Master Hood's Cross-staff: a reconstruction

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Introduction

The end of the 16th century was the start of a new era in the development of navigational instruments. By this time one of the principal instruments for celestial navigation at sea was the cross-staff. The others were the mariner's astrolabe (Fig. 1) and the quadrant (Fig. 2). The cross-staff is a wooden instrument consisting of a square staff and up to four sliding transoms or vanes (Fig. 3).[2] For each vane a scale was engraved on one of the sides of the staff.

The Cross-staff

The cross-staff was the most accurate of those three, but still navigators were looking for an improvement, as it meant that the navigator had to face the sun with the naked eye, or at most protected this by a small piece of coloured glass. Being the most accurate (and much lower in price than the astrolabe), the cross-staff would eventually not only replace the other two instruments but also lead to new instruments.[3]

From the beginning the cross-staff was used for forward observations, facing the sun. 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[5]). Then the vane was slid along the staff until its lower end 'touched' the horizon and the upper end 'touched' the celestial body. The scale on the staff corresponding with the used vane gave the zenith distance or the altitude.

The cross-staff was first described in the early 14th century[7] and adapted for use at sea by the Portuguese in the early 16th century[8], until which it was used for astronomical observations on land. Measuring the sun's altitude while facing it is harmful to the eyes. In order to protect these, observations were done while using a coloured piece of glass to dim the sunlight.[9] Besides the potential blindness the forward method had another disadvantage. One had to observe the horizon and the sun simultaneously, but when observing higher altitudes this was only possible by blinking up and down with the eye, negatively influencing the quality of the observations. Already in the 16th century it was advised not to observe altitudes above 50 degrees using a cross-staff, but to use the astrolabe instead.[10]

In an effort to overcome these problems, a new series of instruments were developed that were based on a new principle that

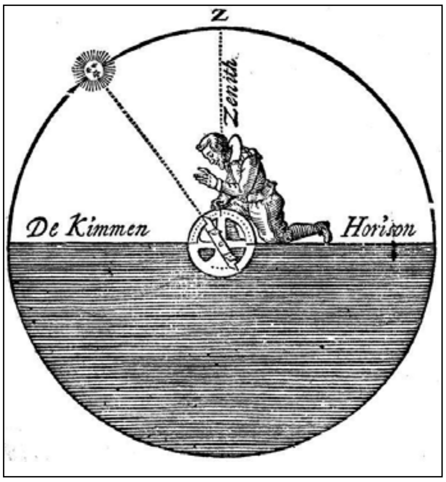

Fig. 1 *The mariner's astrolabe.[1]*

Fig. 2 *The quadrant.[4]*

Fig. 3 *The cross-staff.[6]*

allowed to measure the sun's altitude by using the shadow of a vane (hence called 'shadow vane') attached to the instrument. These instruments, to which I will from now on refer to as 'shadow staffs', lead to a series of instruments most of which allowed the navigator to observe the sun with his back towards it (hence called 'back-staffs'). In a response to this the cross-staff developed into a back-sighting instrument as well. Around 1650 the horizon vane was introduced, being either a separate vane or the smallest vane with a nail or bone protruding from its side(s).[11] The nail or bone could be aimed at the horizon and the shadow of the upper end of the transom had to be projected on to it while looking along the lower end of that same transom. At the same time the aperture disc was introduced. It was made of brass and could be slid on to the lower side of the transom where it served as a peep sight. About a century later a second aperture disc was in use at the upper end of the transom to cast a small beam of light on to the horizon vane. Tests conducted with a cross-staff in this configuration showed that accuracies of a few arc minutes were feasible.[12]

The concept of shadow casting was not completely new: the mariner's astrolabe did in fact the same. The movable arm or alidade of a mariner's astrolabe has two vanes with pinholes (better known as pinnules). Observations were done by casting the bright spot of sunlight from the pinnule in the upper vane onto the lower, but it was thanks to the shadow of the upper vane that the bright spot of sunlight was visible.

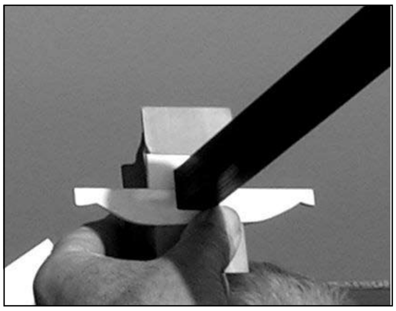

Fig. 4 *Horizon vane with a bone, the small beam of light cast by the aperture disc can be seen left of the staff.[13]*

The disadvantage of the mariner's astrolabe with respect to the shadow staffs was, that due to its small diameter the size of the degrees on the astrolabe was limited. Although large (sea) astrolabes have been made, their usefulness at sea was disproportionate to their size as with size weight increased and so did the susceptibility to wind. In addition most mariner's astrolabes were made of bronze or cast brass which made them relatively expensive. Shadow staffs were made mainly of wood and based on holding (a part of) the instrument level rather than letting gravity do that job.

