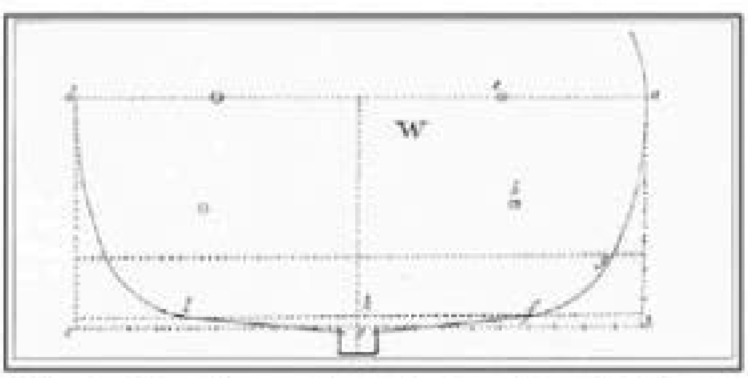
# The missing link

*By Ab Hoving*

## Introduction

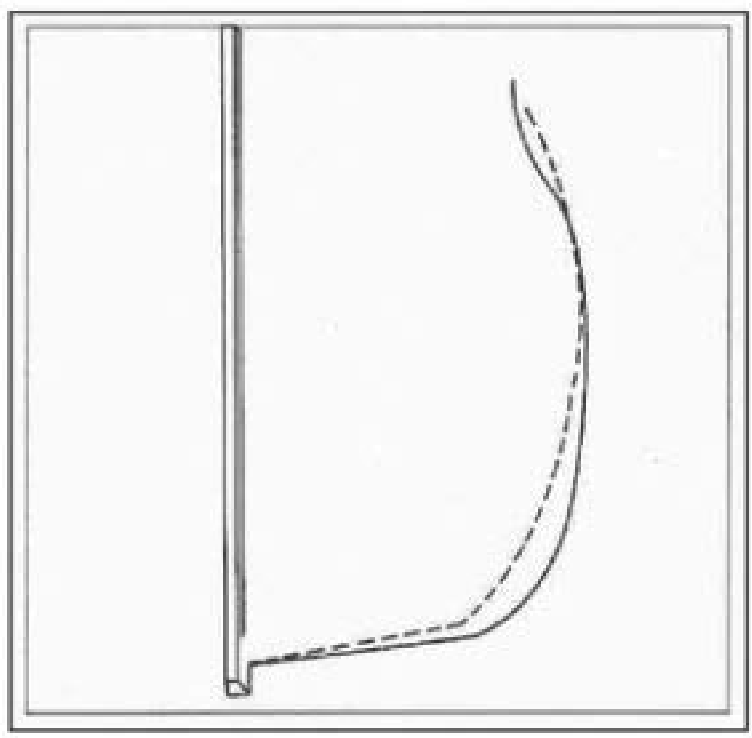
Much has been written in recent years about the technology of shipbuilding in Holland during the seventeenth century. However, an important aspect that has remained underappreciated is how, prior to construction, a ship's original design came about. Did the shell-first technique itself comprise the design or was there more to building a ship? According to what rules was the plan for a ship developed and when did that happen? Was the entire design worked out prior to construction or did that also happen partly during the process? The only thing that the famous book by Nicolaes Witsen (1641-1717) *Aeloude en Hedendaegsche Scheepsbouw en Bestier* (1671) offers us in the field of ship design is a simple sketch of how the shape of the main frame was determined. (Figure 1) However, if his suggestions are applied to, for example, his own example ship, the 134-foot *pinas*, a completely different shape will emerge. What value should we now assign to this scheme? (Figure 2)

Was this all that Witsen managed to extract from his naval architectural informants about this aspect of construction or did he, as I have sometimes suggested, merely want to embellish his book a little because of the painful lack of interesting geometric constructions in the shell first method? Such methods were elaborated in detail in other books he consulted, such as Furttembach, Fournier, Crecentius, and Dudley. Did he perhaps think that Dutch construction methods were a bit poor compared to those of neighboring countries? It is a tempting thought, but it does not seem very likely, especially because Witsen has always proven to be very reliable in the quality of his information.




1. Nicolaes Witsen: Construction of main frame. From: *Aeloude en Hedendaegsche Scheepsbouw en Bestier* (1671), Plate LII, W.

The discussion held on various forums ultimately focused on the wrong question of whether or not the Dutch seventeenth-century shipbuilder built his ships with lines plans in hand. Wrong because making a ship design did not necessarily depend on lines plans. Abroad, too, there appear to have been many other ways to design a ship prior to construction, without the need for lines plans. Consider for example the whole moulding system that worked with three marked molds with which the shape of each frame could be found, or the scratched planks of some Spanish builders. It is better to look at the moments when the ship builder had to resort on paper. As is known, no architectural drawings in the form of lines plans have survived of all those thousands of ships that were built in the Netherlands during the seventeenth century and earlier, so at that point the



2. When Witsen's theoretical frame construction is applied to the main frame of the *pinas* he described in detail, it appears that the impressive method produces a completely different shape. The solid line represents the main frame of the *pinas*, the dotted line that of Witsen's theoretical frame.

3. The remains of the *Samuel* can still be seen on the former Navy shipyard Willemsoord in Den Helder.

discussion, which was sometimes quite viciously conducted by some, came to a halt due to lack of evidence. Yet I cannot deny that the feeling of being left with an incomplete story has always been present in me too. Intuitively a link was missing in the chain of logical successive actions within the construction system.

