A COG-LIKE VESSEL FROM THE NETHERLANDS

A Thesis
by
ALEYDIS MARIA P.A. VAN DE MOORTEL

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A COG-LIKE VESSEL FROM THE NETHERLANDS

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ALEYDIS MARIA P.A. VAN DE MOORTEL

Approved as to style and content by:

J. Richard Stoffy
(Chairman)

George F. Bass
(Member)

Edward J. Soltes
(Member)

Vaughn M. Bryant
(Head of Department)

December 1987
ABSTRACT

A Cog-Like Vessel from the Netherlands. (December 1987)
Aleydis Maria P.A. Van de Moortel, B.A., Katholieke
Universiteit Leuven

Chairman of Advisory Committee: J. Richard Steffy

The meticulous excavation of a small, well-preserved
shipwreck in lot NZ43 of the reclaimed Zuyderzee polders,
the Netherlands, has provided a wealth of new data on late-
medieval shipbuilding. The wreck is of a small local craft
that shares many characteristics with cogs, the leading
seagoing vessels of northern Europe at the time. This study
represents the first in-depth analysis of the actual remains
of a cog-like vessel. The wreck has provided concrete new
information, not only of construction features, but also of
hull design and sailing qualities of cogs. The vessel is
extremely well-built and bears witness of several techniques
known previously only from 17th-century Dutch sources. The
construction also reflects socio-economic conditions of the
time. As such, this small wreck from lot NZ43 constitutes an
invaluable source for understanding the history of northern
European shipbuilding techniques in the late Middle Ages.
DEDICATION

To my parents
ACKNOWLEDGMENTS

First of all, I would like to thank Reinder Reinders of the Museum of Maritime Archaeology at Ketelhaven for giving me the opportunity to work on this project. I also want to express my warmest thanks to him, as well as to Rob Oosting and Karel Vlierman, for granting me their most generous assistance during my research.

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The task of proofreading the manuscript was undertaken undauntedly by Mike Fitzgerald and Beth Braznell. Their meticulous work is much appreciated.

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CHAPTER I

INTRODUCTION

A. Ship archaeology in the Zuyderzee

From 1930 to 1968, large parts of the Zuyderzee were drained for land reclamation (fig. 1). This sea-arm jutting into the heart of the Netherlands had been for centuries a busy route for local and international traffic. During the late Middle Ages it was at the crossroads of the east-west and north-south routes of the Hanses, German merchant cartels that then dominated northern and central European commerce. Local trade in the Zuyderzee region was primarily waterborne because of the poor state of the roads along the marshy shores. The Zuyderzee waters also were busy fishing grounds. Sailing this sea-arm was not easy, however, because strong winds could come up quickly from the North Sea, causing high waves in the shallow water. As a result of heavy traffic and dangerous sailing conditions, the Zuyderzee is strewn with shipwrecks (fig. 2 on p. 3). To date, the reclaimed polders have yielded about 350 wrecks ranging in date from the 13th through 20th centuries. This collection is unique in that it contains not only many

This thesis follows the style of the American Journal of Archaeology.
Figure 1. The Zuyderzee water management and land reclamation project. (de Jong et al., 1982, fig. 1)
Figure 2. Shipwreck sites in the Zuyderzee region. (Reinders, 1982, fig. 3)
specialized craft, but also several examples of the same kinds of vessels, thus enabling ship historians to study the evolution and variation within those types.²

The shipwrecks discovered in the polders have sunk into a layer of clay and are exposed to destruction by the gradual sinking of the water table. Not only is the humid, anaerobic environment in which they have been preserved breaking down, but the clay layer dries out and starts to crack as well, breaking the wrecks apart. The large number of endangered shipwrecks needing excavation on the one hand and the pressure of the land developers on the other for a long time forced archaeologists to limit their activities to quick surveys and salvage.

Since the late 1970s, a preservation method was developed which allows archaeologists to keep the wrecks indefinitely in an anaerobic environment until there is time to study them (fig. 3). The wreck is surrounded with plastic foil that reaches from below the water table to the top of the wreck, leaving over the center an opening shaped as a rain trap. The clay layer underneath the wreck keeps the water from seeping out, while the plastic foil on top reduces evaporation and lets in sufficient rainwater to maintain the water level required inside the tub. The entire structure is covered with sand as an additional protection. In this way, more than twenty important shipwrecks have been
Figure 3. Preservation method for Zuyderzee shipwrecks. (Reinders, 1982, p. 13)
protected and are now awaiting study. The oldest type among them are the so-called cog-like vessels.

8. Cogs and cog-like craft

The term "cog" is used in late-medieval texts to refer to a vessel type that included small local craft as well as the largest seagoing ships of the time. Apparently, cogs were very efficient vessels, and by using them, the German Hanses were able to dominate seaborne commerce in northern Europe for centuries. Because of their importance to late-medieval history, cogs have been studied extensively. Today, much is known about their outward appearance, their qualities and use, but we are still unsure as to their technical characteristics and origin.

Since the early 20th century, more than thirty iconographic representations, mostly medieval city seals, have been discovered. They show that cogs were compact and tubby vessels with a sharply built lower hull, combining a large cargo capacity with good sailing qualities. The rather angular profile and high sides seem typical. The rigging consisted of a single square sail. Several variants are recognized among the represented vessels, but the identification of some as cogs is still debated.