Master Hood's Cross-staff

The oldest written reference to a shadow staff was by Thomas Hood (fl. 1577-1596) in his book *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 any-thing measurable.*, published in 1590.[14] Thomas Hood was a Master of Arts, a Fellow of Trinity House, and a very competent mathematician. As from probably 1587 he was commissioned to lecture privately on the application of mathematics to navigation[15], even though he appears never to have gone to sea.[16]

As the title indicates the book contains two treatises, the first is for the mariner ('*The use of the Crosse Staffe*') and describes the use of an instrument for astronomical purpose. The second is for the surveyor ('*The use of the Jacobs Staffe*') and deals with the use of a geometrical instrument. The first part had originally been presented as a manuscript to Lord Charles Howard, together with the instrument, but became so popular that Hood soon decided to put it to print.[17] Although the titles suggest two instruments, the book deals with one single instrument, '*…Maister Hood his crosse staffe…*'.[18]

Master Hood's cross-staff had the configuration of a surveyor's staff: two perpendicularly mounted staffs that could be used to measure objects by proportions (Fig. 5 B). No example survives, but four similar instruments for surveying are known, two in Florence[19], one in Madrid[20] and one in private ownership in Germany.[21]

Knowledge of Master Hood's cross-staff not only comes from Hood's work, but also from Thomas Blundeville (fl. 1560-1602), who described the instrument in chapters 13 to 18 of *His Exercises*, first published in 1594.[23] Blundeville himself claimed that *His Exercises* was a compilation '*…from the best modern writers…*'[24] and studied works from Cortes, Medina, Bourne, Norman, Borough, Coignet and Hood.[25] In chapter 13 he gives "*A briefe description of the Maister Hoode his crosse staffe, and*

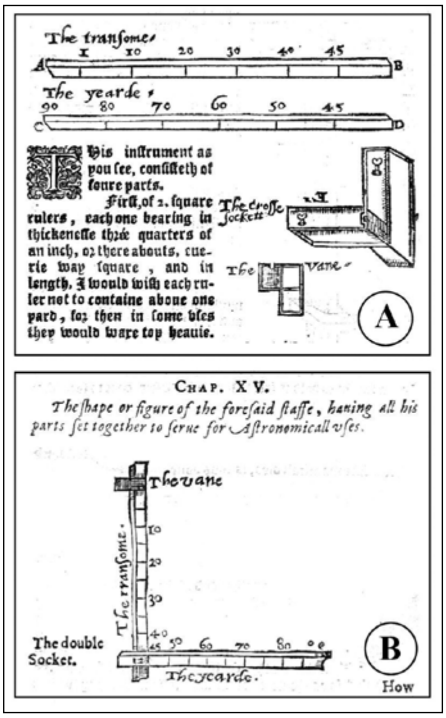

Fig. 5 *Master Hood's Cross-Staff.*[22]

of all the partes thereof."[26]

The accompanying sketches (Fig. 5) show the various parts and the assembled instrument. It consists of two staffs (the *transome* and the *yearde*), a *crosse sockett* and a *vane*. Both staffs were engraved with two different scales: one in degrees for "*…Astronomicall uses…*" and one equidistantly for "*…Geometricall uses…*".[27]

In more recent literature the instrument has been described by Waters and Cotter.[28] Waters referred to period literature while Cotter referred to both Waters and period works. Both valuated the importance of the instrument to the development of navigational instruments of that era just as I do and confirm most of my findings. Waters' explanation of the astronomical scales slightly differs to what I have found in my research and is explained further down this article in the *Scales* section.

Use and Diffusion

Although the instrument has been described in several editions of the works by Hood and Blundeville spanning at least 48 years (see notes 14 and 23), no evidence was found that Master Hood's cross-staff had widespread use, either on land or at sea. The instrument has only been described in the two mentioned English works, no works outside England referring to the instrument are known. Even Joseph Moxon, who in 1659 published his *A Tutor to Astronomie and Geographie* and who showed "*…several shapes and forms […] on the celestial globe. Collected by Dr. Hood.*" did not mention Hood's staff in his section of nautical instruments.[29]

Materials

The transom and the yard were made of wood, while the vane and the cross-socket were made of brass.[30] The type of wood to be used is not mentioned, but most likely this would have been ebony, lignum vitae, redwood or pearwood as those were commonly in use in period mariner's cross-staffs.[31]

Construction

Although construction-wise Hood's staff is a simple instrument all parts were described in great detail.

The transom and yard both were "*…square rulers…*" and "*… everye way square…*".[32] The yard was "*…cut off close to the 90. degree…*" so that it may better "*…come unto your sight: wherein the Centre of the circle is imagined from whence all the lines do come…*".[33] On one of the images in Blundeville's book we see the eye-end of the yard being cut off on the lower side to allow it to be positioned better in the eye socket (Fig. 5 B), a practise also known from mariner's cross-staffs.[34] This was done in an attempt to prevent ocular parallax and was first described by Bourne in 1574.[35] When properly made, the lines of sight along the ends of the vane coincided with the middle of the flat eye-end of the staff. As the lines should actually fall on the eye's retina, slightly beyond the staff's eye-end, Bourne advised to "*…pare away a little of the ende of the staffe…*" in order to avoid ocular parallax.

The cross-socket is made "*…to joine the Transame and the Yard together* […] *squire wise, at right angles.*".[36] each socket has a notch and a screw. The notches are "*…to see howe to set the Transame, and the Yard just upon his place. For the brasse carrying a certaine thicknesse with it, doth hinder my sight so, that I cannot well judge of the true place wheron they should stand…*". The screws "*…serve to none other purpose but this, namely, to keepe the Sockets fast in their places, that they slip not.*".[37]

The socket could of course be mounted in several different ways on the instrument of which only one method was correct. Hood wrote: "*…that the Socket wherein the Transame must bee put, must always hang downeward…*" and "*… that The ende whereat your two Sockets close together, be next unto your sight…* [that is facing towards you]".[38] The transom was the staff that was usually held vertically,

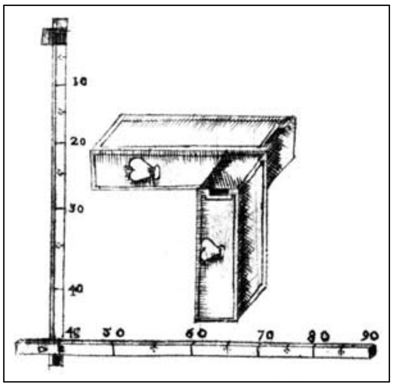

Fig. 6 *The cross-socket.*[39]

while the yard would be held horizontally. There was no definite way to assemble the cross-socket, the drawings show the cross-socket with the transom on both sides of the yard (compare the cross-socket with the assembled instrument in Fig. 6). Hood even replies to the question "*Is it any matter to which hande* [the vane] *standeth…*" with "*…When the Transome standeth on the right hand of the Yarde, let the Vane bende towarde the left hande: and contrawise…*"[40], which is only possible with two differently constructed cross-sockets.