But where should you look to find more information on this matter? Original drawings are therefore not available, the ships themselves no longer exist, wrecks have rarely been mapped to produce a credible and complete lines plan, contemporary ship models are too unreliable to attribute absolute documentary value to them, and too the artistic historical treasure of paintings, prints and drawings are of no value to us in this regard.

Or is this all a bit short-sighted?

## Sources

The nice thing about internet forums is that sometimes someone pops up who can shed light on a seemingly unsolvable mystery. The person who brings enlightenment in this matter is a Polish scientist, Waldemar Gurgul, who has managed to analyze the geometric underlying shape of various ships through reverse engineering. Unfortunately, I cannot let him speak here himself, because he chose not to participate in the writing of this article. That is regrettable, but not insurmountable, although we will have to do without his explanation of his research methods here. The bottom line is that he managed to make it plausible that Witsen was right and that some kind of simple theoretical construction did indeed take place before and/or during construction, probably on paper, although that is not at all certain. The availability of paper was a lot less obvious in the seventeenth century than it is today. It is equally possible that it was done in a much simpler way: directly on the wood, on a slate, or perhaps even scratched into the dirt of the shipyard. That would explain why none of these things have survived.

Which sources turned out to be useful to make geometric design methods in the Low Countries plausible?

First of all, there are the few hull shapes that have been left to us in the literature. As is known, Witsen's *pinas* was measured down to the inch by him in the description of the ship and recorded in his book. The measured dimensions led to a perfect lines plan of an average commercial ship.

A second opportunity is offered to us by the *Vereenigde Oostindische Compagnie* (Dutch East India Company VOC), which laid down the shape of its East Indiamen in a resolution in 1697. The dimensions noted by P. van Dam in his *Beschryvinge van de Oostindische Compagnie* (1701) could also be converted into full-fledged lines plans of three charters of East Indiamen, namely 130, 145, and 160 feet long and of a fluit or hagboat of 130 foot. This defines the original shapes of these five ships and they can be analyzed.

A second source of information appears to be a small number of measured hulls of shipwrecks. An example is that of the *Vasa*, the Swedish royal ship that is so magnificently exhibited in the Vasa Museum in Stockholm. But simpler and also much clearer is the wreck of the *Samuel*, better known among archaeologists as the E81, a *pinas* loaded with wine and oranges, which sank near the island of Schokland (in what is now called the IJsselmeer) around 1650 and was discovered by the Archaeological Service in the 1960s. The hull has been excavated and mapped. Today, large parts of it can still be viewed on the site of the former States yard Willemsoord in Den Helder. Here too, evidence of geometric design appeared to be present in the drawings studied. (Figure 3)



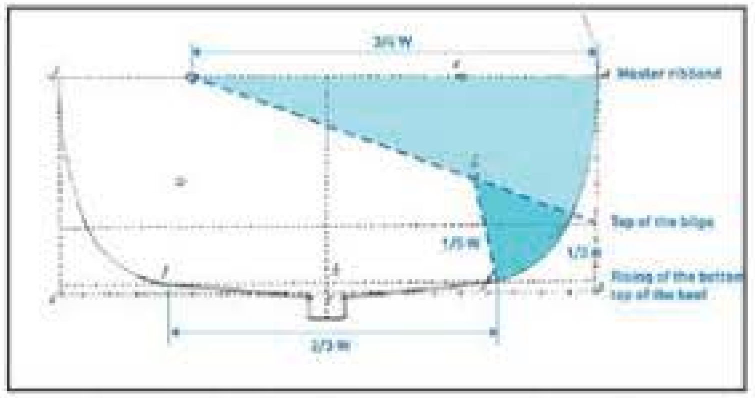


The third source consists of a few early difficult-to-date drawings from the period around the transition to the eighteenth century, which appear to provide information about seventeenth-century ship hulls. Around 1700 there appears to be a tendency to draw lines plans, although the variety in their design shows that a suitable format had not yet been found. Sometimes frame shapes were flipped at their various locations in the side view along their vertical axis, sometimes around a horizontal one in the top view and sometimes an early form of a body plan appears, with views drawn separately from each other as we still use them today. More about that later.

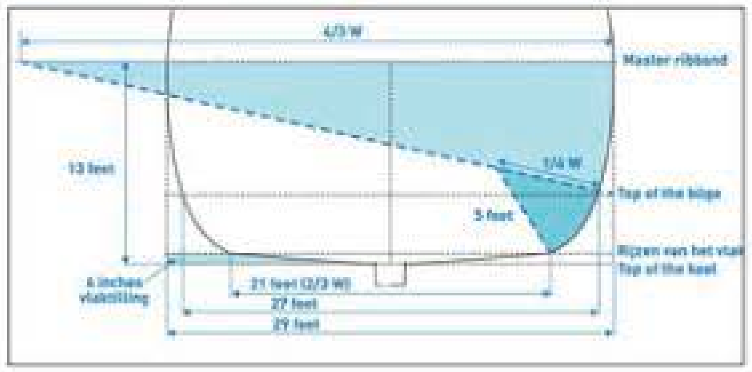
## The main frame

We choose from the first source, literature, Witsen's *pinas*. As can be seen in Figure 2, the shape of the main frame does not appear to correspond to its theoretical sketch shown above. According to his theory, the frame is drawn within a rectangle, the bottom line of which indicates the top of the keel, the line shortly above that indicates the extent to which the bottom rises, the third is the line that marks the top of the bilge, and the top line marks the width and depth of the ship, and is also the location of the master ribband. From the keel, a straight line is drawn diagonally upwards to either side, representing the bottom. The width of the bottom (two-thirds of the width of the ship) and its rise (half an inch for every foot of width) are thus determined. Witsen divides the width of the ship, the top line, into four equal parts, taking three parts as the radius for his circle segment between the top of the bilge and the hull line (a-g). He does not explain the location of point h, but it appears to be found by taking one fifth of the width of the ship in the compass and marking it from both the edge of the bottom and from the bottom of the circular arc just found. From the point thus found, the missing curve between the bottom and the arc can be drawn. (Figure 4)