The first shipwreck identified as a cog was found in 1962 near Bremen, in northern Germany. The on-going study of this largely intact hull has yielded considerable
information on the construction features of cogs. The Bremen cog has a rather flat bottom with its strakes lying flush. The overlapping side planks were connected with clenched iron nails. Seams were caulked with moss, which was covered with laths and secured by iron clamps. Protruding deck beams, reinforced by heavy standard knees, provided considerable rigidity to the upper hull.\textsuperscript{6}

Since the discovery of the Bremen cog, more than fifteen less well-preserved shipwrecks from Denmark, Sweden, Poland, and the Netherlands were found to have similar features. None of these is entirely identical to the Bremen vessel, however, so that the question remains which features can be accepted as being diagnostic of cogs. Two approaches exist among archaeologists. Danish archaeologist O. Crumlin-Pedersen opts for a minimal definition that would be useful to archaeology. He considers as cogs all double-ended craft with angular profile, flat bottom with flush strakes, and steep lapstrake sides.\textsuperscript{7} German scholar D. Ellmers agrees with Crumlin-Pedersen and adds the characteristics of a drop-shaped plan view, the bow being wider than the stern, a possible slight rise of the keel fore and aft, clenched nails joining the overlapping strakes, and butterfly-shaped clamps holding the caulking.\textsuperscript{8}

Zuyderzee archaeologist R. Reinders, on the other hand, searches for an historically accurate definition. As long as we do not know how cogs differed from other contemporary
boat types, he prefers to designate wrecks that are not entirely similar to the Bremen cog as "cog-like vessels." In this thesis, I will adopt Reinders' terminology.9

The information uncovered from the Bremen wreck prompted Cruinin-Pedersen to take up the long-standing question about the origin of the cog type. He places his hypothesis in the framework of a broader theory on the evolution of large ship types. Cruinin-Pedersen distinguishes different basic concepts of boatbuilding in northern Europe that produced simple, small vessels (fig. 4). At certain stages in history, because of economic, technical, or political developments, basic hull types were expanded into large seagoing craft through a mixture of tradition, borrowing, and innovation. The small vessels of the type, meanwhile, remained in use for local trade, and often survived the large craft by centuries. Ethnographic studies of later small boats can thus be used as clues for the construction of large ships of the past.

The cog resulted from one such basic shipbuilding concept, and was probably first developed in Frisia, as several earlier researchers had supposed. Cruinin-Pedersen acknowledges that this Frisian origin cannot yet be proven archaeologically, but argues that smaller cog-like vessels from the iconographic and ethnographic record seem built to suit the tidal reaches of the Frisian Waddenzeee. During the
Figure 4. Basic structural characteristics of four ship types from early medieval northern Europe.
  a) Nordic clinker type, b) cog type, c) hulk type, d) Punt type. (Crumlin-Pedersen. 1979. fig. 2.1)
13th and 14th centuries, these small craft would have been developed into the large Hanseatic cogs in order to accommodate for the growing sea trade in bulk goods. Using data from Danish cogs, Crumlin-Pedersen hypothesizes this evolution involved the use of more and more overlapping strakes, the development of a fully integrated frame structure, as well as a gradual changing of the mast location from forwards toward amidships.¹⁰

Ellmers elaborates on Crumlin-Pedersen's theory, providing additional archaeological, historical and ethnographical evidence. Having studied recent small cog-like craft from Germany, he traces the basic cog shape back to the dug-out canoe, and reconstructs a step-by-step evolution whereby the cog type would have spread from the region between Rhine and Weser northwards up to Poland and southwards to Flanders.¹¹

C. Cog-like vessels of the Zuyderzee

About ten wrecks from the Zuyderzee, dated to the 13th and 14th centuries, share characteristics with the Bremen cog. They comprise large and small wrecks, and several are in excellent condition. This collection of cog-like vessels gives ship archaeologists the unique opportunity to study evolution and variation within the cog-like type, and to test Crumlin-Pedersen's hypothesis on the gradual change of the constructional features of cogs. As such, the Zuyderzee
cog-like wrecks may yield important clues to the problems of
definition and origin of cogs.\textsuperscript{12}

Reinders realized the importance of the Zuyderzee
wrecks and decided to design a research project on cog-like
craft with an emphasis on the Low Countries. Some aspects
have already been studied. A. Luns devoted a short doctoral
dissertation to written documents, and found interesting new
sources.\textsuperscript{13} R. Hulst wrote an elaborate doctoral
dissertation evaluating and comparing all iconographic and
archaeological evidence known to date, mostly with regard to
the construction and design of cog-like vessels. Hulst also
compares cog-like craft to boats of the Scandinavian and
Slavonic traditions.\textsuperscript{14} The present thesis project will be
the first reconstruction and in-depth analysis of a small
cog-like wreck from the Zuyderzee.
CHAPTER II

DISCOVERY AND RECONSTRUCTION OF WRECK NZ43

A. Position of the wreck

In 1971, during irrigation work in lot NZ43 of South Flevoland, at the southern edge of the reclaimed Zuyderzee polders, the remains of a small boat were discovered (fig. 5). The wreck measured about 10 by 4.5 m and was situated approximately 0.5 m below the present surface. The broad central part of the vessel immediately suggested it had been a merchantman, but no trace of cargo was found. The only contents were some fragments of bricks and ceramics, a few iron scraps, some small cattle bones, and, under the ceiling planking, a small piece of textile and a leather fragment.