The vane is made "*… of brasse* […] *the upper edge whereof is pierced with a little round hole for the beame of the sunne to passe through the same.*" and was "*…made with a socket, and with a skrew to hold it fast to that ruler whereon it is set.*"(Fig. 5 A).[41] The vane was similar to the vanes on an astrolabe's alidade (although those had the pinnules pierced in the middle). The cross-socket had notches to compensate for the thickness of the brass, but there is no mention how and if the thickness of the brass of the vane had to be compensated.

Scales

Both the transom and the yard were engraved with two scales: one in degrees and minutes for celestial navigation and one in equal parts for geometrical use, similar to the German and Madrid instruments. A closer look at the sketch of the transom reveals that it has no zero mark on the degree scale, but alike Iberian astrolabes the zero is marked with a 'I'.[42]

Hood wrote that the yard and transom were divided with on one side "*… the degrees of altitude, with their minutes.*" and that the transom contained "*…all the degrees from 1. to 45…*", while the yard "*…conteyneth the rest, namely, the degrees from 45. unto 90.*".[43] Hood also wrote that the main advantage of his scales compared to the mariner's cross-staff (or 'Balla Stella' as he called it) was that "*…the degrees therof are greater then of the other Staffe* [the Balla Stella]*, though the Staves themselves be of equall length. For 5. of them are as bigge as 15. in the Balla Stella.*".[44] Blundeville took the scales further into detail by writing that "*… every degreé is divided againe into sixe lesser parts, making 60. minutes, for sixe times ten maketh 60. …*".[45] Apart from being divided down to 10 arc-minutes Blundeville nor Hood mentioned how the degree scales had to be divided. According to Waters the degrees were equal in size as he wrote that "*…the graduations, besides being equal, were much larger than on a conventional cross-staff…*".[46] That Waters thought the divisions were equal probably was the result of the drawings in the works by Hood and Blundeville as those showed them that way. Hood's text in the second part of his book (the part for the geometrical use) gives however the final answer as he wrote that "*… the partes of the other Staffe* [the astronomical one] *are unequall, and that this* [the geometrical staff] *is divided into equall portions…*".[47]

In order to make the instrument function accurately it had to be divided the same way as the shadow square of a terrestrial astrolabe or a quadrant (Fig. 7). The shadow square was a square part on those instruments that was divided in 90 degrees along two adjoining sides, called the *Umbra Versa* and *Umbra Recta*. *Umbra* (shadow) stands for the trigonometric tangent of the altitude angle. The 45 degree altitude angle divided the two parts of the shadow square; the part from 0 to 45 degrees along the vertical side was named *Umbra Versa* (the shadow projected on a vertical wall opposite), the part from 45 to 90 degrees along the horizontal side was named *Umbra Recta* (the shadow projected on the horizontal plane).[49] The transom of Master Hood's cross-staff would thus be graduated as an *Umbra Versa* and the yard as an *Umbra Recta* as, if graduated equidistantly, the scales would produce an unacceptable maximum error of just over four degrees at 27 and 63 degrees on the scales.[50]

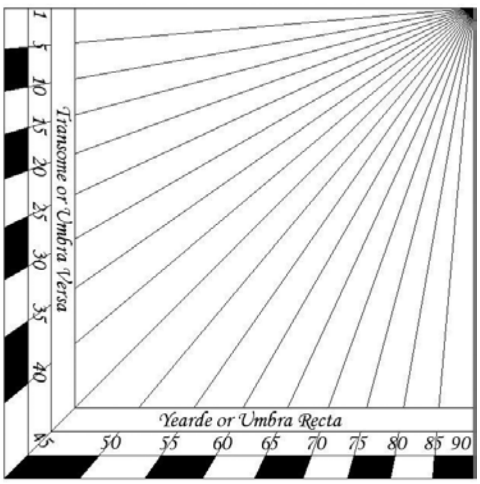

Fig. 7 *The shadow square.*[48]

On the opposite side of the astronomical scales both the transom and the yard were engraved with linear scales. Hood tells the reader "*…if you could divide them into 100000, it were the more commendable, but 1000 sufficeth in this staffe, …*".[51] Blundeville took it again into greater detail by writing "*And on the opposite side of that* [the astronomical scale]*, the said Transome is divided into 1000 equal parts, beginning at 25 and so increaseth by 25, untill you come to 1000. Every which 25 parts is divided into five lesser parts, and every one of those againe into five parts, which maketh in all 25 parts, for five times five is 25,…*".[52]

Again, just as with the astronomical scale on the transom, the concept of zero proofs to be difficult. Starting at 25 and increasing by 25 until 1000 is reached, will result in 975 divisions, not 1000, yet both Hood and Blundeville wrote that the scales were divided into 1000 equal parts. We may therefore assume that the scales would have begun at zero (or more likely at one, just as on the astronomical scale). In Hood's *The Use of The Jacob's Staffe* two geometrical examples were discussed in which the whole length of the transom was used as reference.[53] We may therefore also conclude that it was the whole transom (and thus the whole yard) that was divided into 1000 parts and not the part from the socket to the end of the staff. This also means that both staffs should be equal in length as both were divided in 1000 parts and both scales should have identical equal parts to function.