However, this construction does not appear to correspond to the shape of the *pinas*. It is entirely to Gurgul's credit that he managed to locate the centers




4. Witsen's method explained: The upper circular arc is drawn with three-quarters of the width of the ship in the compass. The small arc is drawn from the lower radius by one-fifth of the width. The width of the surface is two-thirds of the total width, for the rising on both sides the




5. Witsen's method applied to the 134-foot *pinas* according to Gurgul. The pivot point of the compasses for the upper circular arc is at four-thirds of the width. The radius of the bottom one is one-sixth of the width. The bottom rises 6 inches. Both this size and the width of the bottom (21 feet) strictly follow the rule.

of the circular arcs of the *pinas* by means of reverse engineering. These appear to have been chosen differently for the *pinas* than in Witsen's example: instead of three-quarters of the width of the ship for the upper arch, four-thirds was chosen. One-fifth of the width of the lower circular arc has been replaced by one-sixth. (Figure 5) These changes fit in seamlessly with the way in which the shipbuilders dealt with all the other rules of thumb that had been given to them by tradition. Shipbuilders have always played with the norm when it comes to shaping parts, as we will see in a moment. They did this because they hoped to improve the performance of their ship. In any case, it is clear that geometric principles were indeed used by the Dutch shipbuilders when designing the main frame of the *pinas* and that Witsen's drawing was not the result of his imagination.

Creating a main frame design was important, because the shipbuilder could take the shapes found to the timber merchant to purchase trees with the correct curvature.

Witsen received much of his information from shipbuilders, such as Grebber with his generic list of ship parts for ships from 60 to 200 (!) feet, the Frisian Jan Jacobszn Vijzelaar, and the 'famous ship builder Mr. Dirk Raven', from whom he quotes a number of specification contracts. The question is whether they had their tongues in their cheeks with regard to the possibility of varying designs, because the profession of shipbuilder held secrets that would rather not be shared with third parties. It may also be that Witsen did not consider it necessary to write more about it than he did. In any case, the information he provides in his book is like the rest of his material: highly reliable, but it is clearly incomplete in this special case.

## Design and construction

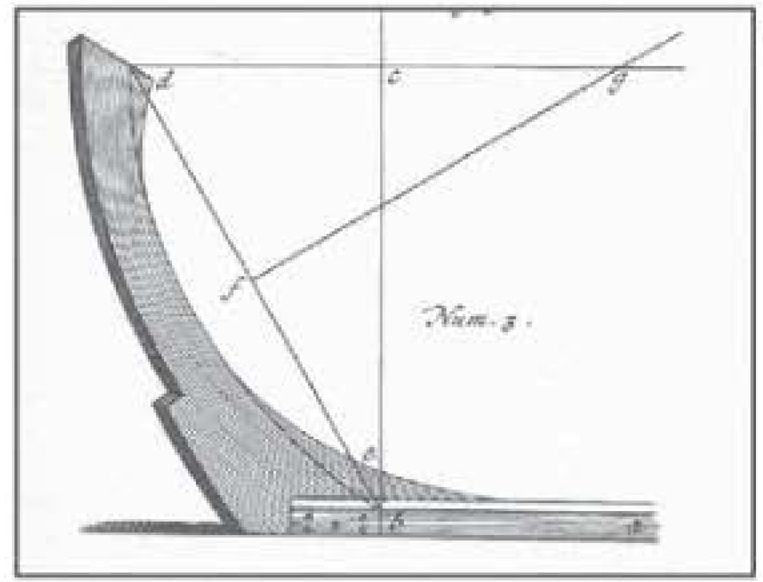
We will follow the construction of a ship here as an example to see where, apart from the construction of the main frame described above, the design moments exactly lay. The dimensions of the ship are of course determined in consultation with the client. Let us assume a desired ship is 120 feet in length. The general building rules prescribe that the width was to be one quarter of the length, i.e. 30 feet, and the depth one tenth, i.e. 12 feet. But in the surviving specifications in, for example, notary archives, you rarely come across a ship that exactly corresponds to the standard in terms of dimensions. How did that happen?

When a new ship is ordered, the client indicates his wishes: type, length, function, geographical destination, size of the crew, possible armament, whether or not there are to be deck beams halfway the hold to create an orlop deck if necessary (an orlop deck is a temporary deck), etcetera. The craftsmanship of the shipbuilder is expressed in the successful application of small variations on the traditional rules of thumb, based on insights gained through experience. In fact, this was often also a matter of feeling. Calculations of stability, resistance, speed, displacement, and loading capacity were not made. For example, for a cargo ship, a somewhat narrower shape would have been chosen for reasons of speed than a quarter of the length prescribed by the rule of thumb; for a large warship, an extra foot or more could be added on either side. However, for the depth, as a rule of thumb one-tenth of the length, generally little deviation from the norm was applied, except in the case of grain carriers, which were made two feet shallower to prevent overloading. Grain is extremely heavy.