The wreck lay on its port side, the bow about 10 cm lower than the stern. Bow, port side and stern were resting against a large dune of undisturbed Pleistocene sand (fig. 6). Under the starboard side, a broad layer of disturbed sediments was found, of which the lower part consisted of displaced Pleistocene sand, and the upper part of alternating fine layers of sand and clay. The entire wreck site was covered by a nearly 10-cm-thick layer of clayish freshwater sediments called Aimerde deposition, which in turn was topped by an approximately 30-cm-thick layer of clayish salt-water deposits called Zuyderzee alluvium. The dating
Figure 5. Distribution of cog-like wrecks in the Zuyderzee. (Adapted from Reinders, 1985, fig. 1)

Figure 6. Bottom profile of wreck site NZ43. (Adapted from drawing by Museum Ketelhaven, courtesy IJsselmeer Developments Authority [R.I.J.P.]; all unpublished drawings and photographs of the R.I.J.P. are covered by first two items of letter of permission on p. 311)
of these sediment layers has not yet been established for this part of the reclaimed polders. At present, it is thought that the Almere clay was deposited possibly before the 16th century, and almost certainly before A.D. 1600, providing a tentative *terminus ante quem* for the sinking of the wreck. The excavators dated wreck NZ43 to the late Middle Ages on the basis of constructional characteristics. Dendrochronological studies of 48 wood samples are to be performed in the near future.

Several explanations can be suggested for the vessel’s sinking. Because of the composition of the disturbed layer and its tapering in a northwest direction (fig. 7), the excavators hypothesized that the vessel might first have stranded on a shallow bank, where it filled with water. Later, the wreck would have sunk further, gliding to the southeast until it came to rest permanently against the sand dune. In the process, some of the sand had been disturbed, and the boat had left several planks behind in its wake.

**B. Condition of the vessel**

Little harm was done to the wreck when it was discovered. Some planks in the bow and stern were partially disturbed by a digging machine. More severe damage, however, had occurred during and after the sinking, before the hull had been covered by sediments.
Figure 7. Disturbed layer tapering in northwest direction. Bow of wreck NZ43. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
The keel plank and hooks—heavy knees connecting keel to stem and sternpost—were found in situ. Attached beneath the stern hook was a short shoe. The stem was preserved over 2.25 m of its length, its lower end also in situ. The upper part of the stem was damaged by the digging machine. A sternpost was not recognized at the time of the excavation, but has probably survived (v. Infra, p. 66).

About 50% of the boat's planking has been found (fig. 8). Because the wreck was listing to port, the planking on this side was partially preserved in situ up to the sheer strake. The lower four strakes were missing only their extremities. Of the fifth through eighth strakes, the central parts and incomplete stern quarters remained. The ninth or sheer strake was preserved from bow to amidships, its central section still connected to the eighth strake. Part of the clamp—a heavy inboard plank running along the sheer line—was lying loose on top of the sheer strake.

The starboard side, on the other hand, was much more deteriorated because it was exposed for a longer time to the action of the sea water. Only the two lower starboard strakes were found in situ. The central parts of the third through sixth strakes had broken off but were lying adjacent. Loose planks rested at some distances from the hull, including an almost completely preserved sheer strake with the foremost part of a clamp still attached.
Partial remains of nineteen frames were uncovered. A twentieth frame, referred to as S13b, was missing entirely and, at its former location, the planking surface was damaged (fig. 9). Apparently the frame was removed violently.22 Perhaps it had been projecting from the wreck and was hit by another vessel, or maybe it was removed deliberately for re-use. A ceiling plank found lying loose over the damaged planking indicates that this damage occurred soon after the vessel sank. In addition, I suspect that a pair of half frames in the bow have disappeared (v. infra, p. 125). Most of the preserved floor timbers and several futtocks were still in situ. Of the last floor timber in the stern, called S19, only a very small fragment remained. In the bow and stern as well as on the starboard side, futtocks were missing or had slid to the lower-lying midship and port side areas of the wreck.

Three substantial parts of straight beams remained: two rather thin pieces situated towards the bow and a larger one lying about one meter south of the hull. The excavators identified these as deck beams. No deck planks were preserved. Three knees, two substantially larger than the third, were also lying inside the hull. Five large fragments of ceiling strakes were found, three in situ, on top of which lay a bulkhead.

On the port side, above the turn of the bilge, a heavy wooden chock was attached to the sixth and seventh strakes,
Figure 9. Damaged planking at former location of frame S13b. Stern quarter seen from starboard. Traces of other frames are clearly visible. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
as well as to the seventh and eight frames. Evidence of a second chock could be seen on the starboard side. The chocks were thought to have been steps for a mast or lifting device (v. infra. pp. 147-150). No trace of a mast step was found on the centerline of the vessel.

The wood was described as being generally in good condition. The survival of the vessel was partially attributed to its sinking during the so-called Almere period, when the Zuyderzee water was still relatively fresh and did not contain wood parasites such as the shipworm Teredo navalis. In addition, the lower hull parts must have been covered by sediments fairly quickly. Preservation was not so good in planking areas that suffered great stress, particularly in the bow and stern quarters, where planks had rather tight curves (v. infra, p. 81).

C. Excavation and conservation

Wreck NZ43 was excavated in 1979 by the Museum of Maritime Archaeology at Ketelhaven. The first site plan recorded the positions of all pieces as they had been discovered (fig. 8 on p. 17). The displaced fragments then were put back in their original places where possible, or were otherwise removed (fig. 10), and a plan of the reconstructed wreck was drawn, this time with the help of aerial photographs (fig. 11 on p. 22). In addition, a
Figure 10. The wreck reconstructed in situ. Seen from bow. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
Figure II. Plan of the reconstructed wreck in situ. Drawn in 1979. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
longitudinal section and several cross sections were drawn (fig. 12).