Dimensions

The transom and yard both were "*…square rulers ech one bearing in thicknesse three quarters of an inch or there abouts everye way square, and in length* […] *not to containe above one yarde, for then in some uses they would ware toppe heavie.*".[54] So the thickness of the staffs was about ¾ inch (19 millimetres), but the length of them is not given, although we are advised not to make them longer than a yard (914.4 millimetres). The horizontal staff is however called 'the Yearde', an indication that it was meant to be that size. A minimum size can be derived from the fact that the staffs had to be divided in 1000 parts. The shortest intervals found on cross-staffs are about 0.7 millimetres in length.[55] Shorter will result in crumbling of the wood the staffs are made of.[56] This value multiplied with 1000 will result in a minimum length of about

700 millimetres. As explained under 'Scales' both staffs had to be of the same length.

The dimensions of the cross-socket and the vane are not given, but based on the original drawings I estimated them at two inches long (50.8 millimetres). In order to function properly the cross-socket should fit tightly on the staffs, but also slide easily.

The width of the vane is also estimated from the drawings and estimated to protrude one inch (25.4 millimetres) from the staff.

Signature, Marks and Decorations

Although the drawings from Hood and Blundeville are all very small and simplified they give us an indication what the scales

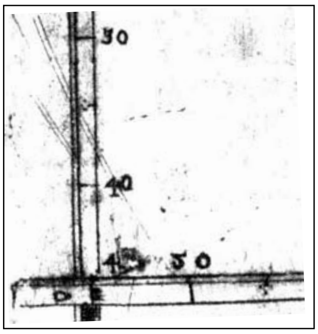

Fig. 8 *The divisions on Hood's drawing.*[58]

must have looked like. On Hood's drawing every 5 degrees a mark has been drawn on one side of the transom and on two adjacent sides of the yard. The 10 degree marks are drawn over the complete width of the staff, while the intermediate five degree marks are much shorter and marked with three dots as seen on other early 17th century instruments.[57] Blundeville only shows fully drawn lines at every 5th degree on one side of each staff.

Both Blundeville and Hood show the cross-socket and vane with lines engraved along all edges, a feature also found on other period staffs.[59]

There is no mention of any signature in Hood's or Blundeville's work.

Using Master Hood's Staff

As a whole the instrument was designed "*… to take the height of the Sunne and Starres…*"[60] and to "*…take the length, height, depth or breadth of anything measurable…*".[61] Hood tells the observer "*… you may choose whether you will apply it* [the instrument] *onto your eye (as you do with the Balla Stella [cross-staff]) or whether you will holde it in your hande, and finde the height of the Sunne by the shadow of the same.*".[62] As this article discusses the relevance of Hood's staff for the development of navigational instruments I will mainly explain the navigational use of the instrument.

The vane serves not only to cast a shadow of the sun, but "*…also to save your sight from the beames thereof…*" when observing the sun directly.[63] In addition to that "*… for some Geometricall uses it were necessarie (as some thinke) that there were two such vanes.*", similar to the staff in Madrid, but unnecessary according to Blundeville.[64] So this vane has three purposes: casting shadows on the staff, protecting the eyes when using the staff as a cross-staff in a forward manner and as visor(s) in geometrical use.

When using the instrument to observe the

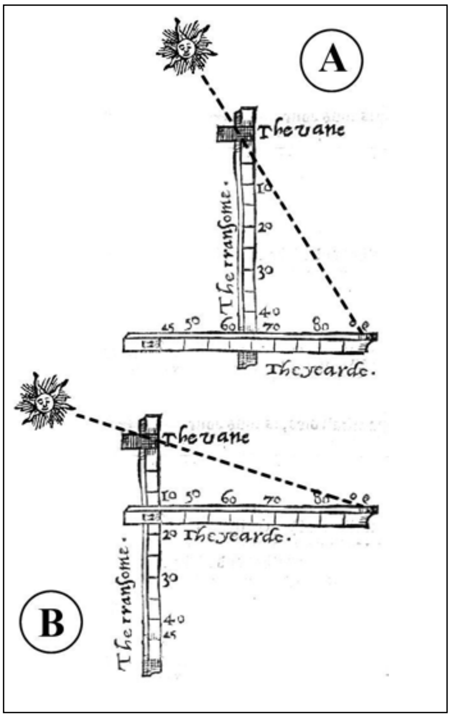

Fig. 9 *Using Hood's staff according to Hood and Blundeville.*[70]

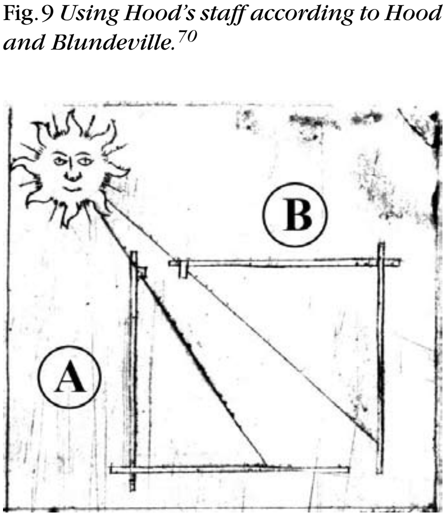

Fig. 10 *Using Hood's staff according to the second method by Hood.*[72]

sun by casting shadows, one had to "*… goe into some open place whereas you may see the sunne, and turning the ende of the yarde marked with ninetie towardes your brest, holde the yarde so level as you can, that it may be a just Parallell to the Horizon, and turne both your face, and also the vane of the transame towardes the sunne.*".[65] It is evident that although this is an instrument that measured the altitude of the sun by its shadow, it was still used in a forward manner. With the use of a shadow vane Master Hood's cross-staff is the earliest example of applying vanes on staffs for shadow measurements.[66] The next step, most probably initiated by Thomas Hariot around 1594, was that the observer had to turn around 180 degrees so that he stood with his back towards the sun.[67]

