the staff with a 'X' to ensure proper assembly of the instrument (Fig. 19) and with two parallel lines perpendicular to the staff near the eye-end of the staff as reference for the adjustment of the cross. The sides of the staff were marked with the side numbers near the eye-end with '1' being the smallest vane and '4' the largest, this in contrast to most cross-staffs.[63] Any other decorations are not mentioned.

To make sure the reconstruction can be recognized as non-original I signed the staff with both Van Breen's as well as my own initials on side 4 (Fig. 8).

In addition to that I marked the eye-end of the staff, the vanes and the cross with the instrument number in between two seahorses (Fig. 19).[64]

On the reconstruction the mirror is engraved with 'Joos van Breen 1660' along the upper edge and '2005 Nicolàs de Hilster' along the right edge, but now with a rotating engraving tool. The mirror-vane itself is not signed on the reconstruction as it is not clear were exactly that was done by Van Breen.

Calibration

Not only was the *spiegelboog* the first navigational instrument with a glass mirror, it also was the first one that could be calibrated by means of an adjustment screw (Fig. 19). The use of a single mirror immediately introduced a parallax, or as he described himself, the glass caused the silvered layer to be elevated like watching the bottom of a tub filled with water. And although he does not go into detail he writes that there are more hidden things than only that (of which I could only find one so far).

Near the eye-end two parallel lines are drawn perpendicular to the staff. Van Breen explains that, when using the mirror, the adjustment screw had to be turned until the cross aligned with the line closest to the eye-end and when used without the mirror the cross had to be aligned with the other line. One of the, and as far as I know the only, hidden things Van Breen mentioned, is that the parallax varies with the angle of

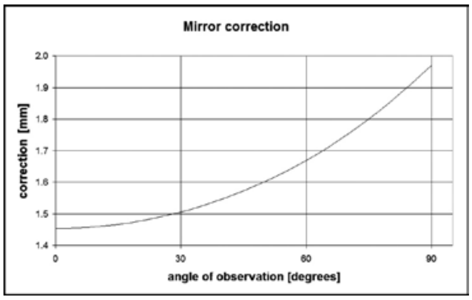


Fig. 20 *The influence of the observation angle on the mirror-correction.*

observation, but the variation of the parallax within the working range of 10 to 90 degrees is that small that he neglected it. The difference in correction for the glass used in the reconstruction varies from 1.46 millimetres at 10 degrees to 1.97 millimetres at 90 degrees (Fig. 20).[65] As the graduation intervals become larger at smaller

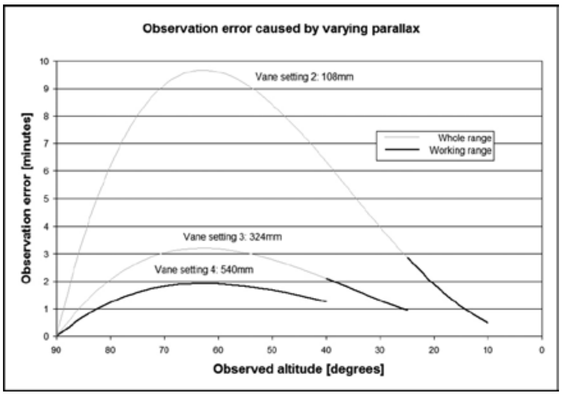


Fig. 21 *The observation error.*

angles the reconstruction is calibrated for the 90 degree observation. In this way the influence of the half millimetre difference along the staff between 10 and 90 degrees is minimized as can be seen in Fig. 21.

The graph shows that the influence of the parallax is minimized when the longest possible vane setting is used for the observations. Van Breen, however, did not realize this as he wrote that for the observations always the shortest possible vane setting should be used. A thinner mirror also helps to minimize the parallax, as half the thickness results in half the error, but Van Breen did use mirrors of varying thickness. When calibrating for 75 degrees an even better optimisation can be realized, as the error will then be between plus or minus two minutes. Along the main range from 25 to 75 degrees the maximum error will then