Heavy rains hindered the excavation, while public works being done at lot NZ43 made it necessary for the excavators to finish as soon as possible. Because the boat's construction appeared interesting, it was decided that the wreck would be dismantled and all pieces transported to the museum for further study. At the museum, the ship timbers were laid out on the floor of a storage shed and kept wet by a sprinkling system. The few artifacts that had been found with the wreck were conserved and put in storage.

Over the next years, the large numbers of rescue excavations to be done in the polders prevented the museum staff from making a thorough study of the wreck. In 1983, they decided to make detailed drawings of all timbers at scale 1:10, and re-bury the wreck according to a newly adopted preservation method (v. supra, p. 4).

D. Reconstruction

My evidence for reconstructing vessel NZ43 consisted of the 1979 site plan. 1979 reconstruction plan and section drawings, photographs and slides taken both during excavation and while the wreck was in storage, and 1:10 scale piece drawings made in 1983 after the wood had been in the Ketelhaven museum for four years. I was unable to see
Figure 12. Longitudinal profile of wreck NZ43 in situ. Scale reflects the horizontal plane in situ. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
the actual wreck because it was reburied before I visited
the museum.

The hull was reconstructed by means of a 1:10 scale
cardboard model (fig. 13). Strakes, keel planks, ceiling
planks, and clamps were made in white cardboard; frames,
hooks, deck beams, knees, chocks and bulkhead in light blue,
seen in the photograph as light grey; and all substituted
parts are in red, showing as dark grey. Only the port side
of the vessel was completed because it was the better-
preserved section. I made the stem and sternpost out of wood
so that they would better withstand the pressure of the
planking. The shoe under the stern hook was omitted for the
sake of simplicity.

For my purpose, cardboard had many advantages over
wood. It saved time not only in the initial making of the
pieces, but also when a timber appeared to be distorted and
needed adjusting. The cardboard could be bent to the
required shape, precluding having to make a new piece. In
addition, mistakes were avoided in that cardboard, unlike
wood, did not demand reconstruction of unrecorded faces of
partially drawn pieces, such as frames. Furthermore, by
cutting out each of the 1:10 piece drawings and gluing them
on the cardboard, I was able to transfer to the model
efficiently and accurately all details recorded by the
museum artists. In addition, I perforated the cardboard
frames at the locations of the treenails that had connected
Figure 13. Reconstruction model of vessel NZ43. Built at scale 1:10. Port (above) and starboard (below) views. Substituted parts are in dark grey. Stem was probably shorter (cf. fig. 20 at p. 41). In the background, reconstruction drawing of a cog based on the Bremen cog. (Photo by author; background drawing by Museum Ketelhaven, courtesy R.I.J.P.)
them to the planking, so that the aligning of frames and strakes by means of their treenails became easier than a similar process in wood, especially when the timbers were somewhat distorted (fig. 14). Finally, the flexibility of the cardboard itself assured the fairness of the reconstructed hull lines, because it was impossible to make angles or hollows in the curvatures of the strakes.

I began the model by laying out keel plank and hooks. The exact fit of the aft keel scarf was determined quite easily after I fit in both garboard strakes and consulted the close-up photographs. The fitting of keel plank to bow hook was more difficult, because this connection had broken at one time and was repaired by means of a triangular chock underneath. The nail holes recorded in the parts to be joined left too much room for interpretation. The length of the garboard strakes did not give conclusive evidence either, because it was not clear how the garboard extremities had fitted against the upright arms of the hooks. Only by putting the second strake into place was I able to reconstruct the bow/keel scarf in a satisfactory way.

When seen from above, the keel line of the uncovered wreck was not straight, but instead curved slightly towards port in bow and stern, without showing any trace of a break (fig. 15). In the model, however, the strakes would fit only
Figure 14. Inboard view of reconstruction model near the stern. Rows of small circles represent treenails. Dark patches are traces of pitch. Hatched lines indicate caulked cracks. (Photo by author)

Figure 15. Distortion of keel in situ. Seen from bow. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
if keel and hooks were laid in a straight line. I believe the hull must have been distorted gradually after sinking, as the port side on which it rested was flattened somewhat under the pressure of the overlying sediments.

A second remarkable observation was that the keel line in situ presented a rise of 10 cm fore and aft (fig. 12 on p. 24). This curvature was quite irregular, the part underneath the ceiling area—between frames S8 and S12—sinking suddenly deeper, and the under face of the stern hook being slightly concave. Obviously, this irregularity was not original, but was caused either by the weight of the cargo during the vessel’s lifetime or by differential support after the sinking. The strakes of the model fitted only if the keel line was given a rise of 14.5 mm, corresponding to 14.5 cm in full scale. The curve still appeared to be irregular, and in the reconstruction drawings I smoothed it out by averaging, the maximum difference between both curves being only 4 mm, or 4 cm on the actual hull, at any point.

The planks of the garboard strake displayed considerable torsion (v. Infra, p. 80). For the port garboard, museum drawings indicated the angles of torsion at several cross sections, so I was able to reconstruct the plank curvatures rather accurately by bending the cardboard planks to the required angles. Information for the starboard garboard rise, provided by cross-section drawings that had
been made on the site in 1979, agreed remarkably well with the data of the port side. The curvature of the second strake was similarly reconstructed on the basis of 1979 site drawings. The ease with which this strake was put in place corroborated the reconstruction of the garboard curvature.