Two different methods were described to conduct the observations. The first method of observing the sun by casting a shadow was described by both Hood and Blundeville. When the sun's altitude was more than 45 degrees "*…then drawe the double socket upon the yarde nigher towards your brest, untill you see the shadowe of the vane to fall just upon the ninetieth degreé of the yarde…*" (Fig. 9 A, shows an observation of the sun at an altitude of 66 degrees).[68] Altitudes below 45 degrees were observed by making "*…the Transame to sinke downe through his socket until the upper edge of the vane standing upon the Transame doe cast his shadowe just uppon the nintieth degreé of the yarde.*" (Fig. 9 B, shows an observation of the sun at an altitude of 14 degrees).[69] The correct altitude could be read at the cross-socket on either the transom or the yard.

In addition Hood proposed a second method to measure the sun by shadows. This involved assembling the instrument in another way. The transom was put into the socket with the zero (or rather one) degree mark, the yard with the 45 degree mark next to it. The shadow vane was mounted on the yard at the 90 degree mark.[71]

Now for measuring elevations of less than 45 degrees the instrument is held with the transom hanging vertically (Fig. 10 B) and the shadow of the vane (which is now mounted on the yard) will cast a shadow on the vertical transom. For elevations above 45 degrees the transom is held horizontal and with the yard pointing towards the zenith (Fig. 10 A). The shadow will now give the zenith distance of the sun, "*… subduct that out of the 90. degrees, and the remainder sheweth the Sunnes elevation.*".[73]

The instrument could also be used to ob-

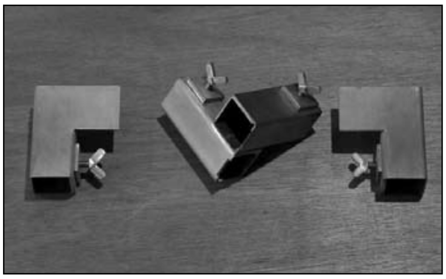

Fig. 11 *The vanes and the cross-socket of the reconstruction. The vane at the right has the little hole pierced in the upper edge (picture by the author).*

serve the stars, in which case the 90 degree mark was held next to the eye like a normal cross-staff and the observation was done by looking over the vane to the star and keeping the yard parallel to the horizon. Blundeville points out that this is easier done at sea as "*…for on the Sea,*

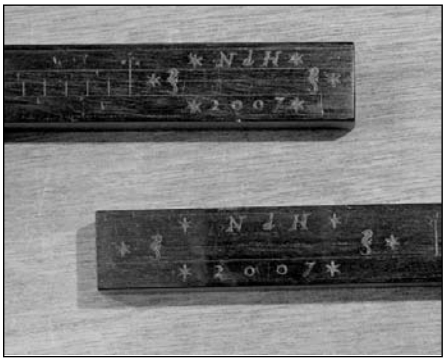

Fig. 12 *The signatures on the reconstruction (picture by the author).*

there be neither hils nor trées to hinder the sight…".[74] So the instrument had to be held horizontally, but no aids were given for this. According to Hood one could use "*… a Plummet of Leade…*" to keep the transom vertical when observing on land, but this was not advised for use at sea.[75]

The Reconstruction

Having studied the works by Hood and Blundeville extensively it was now time to put the instrument to the test. As no example survived I decided to create one myself, as I did before with several other period instruments, using the same materials and techniques available in Hood's days.[76]

As the horizontal staff was called *The Yearde* I made the staffs of the reconstruction one yard each (0.9144 metres). The material used for staffs of the reconstruction is ebony, that of the vanes and cross-socket brass. The sockets of both the cross-socket and the vanes are made two inches long, while the vanes (I made two of them symmetrically, one with and one without a hole) protrude one inch from the staff. The sockets are made by folding 0.8mm brass sheet around the staff and soldering the overlapping ends.

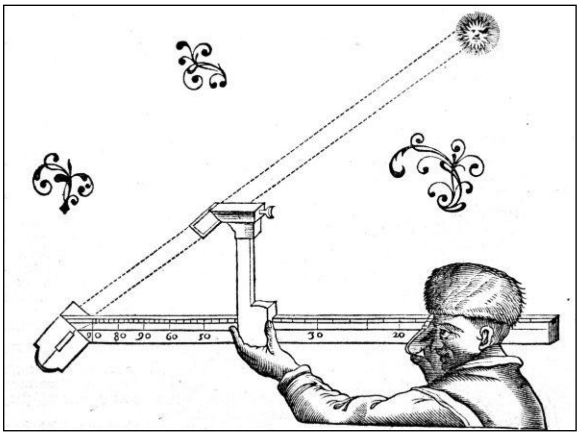

Fig. 14 *The demi-cross.*[78]

The screws in the sockets are also made of brass and modelled after period instruments, but based on modern M4 metric bolts.

On the reconstruction both staffs are signed with '*N d H*' between stars and are dated 2007, again between stars (see Fig.12). The whole signature stands between two sea horses, my instrument makers mark, and two stars. On end, next to the signatures, serial numbers have been stamped in between two seahorses ('01' for both staffs).

The scales are engraved on a single side, with the nautical and geometrical scales on opposite sides (see Fig. 13). The intermediate 5 degree marks have three dots surrounding them as shown by Hood, while the 30 arc minute marks have a single dot above them similar to period instruments. Numbers have been stamped in every 10 degrees, with a 'I' at the start of the transom.

The geometrical scales are divided in 1000 parts over the whole length, divided in groups of 25 and subdivided in groups of 5. Numbers have been stamped in every 100 divisions on the geometrical scales and start again with a 'I', then continue with 100, 200 etc.