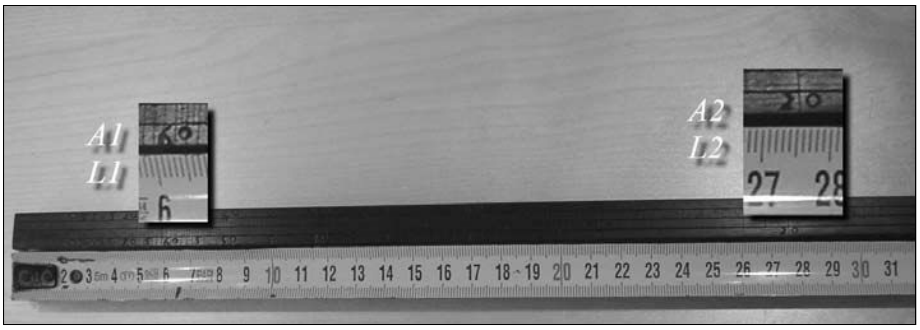


Fig. 22 *Measuring a staff.*

be only 1.3 minutes. Calibrating the instrument for zero degrees results in a large error near the 90 degree observations. The best results are obtained when it is known how far the adjustment screw should be turned in order set the cross to match the parallax for the altitude to be measured, but this method was not applied by Van Breen.

A question is how Van Breen calibrated his staffs in the first place. The scales were most probably graduated for the mirror-vane without the mirror mounted and with the cross flush to the staff. This is at least how it did work out on the reconstruction. The following step is to determine how much the silvered layer of the mirror would appear above the paper of the mirror-vane due to the mirror-frame and breaking index of the glass. With the reconstruction the breaking index was initially measured using a laser, which is very accurate but not to Van Breen's availability. Van Breen did have the following three options:

a) He measured the sun's altitude using a *spiegelboog* with and without the mirror

b) He measured Polaris using a cross-staff and a *spiegelboog*

c) He measured horizontal angles using the *spiegelboog* with the mirror mounted with both the smallest and largest vane setting.

The first option is not very likely to be used as it could be harmful to his eyes and is not very accurate as measuring with shadows is less accurate than measuring with the mirror. Fig. 24 shows this clearly for both the *spiegelboog* without the mirror as for the Davis Quadrant.

The second option is not very likely either as it could only be done at dawn or dusk, needed two observers and relied too much on the quality of the second instrument.

The third option allows for the calibration of the instrument in daytime, using one instrument and one observer only. It was tested with the reconstruction using objects like chimneys and church towers. The observations are carried out in a horizontal plane and the first observation is done with the cross flush to the staff and with the largest vane setting. The corresponding scale is read and the mirror-vane is shifted to the same reading on the scale for the smallest vane setting. Then the same observation is repeated using the smallest vane setting. Now the adjustment screw is turned until the two objects coincide again. The whole procedure is repeated but now with the corrected adjustment screw. After three iterations the adjustment screw does not need further adjustment and the cross is within a few tenths of a millimetre of the location found using the laser calibration.

Distinguishing A *Spiegelboog* From A Cross-staff

The mirror-vane contains the solution to an old problem: how to distinguish a *spiegelboog* from a cross-staff, even when only the staff or a part of it is left. The solution lies in the way the scales are read on both instruments. On a *spiegelboog* this is done on the side of the block on the mirror-vane, while on a cross-staff this is done on the opposite side. For this the scales of the *spiegelboog* need to be shifted by about 25-35 millimetres (approximately 30 millimetres for the reconstruction) towards the eye-end of the staff in order to get an accurate reading. The amount of the shift depends on the thickness of the mirror and the height of the block on the cross. But on the *spiegelboog* only three out of four scales are used in combination with the mirror-vane, the fourth one is used in combination with the shadow-vane for forward observations. For this the fourth scale does not need the shift necessary for the other three scales. As the scales can be calculated from the vane lengths using simple mathematics, the opposite can be done as well. Alan Mills already described this in his article in the *SIS Bulletin* in 1996[66], but the method I use is slightly different.

In order to calculate the vane length and scale offset one should take the altitudes *A1* and *A2* as given by the staff (Fig. 22: 60 and 20 degrees) and the corresponding distances from the eye-end *L1* and *L2* (here 63mm and 275mm):

If the eye-end is damaged a temporary reference can be made by wrapping a piece of paper around the staff and keeping it in place by a rubber band. The reference should be the same for all four sides. The offsets calculated will then be in reference to the paper wrap.