The following lists a number of ship parts that are probably not known to everyone. It is recommended that you visit the website https://witsenshipbuilding.nl, set up by the Cultural Heritage Agency of the Netherlands, where each item in the Encyclopedia is clearly shown and discussed. One can also interactively witness the shell-first construction technique there.

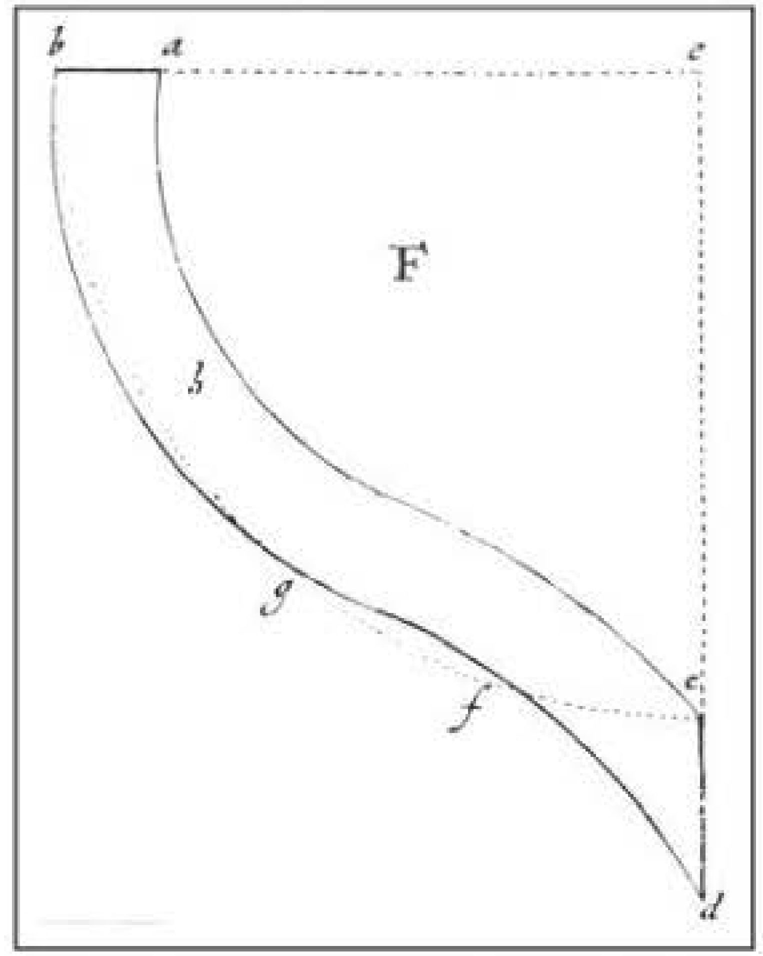
When discussing the main frame above, it was already mentioned that the builder played with the rules of thumb on which the ship's design was based, and it also appears that a lot of variation on the rules of thumb is possible in other shape-determining parts. The shapes of the stem and stern were also determined at the shipbuilder's discretion. That shape depended on the function of the ship and the resulting internal layout. The number of decks was also a determining factor. In the view of the seventeenth century, a strongly raking stem was appropriate for a fast ship, while an upright stem was chosen for a ship that had to be able to load a lot. The same considerations applied to sterns. Van Yk gives the construction on paper of both an upright and a much raking stem. Witsen describes the making of both the stem and stern in detail but nowhere refers to a pre-drawn design. (Figure 6) It is striking in this design that the drawn quarter circle is not strictly followed, but rather served as a guideline in the choice of the shape.






6. Construction of a stem according to Van Yk. Although a circular arc is used, the stem does not follow it completely.

We see the same phenomenon at the transom, the flat rear of the fuselage, where the geometry was also applied rather loosely. Although the use of the compass was leading, it was not absolute. The shape



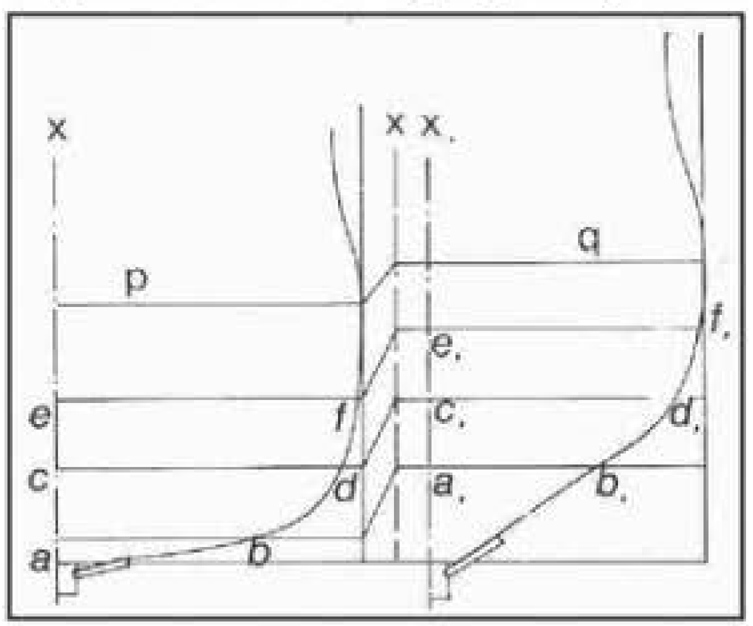

7. Construction of the fashion piece by Witsen. The fashion piece forms the shape of the square tuck. Here too, although the drawn arc is leading, it is not necessarily followed.