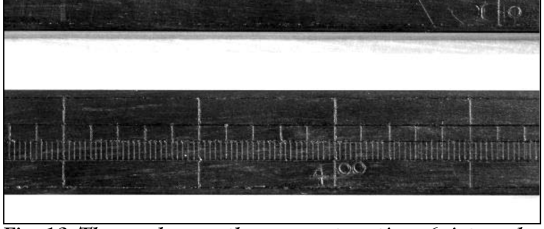

Fig. 13 *The scales on the reconstruction (picture by the author).*

The other two sides (to which the screws clamp) have two parallel lines engraved over the whole length.

The cross-socket and vanes of the reconstruction do not bear any marks, but their modern provenance can easily be recognised as metric thread is used on the screws.

Fig. 15 *Jaap Ypma with the reconstruction (picture by the author).*

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 previous experience with 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 cross-staff.[77]

This time we had Master Hood's cross-staff, a demi-cross (a Dutch development based on John Davis' 45 degree backstaff[79], see Fig. 14), a Davis Quadrant and a cross-staff to our disposal. Already in the early stages it became apparent that using Hood's cross-staff was far from easy. We tried all possible configurations as mentioned by Hood and Blundeville, but none was suitable for observing the sun in a satisfactory manner.

The main problem of the instrument is that you would need three hands to handle it. One to hold the instrument, the second to catch the shadow and steer the instrument and a third to fasten and loosen the screw of the transom and to slide the transom up and down. Only when observing the sun using the instrument with the transom hanging, one could observe using two hands only. In all cases it seemed to be impossible to keep the instrument level long enough to get proper readings. Due to its sheer size it also is very susceptible to wind and especially the vertical part of the instrument tends to get blown sideways by it (that day we had a south westerly 5 Beaufort wind).

When handled by a single man observations could deviate as much as 8 degrees (compared with the calculated sun's altitude and the other instruments used in the test). We also tried to use it with two observers: the first would only take care of the instrument being horizontal, while the other would align it with the sun and read off the scale. Waters wrote that "*... that it was desirable to have a second observer to read off the sun's elevation...*" and that Hood was aware of this.[80] Cotter wrote that "*... it seems that two observers would have been necessary...*"[81], but does not mention Hood being aware of that. Although I have not been able to find evidence for Hood's awareness of this in his or Blundeville's work I do agree as in this way we managed to get two readings with errors of 'only' 20 and 34 arc minutes, which was considerable better than the 8 degrees in single man use. All our observations were taken on solid ground, being on board of a rolling vessel would make things only worse. In total we spend half an hour testing this instrument, during which we managed to take only five observations, the last two of which were the best as mentioned above. After that half hour we felt defeated and simply gave up. With the cross-staff and demi-cross we were able to take twelve observations in half an hour and with the Davis Quadrant even sixteen. Except for four Davis Quadrant observations all of those 40 observations were better than the best taken with Master Hood's cross-staff.

I also checked the usefulness of the hole in the shadow vane the very first time I took the instrument outside. Standing in my very well sheltered back garden I held the instrument at my eye like a mariner's cross-staff. Despite the very favourable conditions I was not able to stabilise the instrument enough to have much advantage of the shadow vane as a protection for the eye, let alone of the hole in it.

Conclusion

Master Hood's cross-staff probably was the start of observing the altitude of the sun using a shadow. It was the start of a new development that would soon result in instruments that allowed the navigator to observe the sun with his back towards it. Instruments used in this way were hence called 'backstaffs' of which at least eight different types were invented in the following 35 years. A development that was initiated by Thomas Hariot around 1594[82] and ended with the fully developed Davis Quadrant around 1670.[83]

The field tests performed with the reconstruction gave a good indication why Hood's instrument did not gain popularity. Although the use of a vane on a staff for casting shadows was an important step in the development of early 17th century navigational instruments, Hood's invention was a mediocre one, difficult in use on land and most certainly not suitable for use at sea, and that despite Blundeville's assurance that no hill or tree would block sight on the horizon.

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Notes and References

1. A.A. Metius, *Astronomische ende Geografische Onderwysinghe*, (Amsterdam, 1632), p. 121, Collection Netherlands Maritime Museum, Amsterdam.

2. At the end of the 16th century the cross-staff was still developing and had the number of vanes increased from 1 to 3 at around 1580 and to 4 at around 1650, see W.F.J. Mörzer Bruyns, *The Cross-Staff, History and Development of a Navigational Instrument* (Zutphen: Vereeniging Nederlandsch Historisch Scheepvaart Museum, 1994), pp.28-29.

3. Mörzer Bruyns, *The Cross-Staff,* p. 33.

4. J. Moxon, *A Tutor to Astronomie and Geographie : or an Easie and speedy way to know the Use of both the Globes, Coelestial and Terrestrial : whereunto is added the Antient Poetical Stories of the Stars : shewing Reasons why the several shapes and forms are pictured on the Coelestial Globe : as also a Discourse of the Antiquity, Progress and Augmentation of Astronomie*, (London, 1659), p. 48, Collection Netherlands Maritime Museum, Amsterdam.

5. C.J. Lastman, *Kunst der Stuerluyden* (Amsterdam, 1661), p. 81.

6. J. Seller, *Practical Navigation*, (London, 1689), p. 166, Collection Netherlands Maritime Museum, Amsterdam.

7. Mörzer Bruyns, *The Cross-Staff,* p. 23.

8. *Ibid.*, p. 14.

9. *Ibid.*, p. 25.

10. W. Bourne, *A Regiment for the Sea*, (London, 1574), in E.G.R. Taylor (ed.) *William Bourne, A Regiment for the Sea and other writings on navigation*. The Hakluyt Society second series no. CXXI, (Cambridge, 1963), p. 207-208.