After erecting the first two strakes of both sides, I placed the ensemble upon a set of wooden molds in such a way that both hooks ended at approximately the same height above the baseline. Five provisional molds, cut on the basis of excavation drawings and placed at regular intervals, served as supports and guides for the rest of the planking (fig. 16). 23

Next, floor timbers S6, S9 and S14 were installed, whose treenail positions provided valuable guidance for the fitting of the remaining three bottom strakes. A wear pattern between frames S7 and S8 also gave important clues. The remains of iron nails provided evidence for reconstructing the plank scarfs. In addition, the discovery that the planking of port and starboard sides had been built in almost similar fashion reinforced the evidence.

In the bottom of the hull, strakes lay flush with one another over parts of their lengths, but elsewhere the planking was built in lapstrake fashion. The different thicknesses of the overlapping planks were simulated by cardboard strips attached to the plank edges. All overlapping parts of the hull had been fastened with iron
Figure 16. Model under construction. Two strakes at either side and four frames are in place. Ensemble supported by five provisional wooden molds. (Photo by author)
nails, and these provided important evidence for reconstructing the relative positions of the strakes. Amidships almost all nails lined up exactly. At the extremities, the nails did not fit well, presumably because of distortion, but reconstruction often was facilitated by the presence of mutual bevels or offsets in the plank edges (v. infra, pp. 100 and 109).

By inserting more floor timbers and futtocks whose original locations were known, I was able to control the accuracy of the planking reconstruction. In general, frames and strakes lined up quite well, except for some V-shaped floor timbers in the bow and stern which seemed distorted. Trenail hole positions also allowed the futtocks to join the floor timbers quite easily, and in this way I was able to reconstruct fore-and-aft as well as transverse curvatures of the side planking. As a rule, I estimate the maximum error in the fitting of the preserved strakes to be 3 mm on the model, corresponding to 3 cm on the actual vessel.

The reconstruction of the bow and stern quarters, on the other hand, was rather hypothetical because of poor preservation. Forward of frame 54, the fifth through eighth strakes had disappeared and all futtocks were dislocated. I substituted the missing bow planks by extrapolating from the existing strake fragments, letting them taper in a reasonable degree toward the stem similar to the way in which the preserved strakes tapered in the bow and stern (v.
infra, p. 78). This reconstruction agreed quite well with the offsets cut in the under faces of the tentatively relocated bow futtocks. The hooding ends of the strakes were made to enter the stem under much the same vertical angle as can be seen in the cog excavated in Bremen (fig. 17). Fortunately, conjecture was limited by the sheer strake, which was preserved up to the stem, and by the fact that the bow part of the clamp had survived on the starboard side. By making a mirror image of the clamp, I was able to reconstruct rather accurately the fullness of the sheer strake near the stem (fig. 18 on p. 35). Nevertheless, I think it possible that the curvature of the substituted strakes had been somewhat fuller in reality.

The stern area was reconstructed with greater certainty than the bow because more strakes and futtocks had been preserved. Mirror images made of half frames S16 and S17, reaching from the keel up to the seventh strake, proved very helpful, and the highly probable relocation of timber A4 as port futtrock of frame S17 provided especially strong clues with regard to plank configuration and curvature (fig. 19 on p. 36). On the starboard side, the sheer strake had been preserved from the bow as far aft as frame S14, so that I could complete the port sections that had disappeared. Taking the length of futtock S17/BB (A4) as an indication of the sheer height, I extended the sheer line in a reasonable way up to the sternpost. However, since the head of futtock
Figure 17. Bow views of model NZ43 and the Bremen cog. To the left: model NZ43. (Photo by author) To the right: Bremen cog. (Kiedel and Schnall, 1985, p. 2)
Figure 18. Clamp fragment A41 from starboard bow. Above: piece drawing with bow part of starboard sheer strake. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.) To the left: mirror image used at port side of model. (Photo by author)
Figure 19. Frames S16 and S17, together with futtock S17/BB. Seen from bow. Mirror images of frames S16 and S17 are dark grey. (Photo by author)
S17/BB is somewhat eroded, I think the sheer strake aft may have been as much as 4 mm (cm) lower. In that case the strake would have tapered to a width of 14 mm (cm) just as it does in the corresponding area of the bow. The curvature of the stern area may have been somewhat sharper than reconstructed.

The reconstruction of the other hull members will be discussed in the next chapter. Table 1 gives an overview of the reconstruction of dislocated timbers found on the wreck. The model yielded for vessel NZ43 an overall length of 11.815 m, an overall beam of 4.26 m, and a sheer height amidships of 1.2 m above the baseline. The sheer at the stem was 2.257 m high, at the sternpost 2.12 m. The boat's keel length--here taken to be the combined lengths of keel plank and horizontal hook legs--was 9.125 m. Amidships, the bilge started to turn at 0.99 m from the centerline, between the third and fourth strakes.