The vane length (*L*) can now be calculated using the following formula:

$$L_{vane} = 2\cdot(L2 - L1)\cdot\frac{\tan\left(\frac{A1}{2}\right)\cdot\tan\left(\frac{A2}{2}\right)}{\tan\left(\frac{A1}{2}\right)-\tan\left(\frac{A2}{2}\right)} = 2\cdot(275-63)\cdot\frac{\tan(30)\cdot\tan(10)}{\tan(30)-\tan(10)} = 107.64\text{mm}$$

The scale offset (*O*) can be found using the following formula (where L_{vane} is calculated using the formula above):

$$O_{scale} = L1 - \frac{L_{vane}}{2\cdot\tan\left(\frac{A1}{2}\right)} = 63 - \frac{107.64}{2\cdot\tan(30)} = -30.21\text{mm}$$

So for this scale the vane length is roughly 108 millimetres and the offset roughly –30 millimetres, which is correct for side 2 of the *spiegelboog* reconstruction (remember the smallest vane setting was 108 millimetres).

In this way one can calculate the vane lengths and offsets for all of the scales. A difference in offset for one of the scales of about 25-35 millimetres is a good indication that the staff belonged to a *spiegelboog*.

The Accuracy Of The Instrument

On July 29th, 1661 Van Breen tested the *spiegelboog* on *Fort Den Haeck* in Zeeland. Two months later Hans Penne and Arent Roggeveen joined him on board of a vessel close to *Fort Den Haeck* to test the