11. Mörzer Bruyns, *The Cross-Staff,* pp. 40-41.

12. N. de Hilster, 'The Spiegelboog (Mirror-staff): a reconstruction', In: *The Bulletin of the Scientific Instrument Society,* No. 90 (2006), p.14.

13. Picture taken by A. Twisk during the 2006 trials, see note 12.

14. This is a book in two parts: *The Use Of The Crosse Staffe* and *The Use Of The*

Jacobs Staffe, (London, 1590), bound together as one book and is registered as shelfmark 8534.b.22 at the British Library. The title according to their database is *The Use of the Jacobs Staffe. (A dialogue teaching the use of the Crosse staffe.)*, which is in fact the title of the second part as can be seen in the 1596 edition (BL shelfmark 529.g.6.(3.)).The general title page (*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.*) and first title page are missing, and the second part has been bound as first. Both missing pages are known from a complete 1596 copy in the British Museum, known as shelfmark 529.g.6(3), which has been reproduced by Theatrum Orbis Terarum Ltd. & Da Capo Press Inc. in 1972. Also see D.W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, (London, 1958), p. 188, footnote 1.

15. D.W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, (London, 1958), p. 185.

16. *Ibid.*, p. 192.

17. E.G.R. Taylor, *The Mathematical Practitioners of Tudor & Stuart England 1485 – 1714*, (Cambridge 1967), pp. 229-330.

18. T. Blundeville, *His Exercises* (London, 1594), p. 315.

19. Mörzer Bruyns, *The Cross-Staff,* p. 24.

20. J. Jiménez, M. Martinez, A. Sebastian, *The Royal Academy of Mathematics and the Imperial College in the National Museum of Science and Technology of Madrid* (Florence, 1995), pp. 183-184.

21. After initial contact with the owner on July 17th, 2006, this particular instrument has been examined by both the author and W.F.J. Mörzer Bruyns in Bussum, The Netherlands, on April 13th, 2007. The instrument is made of wood covered on all six sides with ivory or bone. On the four sides one astronomical and seven geometrical scales are engraved. The engravings are explained with engraved texts and are filled in with red and black paint. The instrument is an almost exact representation of the instrument described by Apian in his 1533 treatise *Instrument Buch.*

22. Blundeville, *His Exercises* (1622), p. 670, 672, by courtesy of P. Ifland.

23. Five versions of the book have been examined: the first edition of 1594 in the collection of the Rotterdam Maritime Museum (inv. no. BWAE299), the fourth edition of 1613 (Netherlands Maritime Museum Amsterdam (inv. no. S.0161(320)) and the sixth edition of 1622 in the private collection of Peter Ifland. In addition to that the staff of the British Library checked the seventh edition from 1636 and another seventh edition from 1638 in the University of Illinois Library (Call Number IUA01631) was checked by their staff. Both libraries confirmed that Master Hood's cross-staff was still mentioned in them, a copy of the first two pages of Chapter XIII of the 1638 edition has been sent to me for verification.

24. Taylor, *The Mathematical Practitioners of Tudor & Stuart England 1485 – 1714*, p. 331.

25. Waters, *The Art of Navigation*, p. 214.

26. Blundeville, *His Exercises* (1594), p. 315.

27. *Ibid.* The use of equidistant divisions for geometrical uses and land-surveying is also described by Apian in his 1533 treatise *Instrument Buch*.

28. Waters, *The Art of Navigation*, pp. 185-189, C.H. Cotter, *A History of the Navigator's Sextant*, (Glasgow, 1983), pp. 89-94.

29. Moxon, *A Tutor to Astronomie and Geographie*, title page.

30. T. Hood, *The use of the Two Mathematicall Instruments* (London 1590), pp. 2-3 of part *The Use Of The Crosse Staffe*.

31. Mörzer Bruyns, *The Cross-Staff,* p. 35.

32. Blundeville, *His Exercises* (1594), p. 315.

33. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 3 of part *The Use Of The Crosse Staffe*.

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

35. Bourne, *A Regiment for the Sea*, p. 209.

36. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 3 of part *The Use Of The Crosse Staffe*.

37. *Ibid.*

38. *Ibid.*, p. 3 of part *The Use Of The Crosse Staffe.*

39. Idem., detail of the single foldout page at the end of the book. © British Library Board. All Rights Reserved, shelfmark 8534.b.22.

40. *Ibid.*, p. 4 of *The Use Of The Crosse Staffe*.

41. Blundeville, *His Exercises* (1594), p. 316 left.

42. A. Stimson, *The Mariner's Astrolabe* (Utrecht, 1988), p. 56

43. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 2 of part *The Use Of The Crosse Staffe*.

44. *Ibid.*, p. 1 of *The Use Of The Crosse Staffe*.

45. Blundeville, *His Exercises* (1594), p. 315.

46. Waters, *The Art of Navigation*, p. 189.

47. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 4 of part *The Use Of The Jacobs Staffe*.

48. Sketch by the author.

49. J. Stöffler, *Elucidatio Fabricae Ususque Astrolabii*, (Paris, 1553), in: A. Gunella, J. Lamprey (eds.), *Stoeffler's Elucidatio, The Construction and Use of the Astrolabe*, (Cheyenne, 2007), p.70-n1.

50. Even an astrolabe would perform better with an accuracy of 20 arc-minutes, see: S. van der Werf, 'Het Astrolabium', in: *Cornelis Douwes*, no.160 (2004): p. 20-21.

51. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 4 of part *The Use Of The Jacobs Staffe*.