8. A twisting garboard strake modeled by Maarten Bunte. The position of the plank changes from almost horizontal to vertical against the stem. The location of the rotation determines the shape of the hull.

of the important and extensive fashion piece, which connected the transom to the stern, as it were, winds around and through the drawn circular arc. (Figure 7)

Another important design element was the garboard strake. This first strake next to the keel twisted somewhere aft from almost horizontal to vertical, to fit against the foot of the stern. (Figure 8) The exact location of that turn had a major influence not only on the fullness of the ship and therefore on its loading capacity, but also on its correct position in the water, laying down by the stern one foot for every 50 feet of the ship's length. There was a method to determine where that rotation should take place. The Delfthaven Cornelis van Yk notes a passage in his *De Nederlandsche Scheeps-Bouw-Konst Open Gestelt* (1697) about the shape of his fore and aft frame. He describes a somewhat different construction process than Witsen did. In his vision there were two central frames of the same shape and a front and a rear frame, all four of which were decisive for the shape of the ship. (see Figure 12) He shows how a connection could be made between the shape of the forward frame, which he placed on the butt of the stem and keel, and the aft frame, which was placed at the same distance from the aft perpendicular. He achieved taking into account both the desired amount of laying deeper at the stern and the narrowing of the ship towards the rear in his design. (Figure 9)

The randomly drawn horizontals in the fore frame on the left are raised as a result of the ship lying deeper in the stern and shorter due to the narrowing of the ship towards the aft. The position of the garboard strake gives an indication of where it should start to twist. It is clear that these two frames must have been designed on paper. On top of that, Van Yk depicts a number of adjustable squares, all of which indicate the angle with the keel on the fore and aft frame of different types of ships, a hooker, a fluit, two three-masted ships, and a herring buss (Figure 10). A good example of archiving for reuse. Apparently a new design was not made for every ship, but experiences



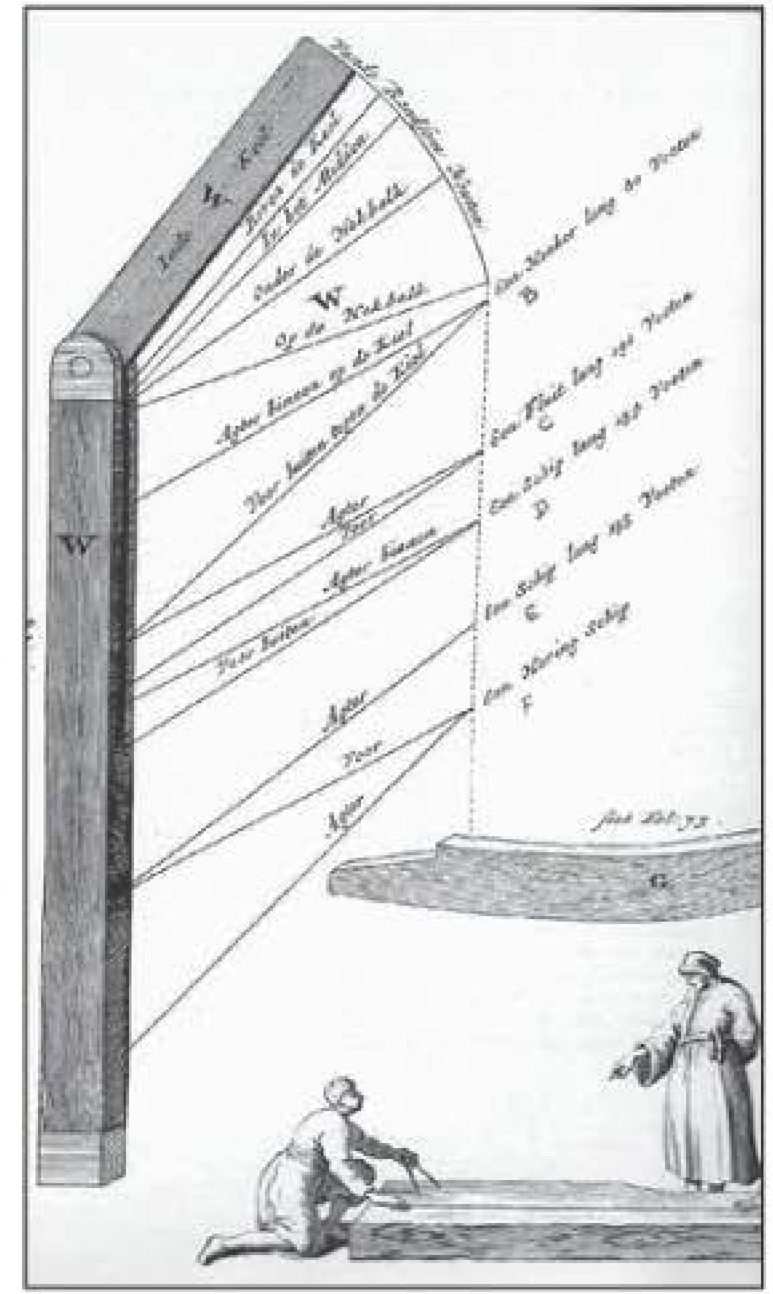

9. Construction of the aft frame (right) derived from the fore frame (left). The fore frame is a slightly smaller copy of the main frame and is located at the junction of the keel and stem. (see also Figure 12) The difference in height between the horizontals in both frames is caused by the desired stern depth (the rear of the ship lying deeper than the front). The stern is narrower because the master ribband narrows towards the rear. The lengths of the horizontals form the outline of the frame. Note the angle of the garboard strake, the first bottom plank next to the keel.



gained from previous construction projects were reused.