Measurements of the cardboard model were converted into two- and three-dimensional lines drawings (figs. 20 and 21 on p. 41 and 42, respectively). I chose frame S10 as the midship frame because it was situated in the widest part of the hull. Since the frames were spaced rather irregularly, I decided to draw body lines at arbitrary distances of 1 dm (m), instead of using the frame centers.
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In order to control the accuracy of my measurements, I first drew cross sections of the planking at each body station and compared those with available cross sections of the actual strakes drawn in 1983. I took the lines to the insides of the flush-lying planking, and to the upper inner corners of the overlapping strakes, except in the bilge, where the transition from flush to lapstrake planking would have resulted in an offset in the body line. At the bilge, the hull lines skip the edges of the last flush strakes and/or first overlapping strakes, while still following as closely as possible the actual course of the planking. As a result, the bilge curves look rather hard (fig. 20).
Figure 20. Two-dimensional lines drawing of vessel NZ43. Drawn with Bausch & Lomb Producer Drafting System. (Drawing by author)
Figure 21. Isometric drawings of vessel NZ43. Reproduced at scale 1:100. Above: bow quarter; below: stern quarter. Drawn with Bausch & Lomb Producer Drafting System. (Drawing by author)
CHAPTER III

CONSTRUCTION OF VESSEL NZ43

A. Materials

All wooden hull parts were made out of oak. This wood type is durable while also being elastic and relatively easy to work. During the late Middle Ages, oak was commonly used for ship components in most of northern Europe, except in Scandinavia where pine was preferred for strakes. Documents indicate that Zuyderzee cities imported oak for shipbuilding in considerable quantities from the Baltic and Norway, as well as from Westphalia and the upper-Rhine region. Local oak was also used, however, and since our vessel was rather small, it may have been built from local timber.

Nails, caulking clamps, gudgeons, and reinforcing strips were made of iron. About A.D. 1400, an important improvement was achieved in European ironworking. The introduction of the blast furnace made possible the smelting of iron at much higher temperatures than before, producing a purer, better-quality metal. Close examination of the iron remains of wreck NZ43 might reveal their original composition and, in this way, provide clues to the vessel’s date.
Moss was used for caulking. In the late 17th century, the Dutch shipbuilder C. van Yk wrote that caulking moss was a water plant found in ditches and moors of the provinces Brabant and Holland. In the 19th century, the provinces Gelderland and Overijssel were also moss producers. The moss used in our vessel may have come from any of those regions, or it might have been imported from the German Rhine region, where moss was used for the same purpose.  

Several traces of tar or pitch remained on the hull planking and in the bow keel scarf. The substance has not yet been analyzed. Other hull-finishing materials that may have been used are discussed below (pp. 120-121).

B. Tools

Adzes, axes, a hand saw and frame saw, an auger, and a pair of pincers have been found in various late-medieval wrecks from the Zuyderzee polders (Fig. 22), so we know they were in use at the time vessel NZ43 was built. Since few tool marks were observed on the wood of this wreck, little can be said about specific tool use. Possible adze marks were seen on the sculpted outboard faces of bilge planks G5b and G15a. A circular mark with a radius of 3 mm, apparently made by an auger, was found in the corner of a notch in plank G3c, indicating that this tool had been used to start the notch. Perhaps the auger had been a breast auger, a
Figure 22. Late-medieval shipcarpenters' tools found with Zuyderzee wrecks and the Bremen cog. Not to scale. Top left, from vessel K73/74: adzes, pincers, auger, axe, caulking iron. (Reinders et al., s.d., appendix 3) Top right, from vessel N5: axe, adze, caulking iron. (Reinders et al., s.d., appendix 7) Below right, from Bremen cog: adzes, axe, shoe. (Lahn. I11. 50)
version with a transverse handle, which was easier to use than the older type. With regard to the building of the Bremen cog, W. Lahn additionally mentions the use of chisels, probably rabbet planes, and a knife-like bar with triangular cross section that was used in clinching nails (fig. 22 on p. 45).

An interesting question concerning tool use is whether the timbers had been cut with an axe or a saw. The answer can be found by studying the grain pattern of the planks, because a saw is able to cut through wood grain, while an axe tends to follow it. In the late Middle Ages, Scandinavian shipbuilders favored the axe, since they had an abundant supply of straight-grained wood at their disposal and were able to cut straight planks more quickly with an axe than with a saw. Moreover, an axe suffered less wear, and the cleft timbers were stronger because the grain had not been cut through. In the Mediterranean, on the other hand, most of the trees utilized in shipbuilding had twisted grain, and shipwrights commonly used saws to shape timbers. A comprehensive study on tool use in the building of cog-like vessels has yet to appear, but some information from wrecks and written documents is known, indicating that saws as well as axes were used for making hull components. Planks in the Danish wrecks and the Bremen cog mostly had been sawn. The keel of the Bremen cog had been cut with a saw, probably hand-held, then finished with
axe and adze; futtocks, however, had been shaped with an axe. The importance of saws in the construction of cog-like craft is illustrated by a 1285/6 shipbuilding account from the Dutch city of Dordrecht, which contains two entries concerning saws, but does not mention axes. In wreck NZ43, the artists doing the recording stated only once that a saw was used, on futtock A21, which was probably starboard futtock S13/SB. Closer inspection of the wood surfaces might yield more information.

Cog-like vessels, as well as later Dutch craft, typically had bottom planks that radically curved fore and aft. Curvature was obtained by bending planks and/or twisting them along their longitudinal axes. Medieval techniques for the curving of planks are as yet unknown, as the earliest information dates from the 17th century. At that time, an oak plank was heated over a fire, and sometimes wetted, so that it became flexible and could take on any desired shape. In some cases, heavy weights were used at the extremities of the plank to help bend it. Perhaps these techniques already were used in the late Middle Ages, but as R. Hulst remarks, it is also possible that planks were bent and twisted by sheer force. In this context it would be useful to know whether the planks of vessel NZ43 had been cleft or sawn, because cleft planks supposedly can be bent more easily. I do not have sufficient information on
the condition of the planks to be able to draw a conclusion as to the bending or twisting methods used.