Fig. 23 *Comparing the replicas and reconstructions in IJmuiden.*

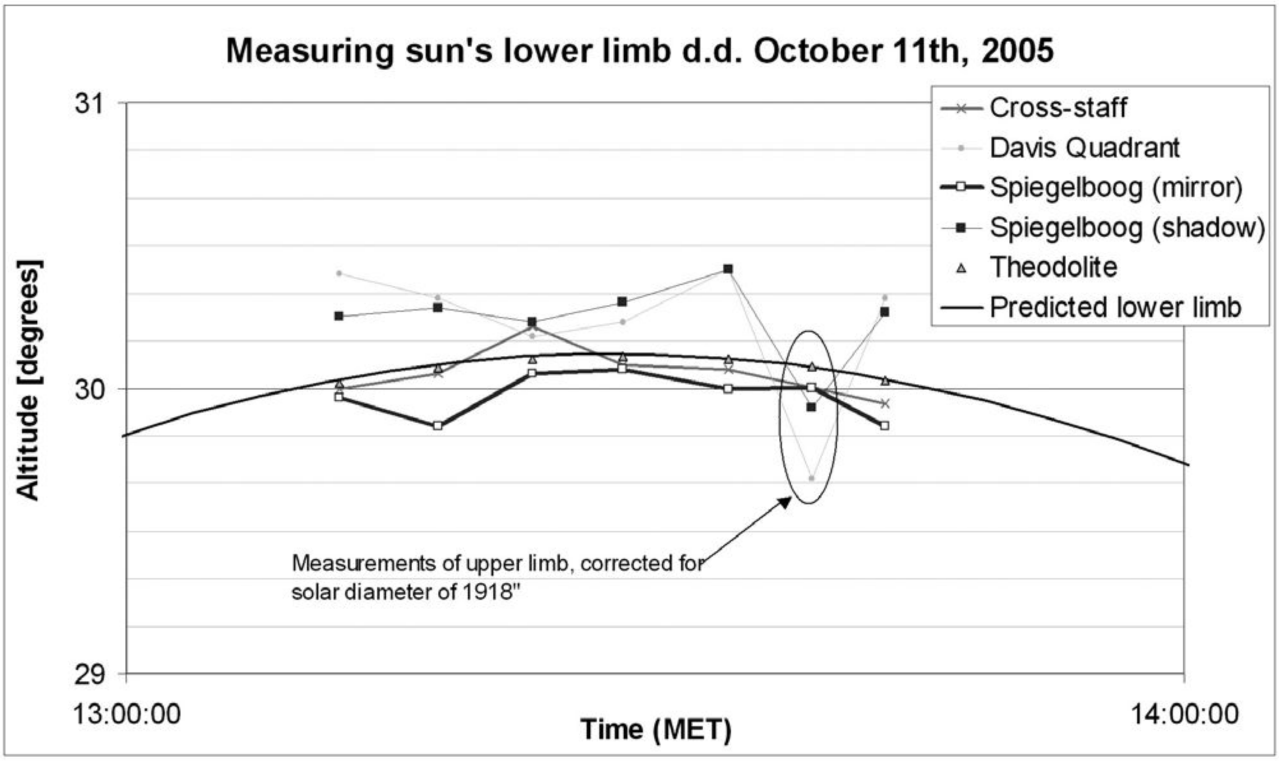


Fig. 24 *The results of the comparison test in IJmuiden.*

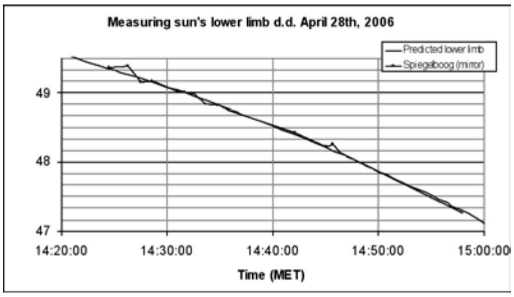


Fig. 25 *Testing the* spiegelboog *on Terschelling.*

spiegelboog against a cross-staff and a Davis Quadrant. On October 11th, 2005, three skilled navigators and a survey specialist (Nico Duijn, Jan Jonker, Jaap Ypma and Ad Pieters) joined me (Fig. 23) on a similar exercise in IJmuiden (approximately 4°-32'E, 42°-27'N).

This time we not only used replicas of a cross-staff and a Davis Quadrant as reference, but also a sextant and a theodolite. Recording the accurate time and place of the observations using GPS made it possible to compare the measurements against the calculated altitude of the sun. From this exercise we now know that the *spiegelboog* performs almost as well as a cross-staff, but is more difficult to handle, something Van Breen already recognized. When used without the mirror the *spiegelboog* performs just a bit better than a Davis Quadrant. In the graph above no data is shown from the sextant as around this noon session the southern horizon was not yet visible, instead a theodolite was used as an accurate reference.

In comparison to the results of Van Breen's test in 1661 our results are quite similar (Fig. 24). In 1661 differences were found of up to 7 minutes between two *spiegelbogen* and between a *spiegelboog* and a cross-staff. In our test we found differences up to 11 minutes, but of course we were all inexperienced in using these 17th century navigational instruments. The average error measured with the *spiegelboog* was 8.3 minutes with a 4.1 minute standard deviation (1σ, 68%). Fig. 21 shows that this average has to be compensated with 1.3 minutes, resulting in a 7 minute average error.

Last April 28th I repeated the test on the Dutch island Terschelling (approximately 5°-23'E, 53°-25'N) using the *spiegelboog* only, comparing it again against the calculated lower limb of the sun (Fig. 25). This time I was better prepared, more experienced and the weather conditions were ideal for the *spiegelboog*. It was completely overcast with the sun just visible through the clouds, allowing me to take the observations without the need of a solar filter. Although a noon observation was not possible due to showery rain I was able to take 16 observations in 34 minutes an hour later. On average the altitude was measured 0.7 minute too low with a 2.7 minute standard deviation (1σ, 68%). Again this average needs to be compensated, but now with 1.7 minutes, resulting in an average 1 minute observation error (which compares to one nautical mile or 1852 metres). The maximum observed difference with the calculated lower limb was seven minutes.

Conclusion

Some 350 years ago the use of a glass mirror in a navigational instrument was innovative. Now the reconstruction of the *spiegelboog* finally tells us how to distinguish a *spiegelboog* from a cross-staff when only the staff or a part of it is found. We could say it is an innovation on our knowledge.

In addition to that we now know that Van Breen's depiction of the staff was quite accurate, which might help to identify any *spiegelboog* parts when found on archaeological sites.

We also know how it is to use one, how it compares to contemporary instruments like the cross-staff and Davis Quadrant and that the accuracy given in Van Breen's book is realistic.