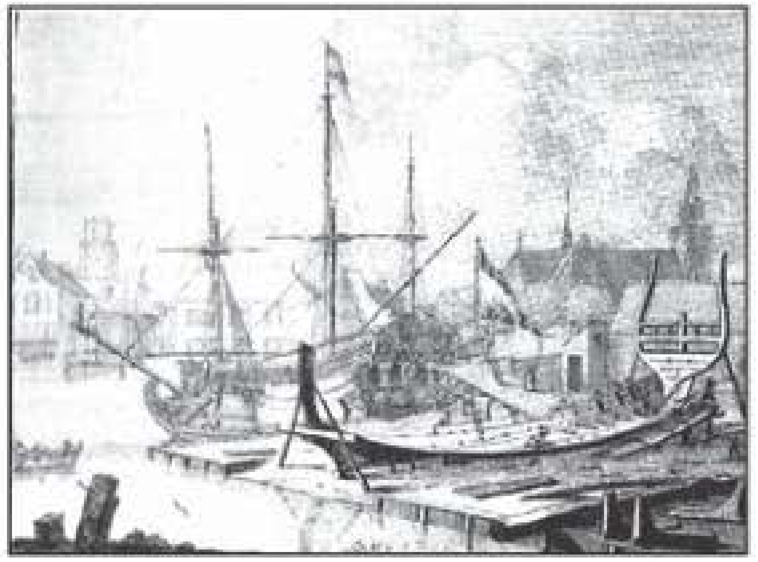
Another part that influenced the character of a ship was the width of the bottom of the ship, which, according to Witsen, should be two-thirds of the entire width. Another decisive part, the transom, should be given the same proportion. Van Yk, who published his book twenty-six years after Witsen, sees no connection between the two and opts for a transom that measures three-quarters of the width, which resulted in a more spacious stern, entirely in accordance with the development of ship design in the seventeenth century. (Van Yk, 62) The bottom could rise more or less, depending on the views of the master builder, and also with regard to the width, various specification contracts show that the rules were not always rigidly followed. Here too, more variation is possible than just what the standard prescribed. However, an elaboration on paper does not seem to have been necessary here. As the bottom grows, construction already begins to reach a stage where one action calls for the next, without the need for any means other than constant control of symmetry.

The run of the master ribband was of great importance. This was a temporary strake that was placed around the ship and made visible the outline and therefore the width of the hull to be built. In addition to the width, the strake also determined the depth in hold (the distance in the hold between the top of the keel and the height of the master ribband) and it is no wonder that Van Yk writes that some shipbuilders kept those master ribbands to be reused for a possible later similar ship. (Van Yk, 75). It was also important that the master ribband indicated the sheer of the ship: the wales, the timbers that were so visually important were placed exactly above and below the ribband. Here Gurgul noticed something that has hitherto been overlooked by everyone: the stem was supported on either side by a brace. (Figure 11) Several images show that a horizontal plank had been placed against those two braces. It may have been intended as an interconnection between the braces

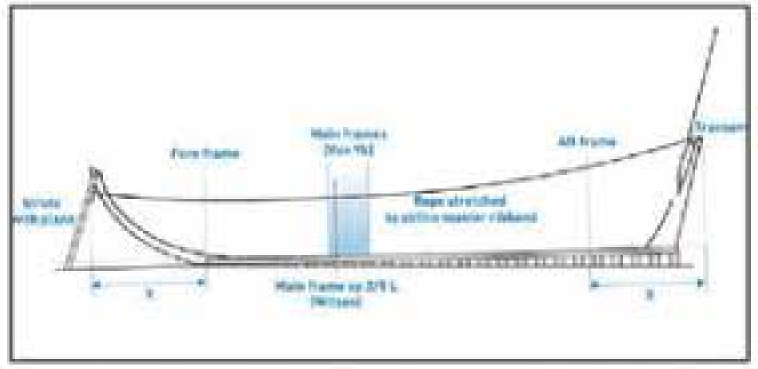


10. Adjustable square used to measure the angle between garboard strake and keel, registered for a hooker, a fluit, two ships, and a herring buss. The position of the turning of the strake was important for the shape of the ship and the angles were measured at the location of the fore and aft frame. From Van Yk, *De Nederlandsche Scheeps-Bouw-Konst Open Gestelt* (1697), 68.

and the stem, but it is more likely that a rope with a small depression was stretched from the transom at the stern, with which the sheer of the latter to be added master ribband could be determined. (Figure 12) The rules of thumb for the rising of the wales and the deck will have guided the degree of curvature. A part of the design was not determined geometrically, but whose correct shape could be obtained using simple carpentry techniques.



11. Siewert van der Meulen: a shell-first built ship in an early stage. Note the cross plank on both braces for the stem.