In view of the size of some hull members, particularly floor timbers and deck beams, it is likely that the builder of vessel NZ43 employed a lifting device to place them. Documents of medieval guilds, from the late 14th century on, frequently mention jacks. The reconstructors of the Bremen cog report that they needed to use lifting devices after erecting the fifth strake.\textsuperscript{35} We know that cranes were widely present in late-medieval harbors, but for the construction of this small vessel the builder may have used just an A-frame, or even rigged a simple lifting boom, as is shown by N. Witsen (fig. 23). Perhaps he also used a windlass, which was part of the standard shipbuilding gear in the 15th century.\textsuperscript{36}

Little is known about measuring tools, but we may assume that the builder used, among others, a thumbstick, plumb and bob, and maybe squares.\textsuperscript{37} The possible application of a standard measure in the construction of this vessel will be discussed below (pp. 210 ff.).

Caulking tools were usually made of iron, as illustrated by caulking irons from some late-medieval Zuyderzee wrecks (fig. 22 on p. 45). A similar tool, made of wood, was found with the Bremen cog and was perhaps also used for caulking.\textsuperscript{38}
Figure 23. Lifting jack used in late-17th-century Dutch shipbuilding. (Adapted from Witsen, ill. facing p. 168)
C. Hull members

1. Keel plank

The keel of vessel NZ43 is a 6.5-m-long plank varying in width and thickness from 15 by 5.7 cm at its forward end to 18.5 by 7 cm amidships and 16 by 5.5 cm aft. It is slightly narrower than the narrowest hull strake but about twice as thick. This keel plank was thus essentially a center strake joining both sides of the hull, and not a backbone providing rigidity to the structure. This is illustrated by the weak joints with bow and stern hooks and by the fact that the keel was not connected to the garboard strake (v. infra. p. 94).

Keel planks are very common in shallow-water craft because they reduce the vessel’s draft. They are still characteristic of Dutch craft and have been found on most cog-like vessels except for the Bosholmen wreck in Sweden, which has a keel section of 20 by 20 cm.39 A comparison of dimensions of keel planks and garboards shows that vessel NZ43 falls within the range of other cog-like craft. Its keel plank is about half as wide as its garboard, as in a wreck from adjacent lot NZ42. The keel planks of the vessels from Bremen and lots OZ43 and M107, on the other hand, are about as wide as their respective garboards. The thickness of the keel plank is usually two to three times that of the garboard, seldom more. In shape, the keel plank of wreck
NZ43 is similar to all others on which information was available.

The keel plank of wreck NZ43 has been reconstructed with a rocker of 14.5 cm over a length of 4.5 m, or 3.2% (v. supra, p. 29). It may have been built this way initially, because such a keel would have set the vessel afloat more easily if it ran aground in the shallow Zuyderzee. Beaching must have happened rather frequently, because it seems to have been a common way of unloading cargo. Even now, a gently curving bottom is common in traditional Zuyderzee craft. The keel may also have been built rockered to offset the tendency of the hull to hog, as R.M. Rose suggests. A relatively greater weight of bow and stern is a typical result of this type of construction (v. infra, p. 209), and perhaps for that reason, other cog-like wrecks and related vessels have been found with a hogged hull.

It is possible, however, that the initial rocker of vessel NZ43 was less pronounced than the reconstructed one, and that the central part of the hull had sagged under cargo pressure during its lifetime (v. infra, p. 191), or under the weight of the overburden after sinking. The keel plank originally may have been straight with only the ends slightly rising, as D. Ellmers suggests with regard to the Bremen cog. Also, wreck OZ43 was reconstructed with such a keel line, but this has not been attested in other wrecks.
If this were the case, the lower planks in the bow and stern of vessel NZ43 would be quite distorted because, in the model, the planks did not fit if the keel was laid straight. An inspection of the actual remains of NZ43 could yield more clues.

Iconography does not offer conclusive evidence either. When reviewing the 36 cog representations collected by Hulst, I found that on 23 the keel line is not present, because the vessels are depicted afloat. Five representations show curved keel lines: a 1246 seal from the Zuyderzee port of Staveren (fig. 24); seals from Baltic Wismar (1256) and Stralsund (1265 and 1278); and a miniature of a Historia Troyana manuscript (1350). Other pictorial evidence from the Zuyderzee, seals from Kuinre (1399) and Genemuiden (1461), displays straight keel lines (figs. 25 and 26 on pp. 53 and 54, respectively), while in four representations the keel is not shown.45

2. Hooks

Hooks are heavy, grown knee-like timbers which make the transition from keel plank to stem or sternpost. They are present on all cog-like wrecks for which we have sufficient data. Often the horizontal leg exhibits an apron-like rise, as can be seen in the Bremen cog (figs. 27 and 28 on pp. 54 and 55, respectively). Hooks do not seem typical for the cog family alone, because they also are found in the sterns of
Figure 24. Oldest town seal of Staveren, 1246. (Ewe, fig. 189; all figures and photographs from Ewe are covered by letter of permission on p. 307)