Acknowledgements

This paper was partially presented during the '*Who Needs Scientific Instruments?*' conference in Museum Boerhaave in Leiden, The Netherlands, in 2005 and published as a shortened version in the forthcoming proceedings[67]. I am very grateful to both the former and current curators of navigation of the Netherlands Maritime Museum in Amsterdam (W.F.J. Mörzer Bruyns and D. Wildeman) for supplying me a copy of chapter 13 of Van Breen's book, allowing me to study several original cross-staffs and Davis Quadrants in the collection, and for commenting on my instruments and this paper. I also wish to thank former curator of the University Museum of Utrecht

(K.B. Staubermann) for allowing me to study several instruments in their collection, Huib Zuidervaart for his information on Van Breen as an inventor, Toon Franken of the *Zeeuws Archief* (Zeeland Archives) and Cathrien Steenbeek for doing a splendid job engraving the mirror. Special thanks to Peter Ifland as without him I probably would never have started this kind of research.

For this subject see also: www.dehilster.info.

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2. W.F.J. Mörzer Bruyns, *The Cross-Staff, History and Development of a Navigational Instrument* (Zutphen: Vereeniging Nederlandsch Historisch Scheepvaart Museum, 1994), p. 23.

3. *Ibid.*, p. 14.

4. From left to right: J. Sellers, *Practical Navigation* (London: 1672), collection of Netherlands Maritime Museum Amsterdam; A. Hastings Markham, The Hakluyt Society, *The voyages and works of John Davis* (London: 1880), courtesy of The Hakluyt Society; W.J. Blaeu, *Zee-spiegel* (Amsterdam: 1623), collection of Netherlands Maritime Museum Amsterdam; Sellers, *Practical Navigation.*

5. Lastman, *Kunst der Stuerluyden*, p. 78.

6. W.F.J. Mörzer Bruyns, *Schip recht door zee, De octant in de Republiek in de achttiende eeuw* (Amsterdam, 2003), pp. 8-11.

7. Lastman, *Kunst der Stuerluyden*, p. 84.

8. Markham, *The Voyages and Works of John Davis*, p. 329.

9. From left to right: Sellers, *Practical Navigation*; Markham, *The Voyages and Works of John Davis*; J. van Breen, *Stiermans Gemack* ('s Gravenhage, 1662), collection Netherlands Maritime Museum Amsterdam; J. van Breen, *Stiermans Gemack* ('s Gravenhage, 1662), by courtesy of Leyden University Library.

10. Mörzer Bruyns, *The Cross-Staff*, p. 27.

11. Two examples of the book were used for the research: one held in the library of the Netherlands Maritime Museum in Amsterdam, of which I got a full copy of chapter 13 and one in the collection of the library of the University of Leiden that, in contrast to the version in Amsterdam, still contains the original drawing.

12. *Notulen van de Staten-Generaal*, September 25th, 1660, Nationaal Archief, inv. No. 112311, folio 432 left.

13. Mörzer Bruyns, *Schip Recht door Zee*, p. 28.

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20. G. Doorman, *Octrooien voor uitvindingen in de Nederlanden uit de 16e - 18e eeuw* ('s Gravenhage, 1940), G487, p. 236. Although it is the first patent on glass mirrors I found in this book, it might not be the first given ever in The Low Countries since 1495, the year Doormans work starts. As the patent on the *spiegelboog* is not mentioned in this book or in the later additions, the list of patents seems not to be 100% complete.

21. *Idem*.

22. C.A. Davids, *Zeewezen en Wetenschap. De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 and 1815* (Amsterdam/Dieren, 1986), p. 175.

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27. Van Breen, *Stiermans Gemack*, title page and page after the title page

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31. Davids, *Zeewezen en Wetenschap*, p. 173.

32. *Ibid.*, pp. 349-350.

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34. *Notulen van de Staten-Generaal*, September 25th, 1660, Nationaal Archief, inv. No. 112311, folio 432 left.

35. H.J. Zuidervaart, 'Het Natuurbeeld van Johannes de Mey (1617-1678), hoogleraar filosofie aan de Illustere School te Middelburg', *Archief. Mededelingen van het Koninklijk Zeeuwsch Genootschap der Wetenschappen*, 2001, 1-40.

36. A.L. Callenfels & M.H. Callenfels, *Bibliotheca Windiana*, Middelburg, 1753, 8°: [20] 294 72 [2]; present in the Zeeuwse Bibliotheek in Middelburg, signature original: ZB 1113 F 3.