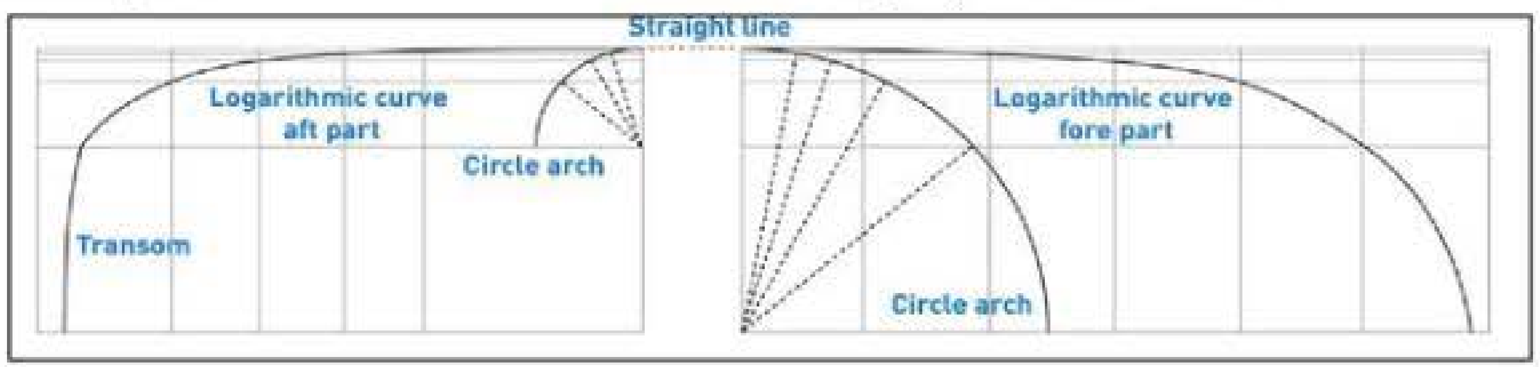
12: With a rope that is not stretched too tightly between the end of the plank on the struts and the transom, the sheer of the ship could easily be determined. The master ribband was copied from this line and provided the location of the wales to be added later. The location of the fore and aft frame is indicated, Witsen places the main frame at 2/5 of the length, Van Yk mentions two center frames, about 10 feet apart, the only location 'of the entire ship that is of equal shape'.

The top view of the ribband on the other hand, required some simple math. It is again Gurgul who discovered that in the top view of the *pinas* two geometrically determined curves have been applied, both designed as a logarithmic curve, connected in the middle with a straight line. With a logarithmic curve, a quarter circle is halved repeatedly: 1/2, 1/4, 1/8, 1/16, etcetera. Horizontal lines are drawn crossing the radial points. The distance to be drawn is divided into equal parts and the logarithmic curve is drawn through the intersections of verticals and horizontals, which delivers in fact a stretched circular arc. (Figure 13)

Once the position and shape of the master ribband had been determined in this way, nothing could actually go wrong. The design of the underwater part was complete.

Above water, the shape of the hull was mainly determined according to the wishes of the shipbuilder and his client, without the need for mathematical tricks. Van Yk even fulminates against master builders who, in his opinion, "due to a wrong delusion of beauty, allowed the top timbers (the upper frame parts) in the bow to bend too far outwards, although causing a lot of wood spilling." (Van Yk, 72) In short, the design was too free for his liking.

Witsen gives the rule for the tumblehome of the top timbers that they must bend inwards almost two feet at the height of the upper deck to make the top of the ship narrower. (Witsen, 74) That was good for stability and made the ship more difficult to board by enemies. But warships were made as wide as possible above, partly for the same reasons.

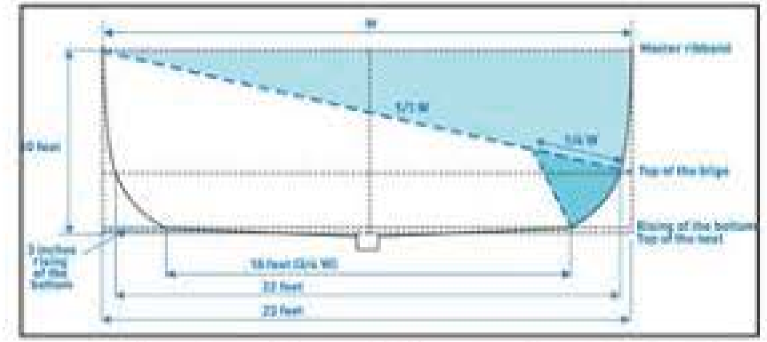



13. Viewed from above, the master ribband formed a logarithmic curve. Such a curve is created by repeatedly dividing the arc by two. The first radius goes to half the arc, the second to a quarter, the third to one-eighth, etcetera.