52. Blundeville, *His Exercises* (1594), p. 315.

53. Hood, *The use of the Two Mathematicall Instruments* (1590), pp. 19-20 of part *The Use Of The Jacobs Staffe*.

54. Blundeville, *His Exercises* (1594), p. 315.

55. An example of this is the 1720 cross-staff by J. Hasebroek. It has full range scales (each starting at 90 degrees) with decreasing intervals. Side one starts with 10 arc minute intervals that are 0.66 millimeters apart. At 30 degrees the interval is reduced to 5 arc minutes and again the interval is 0.66 millimeters. The values given are based on a copy made of the instrument by the author based on archaeological drawings of the original instrument (no. 35 in *The Cross-staff*).

56. This is what happened to me in the first attempt on the Hasebroek staff.

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

58. Hood, *The use of the Two Mathematicall Instruments* (1590), detail of the single foldout page at the end of the book. © British Library Board. All Rights Reserved, shelfmark 8534.b.22.

59. The cross-staff attributed to Christoph Schiffler in the *Istituto e Museo di Storia della Scienza*, Florence (inv. no. 3167) shows similar lines.

60. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 1 of part *The Use Of The Jacobs Staffe*.

61. Hood, *The use of the Two Mathematicall Instruments* (1596), title page.

62. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 4 of *The Use Of The Crosse Staffe*.

63. *Ibid.*, p. 3 of part *The Use Of The Crosse*

Staffe.

64. Blundeville, *His Exercises* (1594), p. 316 left.

65. *Ibid*., p. 317 left.

66. Waters, *The Art of Navigation*, p. 189.

67. 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), p.135.

68. Blundeville, *His Exercises* (1594), p. 317 left.

69. *Ibid*.

70. Sketch by the author based on the sketch in *His Exercises* by T. Blundeville, 1622, p. 672

71. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 9 of *The Use Of The Crosse Staffe*.

72. Idem., detail of the single foldout page at the end of the book. © British Library Board. All Rights Reserved, shelfmark 8534.b.22.

73. *Ibid*., p. 10 of *The Use Of The Crosse Staffe*.

74. Blundeville, *His Exercises* (1594), p. 317.

75. Hood, *The use of the Two Mathematicall Instruments* (1590), p. 5 of *The Use Of The Crosse Staffe*.

76. De Hilster, *The Spiegelboog (Mirror-staff): a reconstruction*.

77. *Ibid*., p.14.

78. A. Jacobsz., *Loots-mans Zee-spiegel*, (Amsterdam, 1652), Collection Maritime Museum Rotterdam, The Netherlands.

79. In basic shape the demi-cross is similar to Davis' 45 degree backstaff. The main differences are that due to it's design the demi-cross was capable of taking observations up to 90 degrees and that, in addition to the shadow vane and horizon vane, it was equipped with a sight vane. Also see J. Moore, *A New Systeme Of The Mathematicks* (London, 1681), p. 243.

80. Waters, *The Art of Navigation*, p. 189.

81. Cotter, *A History of the Navigator's Sextant*, p. 91.

82. Taylor, *The Doctrine Of Nauticall Triangles Compendious*, p.135.

83. De Hilster, 'The Spiegelboog (Mirror-staff): a reconstruction', p.6.

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Evolution of the Mining or Pit Barometer

Patrick Marney and Anita McConnell

Fig. 1 *Pit barometer signed by Davis & Son of Derby.*

By the mid-nineteeth century the development of technology allowed coal mines in Britain to be sunk to greater depths than hitherto. This put the colliers at greater risk of shaft collapse, inadequate ventilation and, above all, fire, with often huge loss of life. In response, the government sought to regulate the construction and operation of such mines, by imposing an inspection system and specifying the equipment that would, it was hoped, lower the accident rate among colliers. By insisting that all pits must have two shafts, ventilation was improved; by banning matches, candles, and gunpowder for blasting, and insisting on illumination by safety lamps, the risk of fire was diminished, but debate continued over the causes of sudden emissions of methane gas into the working areas.

Many coal seams release methane when exposed. Small quantities may be diluted and harmlessly expelled by the ventilation system, but large powerful emissions, when mixed with coal dust and oxygen, may ignite, with devastating results. It seemed possible that changes in atmospheric pressure could also encourage outflow of gas, but this was energetically disputed in the mining literature and in the various parliamentary enquiries. The engineers were not well-versed in current meteorological science, while the meteorologists who were called on to testify, knew little of conditions underground or of the chemistry of explosive mixtures. Nevertheless, among the regulations imposed by the Coal Mines Regulation Act of 1872, c76, was the keeping of a barometer (Figs 1 and 2) and thermometer at the pit head and this requirement was repeated in subsequent Acts during the nineteenth and twentieth centuries.

The first mention of a barometer intended to be taken down a mine is however considerably earlier: in a pamphlet *On the Ventilation of Coal Mines* published in 1849 by William Brunton (1777-1851), a civil engineer then resident in Wales, Brunton claims to have designed a sturdy barometer which can be taken down the pit, examples of which he is willing to supply. At this date the aneroid was still a new and untried instrument, and as Brunton does not refer to the novelty of his instrument he is probably speaking of a mercury barometer. Brunton exhibited his ventilating machinery at the 1851 Exhibition, but regrettably not the barometer, no illustration or example of this instrument having been located.

In1860 the instrument-maker L. P. Casella advertised in his *Illustrated and Descriptive Catalogue …* 'The numerous accidents occurring in coal mines in particular, and the close connection of these with atmospheric pressure, has induced L. Casella to modify and arrange his Economic Cottage Barometer, so as to be perfectly applicable for this purpose; and with a view to its extensive adoption at home and abroad, has fixed the price as above; the instrument being in every way as sensitive, hardy, and reliable as the much more expensive instrument now in use.' The price was 17/6d, or of larger construction and more elaborately furnished, £1-15s.

The 'much more expensive instrument now in use' was in fact the mining barome-