37. Mörzer Bruyns, *The Cross-Staff*, p. 44.

38. G. Forty, 'Sources of Latitude Error in English Sixteenth Century Navigation', *The Journal of Navigation,* **36** (1983): pp. 388-403.

39. R. Price, K. Muckelroy, 'The Kennemerland', *The Journal of Nautical Archaeology*, **6**-3 (1974), p. 210. The object has been examined by the author using photogrammetry which proved that it did belong to a *hoekvoog* and it showed that the accuracy of the graduation was extremely good with a 1.5 arc minute standard deviation.

40. Lastman, *Kunst der Stuerluyden*, p. 84.

41. S. van der Werf, 'Het Astrolabium', *Cornelis Douwes*, **160** (2004): pp. 20-21.

42. Willem F.J. Mörzer Bruyns, 'The Cross-staff Ten Years Later. An Update with Recently Found Examples', *Bulletin of the Scientific Instrument Society,* No. 80 (2004) pp. 18-23.

43. Davids, *Zeewezen en Wetenschap*, pp. 173-175.

44. R. Putman, *Nederlandse Zeekaarten uit de Gouden Eeuw* (Abcoude, 2005), pp. 6-7

45. Print A taken from the Leiden University Library copy of the book by Van Breen, prints B – E are taken from prints in the collection of the Netherlands Maritime Museum in Amsterdam with inventory numbers A.0149(752), A.3172, S.0820 and A.3170. All prints courtesy of Netherlands Maritime Museum Amsterdam.

46. At least two of the nine examples I found were made using the same, but modified, copper plate. The only thing modified was the name of the maker and the town, the rest of these two prints, including the *spiegelboog*, was identical. Three of the four different versions found had a similar lay-out, but with parts of them mirrored or completely changed. The fourth and oldest example has a totally different lay-out, but parts of it can be found as an exact (at times mirrored) copy on the other three prints.

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

48. I know this from my own research which resulted in a replica of the W. Garner Davis Quadrant from the collection of the National Maritime Museum, London.

49. Tanap. VOC Maps and Drawings. Available from http://www.tanap.net/content/voc/maps/maps_making.htm. Last accessed No-

vember 2^{nd}, 2005.

50. H.C. Pouls, *De Landmeter van de Romeinse tot de Franse tijd* (Alphen aan den Rijn, 1997), p. 179.

51. A.P. Buijs, 'Meten met twee maten', *Historisch jaarboek voor Zuid- en Noord- Beveland*, No. 19, (1993) p. 62.

52. Van Breen, *Stiermans Gemack*, title page.

53. Mörzer Bruyns, *The Cross-Staff*, p. 101.

54. *Idem*, p. 40.

55. *Ibid.*

56. *Ibid.*

57. Brass was (and still is) often referred to as copper, also by Van Breen. This, combined with a replica cross-staff I once examined (Inv. No. UM2991 University Museum in Utrecht) without knowing it to be a replica, added to the confusion and resulted in the use of copper for the frame. It was only after discussing this with Mörzer Bruyns that I realised that it should have been brass, but by then I already had finished the instrument.

58. Lars Einarsson, Willem F.J. Mörzer Bruyns, 'A Cross-staff from the Wreck of the Kronan (1676)', *The International Journal of Nautical Archaeology,* **32**.1 (2003): p. 56.

59. Mörzer Bruyns, *The Cross-Staff,* 1994, p. 42.

60. *Idem*, pp. 35, 37.

61. The Kronan sank off the east coast of the island of Öland in the Baltic Sea on June 1^{st}, 1676. There is no literature on this particular object from the wreck, but it was measured by the author on May 31^{st}, 2005 at the Kalmar Läns Museum in Kalmar, Sweden. More information on the Kronan can be found on: http://www.kalmarlansmuseum.se/site/kronan/proj_kronan/english/index.html.

62. From correspondence between Mörzer Bruyns and the author on March 31^{st}, 2006.

63. Mörzer Bruyns, *The Cross-Staff*, p. 36.

64. The seahorse is the sign of the hydrographic surveyor, which is my profession. The numbers enclosed by seahorses can be found on all of my replicas and reconstructions.

65. From laser measurements the breaking index of the 3.9 millimetre thick mirror was found being 1.5945.

66. A.A. Mills, 'The 'Eye Error' of the Cross Staff With a Method for Calculating the Original Dimensions of Modified or Missing Parts', *Bulletin of the Scientific Instrument Society*, No. 88 (1996), pp. 15-18.