## Wrecks

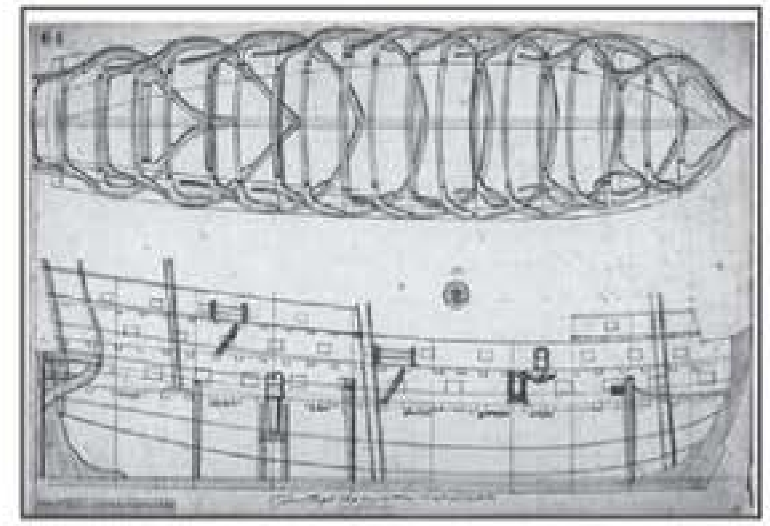
So far we have only followed the literature in our search for geometric techniques. But even if we look at the scarce wrecks that have survived time in such a condition that we can still represent them in a reasonable lines plan, it appears that Witsen's theoretical representation of the construction of the main frame can also be clearly demonstrated here, albeit with a similar variation in the choice of the location of the compass points for the used circular arcs as what we saw with the *pinas*. Here is the reconstruction of the main frame of the *Samuel*, as analyzed by Gurgul. (Figure 14) As can be seen, the center point for the large arch is taken at the full width of the ship and that of the small one is at one sixth of the width. The ship has only three inches of bottom rising, and the bottom here, also deviating from the norm, has gone from two-thirds to three-quarters of the width.



14. Gurgul's analysis of the wreck of the *Samuel* (ca 1650). The radius of the upper circular arc is the full width of the ship, the lower one one-sixth of that. The bottom was not two-thirds of the width, but three-quarters. The bottom rose only three inches.

## Drawings

Regarding the last category, the original drawings, it can be reported that a small number of early ship drawings have been preserved, most of which date from around the transition from the seventeenth to the eighteenth century. Around that time, for various reasons, interest arose in archiving the shape of ships, which meant drawing up lines plans. That did not happen automatically. I mentioned earlier that the format as we know it today had not yet been developed. Only after the introduction of diagonal lines around 1725 do we gradually see a general consensus emerging about what a complete lines plan should look like. (A.J. Hoving & A.A. Lemmers, *In Tekening Gebracht*, De Bataafsche Leeuw B.V., 2001)



15. Drawing of *A 72 guns frigate ship, long between stem and stern 162 feet*. Navy Collection, The Hague.

Gurgul has analyzed a beautiful drawing in the Navy archives that was probably made around the turn of the century. (Figure 15) Some more geometric techniques have already been applied to this drawing, such as an elliptic curve for the stern (with an elliptic curve the arc of a circle is not repeatedly halved, but divided into equal parts), but in principle the old division of bottom, bilge, and master ribband is still used. Yet here we are looking at the announcement of a whole new era, with complex frame constructions consisting of no fewer than four different connecting circular arcs. It would take too long to follow this development here, but it is clear that both from the example of literature (Witsens *pinas*) and from found wrecks such as the *Samuel* and also from the early drawings, geometric principles have not been foreign to Dutch shipbuilders. It should be noted that the selection of frame constructions presented here is mine; Gurgul has worked on several wrecks and drawings, from which the same conclusions could always be drawn.

## Conclusion

Back to the disagreement about whether or not the Dutch master builders built from drawings. I stated earlier that the question was wrong. It should have

16. In this painting by Moolenaar from 1682, the Edam shipbuilder J.M. Oosterlingh proudly shows his imaginary complete oeuvre to his daughter and son-in-law Tjerk Lolckes. The many waterships and fluits make it clear which types he specialized in.

been: did they use mathematical design techniques or not? They did. Did they create useful lines plans for us? No, we definitely would have found them. They designed (perhaps on paper) parts, such as stem and stern, the master ribband, and the main frame, but that apparently never led to the kind of plans that are recognizable and useful to us. They needed the drawings partly for the start of construction, but also to order the shape and dimensions of the required wood. Once construction was underway, with a few exceptions, no master builder needed extensive plans, one construction phase automatically led to the next. "The ship built itself," as Bill Leonard, the master builder of the Australian shell-first replica of the VOC yacht the *Duyfken*, built in the late last century, noted. Model building tests with the shell-first method showed exactly the same thing. Carpenter's solutions, such as applying splines over the frames and the use of flexible battens to draw curves on the wood, together with the experience of the master builder, were sufficient to deliver a perfect ship.

Was a new design made for each ship? No, it is almost certain that a shipbuilder specialized highly in certain ship types. And once he had a good design in hand, it was much easier to follow it than to create new designs over and over again. This may have been one of the reasons for the particularly slow pace at which many developments in shipbuilding took place. In a painting by Moolenaar we see a proud Edam shipbuilder showing his entire production to his daughter and son-in-law. They are almost all waterships and fluits, with here and there a prestigious big ship. It is anyone's guess whether the builder made a new drawing for each ship. (Figure 16)

With thanks to Waldemar Gurgul and Maarten Bunte, and Emiel Hoving, who made all the technical drawings.

Ab Hoving was the lead restorer of model ships and curator of the Marine Model Room at the Rijksmuseum in Amsterdam from 1989 until 2012. He has published many articles on Dutch shipbuilding and its history in academic and modeling journals, including the *NRJ*, and wrote *Nicholaes Witsen and Shipbuilding in the Dutch Golden Age, The Statenjacht Utrecht, 17th-Century Dutch Merchant Ships, Message in a Model*, and most recently, *Dutch 17th Century Ship Models in Paper*. He also was involved in the creation of the full-size replicas of *Duyfken* in Australia, the statenjacht *Utrecht*, and the revised design for Michel de Ruyter's *De Zeven Provincien*.