67. N. de Hilster, 'Reconstruction of the *Spiegelboog*'. B. Grob, H. Hooijmaijers, eds, *Who Needs Scientific Instruments? Conference on scientific instruments and their uses - 22 October 2005* (Leiden: Museum Boerhaave, 2006), pp 219-225.

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Callendar Electric Recorder

(Origin of the Potentiometer Recorder?)

D.J. Vermeulen

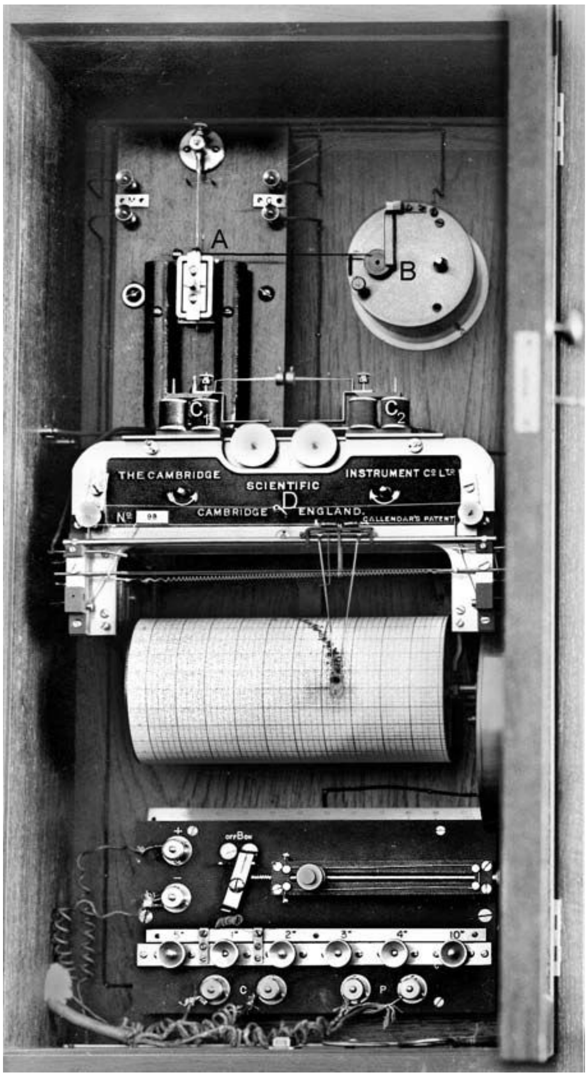

Fig. 1 *One of the Callendar Electric Recorders used at the Transvaal meteorological station in Johannesburg of 1905. Dimensions*[5] *(740 high x 410 wide x 210 deep).*

In November 1902, soon after the South African War, Viscount Milner's Transvaal Government decided to establish a Meteorological Department with headquarters in Johannesburg. The original estimate for the cost of instruments was £1,350 but this amount, rather surprisingly, was increased to £5,629 so that better equipment could be provided. Included were two Callendar Electric Recorders[1] (Fig. 1) for recording temperatures derived from platinum sensing elements housed in an outside louvered hut. The lightning recorder described on page 28 of *Bulletin* No. 66 (September 2000) of the Scientific Instrument Society was another of the interesting instruments purchased by this institution at about that time.

In 1886 H.L. Callendar described a precise thermometer based on the variation of electrical resistance of platinum that became a standard for temperature measurements.[2] Between 1893 and 1898 he was Professor of Physics at McGill University and in 1897[3] he patented recorders based on self-balancing potentiometers or Wheatstone bridges. The recorder pen coupled to the usual slide wire was driven to the left or the right by separate clockwork motors. Callendar is probably best known for his later work on steam tables.

In this particular installation the platinum temperature sensing elements were connected via long cables with compensating leads to a Callendar and Griffiths bridge[4] within the recorder. The state of balance of the bridge was sensed by a large d'Arsonval (moving coil) galvanometer (Fig. 1 A). A horizontal arm projecting from the right of the moving coil carried two noble metal fingers making contact with the front or back of the rotating disc seen on the left hand side of the clockwork motor (B). Contact was made