Figure 25. Town seal of Kuinre, 1399. (Ewe, fig. 88)
Figure 26. Town seal of Genemuiden, 1461. (Ewe, p. 66 and fig. 56)

Figure 27. Hook of the Bremen cog, A.D. 1380. (Adapted from Ellmers, 1979, fig. 1.8)
Figure 28. Hooks and posts of cog-like vessels from the Zuyderzee. (Reinders, 1985, fig. 6)
vessels from other shipbuilding traditions, such as the 14th-century Scandinavian-built wreck Kalmar I, and the 16th-century Basque whaling vessel excavated in Red Bay, Canada. A comprehensive study on hooks has yet to appear.46

The bow hook of vessel NZ43 has a 92-m-long horizontal leg without apron. It varies in sided and molded dimensions respectively from 14 by 7 cm near the keel plank to 9 by 14 cm at the upward turn. Its vertical leg is about 50 cm long and begins at 9 by 16 cm, the molded dimension tapering outboard almost immediately to form a scarf with the stem. The stern hook has a horizontal leg of 176 cm, or almost twice the length of the bow hook. Its section measures 16 by 6 cm near the keel plank and 8 by 14 cm at the upward turn. Its vertical leg is only 28 cm long and measures 8 by 10 cm, also tapering outboard immediately to join the sternpost. Unlike the keel plank, both bow and stern hooks have rabbets cut into their upper edges to receive the garboard extremities. The rabbets are c. 2.05 m long, and begin at the upward turn with a width of 4 cm and a depth of 2 to 2.5 cm, diminishing gradually as they approach the keel plank. Even though the bow hook is only half as long as the stern hook, their rabbets are about the same length.

Hooks and keel planks of cog-like vessels were usually joined by a horizontal flat scarf. In the wrecks from Kalmar (I) and Red Bay, however, this scarf was vertical, probably because the keels were much thicker. The aft keel scarf of
vessel NZ43 was 20 cm long, and was secured by only two iron nails and by the treenail that connected both pieces to the overlying frame. Shipwrights sometimes put the aftmost component of a keel scarf on top of the foremost one so that the scarf would draw less water as the vessel moved forward. In vessel NZ43, however, the stern hook was laid on top of the keel plank. In the bow, both hook and keel plank tapered upwards, and a triangular wooden chock was fastened underneath with five nails at either leg. The nails penetrated only half the thickness of the keel plank, so the joint was quite weak. The chock has been reconstructed as protruding a few centimeters beneath the keel line. Inside the hull, a short thin plank was laid on top of the joint and under the overlying floor timber S3, apparently without being fastened. The plank is 43 cm long and 5 cm thick, its width tapering with the hook and the keel plank. The most likely explanation for this awkward construction seems to be that sometime during the vessel’s lifetime the bow scarf was damaged and then repaired with the chock. It was impossible to determine the original arrangement of the scarf.

The bow hook has an iron nail at its outboard face, which seems to be evidence for a lost outer post. Such outer posts have been recorded on only four other wrecks, but are seen frequently in iconography. The outer stem of the Bremen cog is slightly heavier than the inner post and increases in
size toward the top. It was connected to the inner post with four iron bolts (fig. 17 on p. 34). The outer sternpost is a much lighter beam, joined to the inner post with three heavy square nails and a bolt. The outer posts of wreck NZ42 seem to have had similar dimensions. In the vessel of lot M107 and in the wreck found in present Lake Yssel off Medemblik, only the stems are reported to have carried outer posts, but it is possible that there were also outer sternposts. The outer stem of the Medemblik vessel is a small timber only 8 to 10 cm thick. In most cog-like wrecks, the lower parts of the hooks protrude somewhat in order to provide better means of attachment for the outer posts. The function of outer posts apparently was to protect the hooks, posts, and the hooping ends of the strakes. Heavy outer posts also must have added to the vessel’s stability and sailing qualities.47 Because in the bow of NZ43 the plank hooping ends were protected by the stem rabbet, it is likely that the outer post served to protect only the stem scarf and did not extend very high. This would explain why no other nails were found in the stem. As the bow hook does not have a projection, the outer post was probably rather thin.

At the stern there is no evidence for an outer post, but under the stern hook a shoe 116 cm long, protruding aft about 5 cm, was discovered (fig. 28 on p. 55). Although narrower than the hook, this small timber tapers in a similar way. Its cross section is 6 by 5 cm at its aftmost
end, changing forward to 8.5 by 2 cm. In view of its narrower width and its protruding length, the shoe probably offered more protection to the sole of the rudder than to the stern hook. The shoe was merely nailed to the hook with iron nails, so that it could be removed and replaced easily. No evidence for a shoe was found elsewhere under the keel.

In Zuyderzee wreck Q75, two rather substantial shoes were reported, which protected the bow and stern keel scarfs as well as the hooks (fig. 28 on p. 55). \(^{48}\)

3. Stem and sternpost

Hooks were joined to stem and sternpost by means of flat scarfs, each secured by one treenail. Compared to the post scarfs in the vessels of Bremen and Medemblik, those in vessel NZ43 seem to have been weakly fastened, perhaps because of the narrow inboard faces of both stem and sternpost. No detailed information could be obtained on the post scarfs of other wrecks. \(^{49}\)

The stem is preserved over a length of 2.25 m but may have been somewhat longer, because the upper extremity is eroded. It has a trapezoidal section, the outboard face being 4 cm wide and the inboard one 10 cm. Both faces taper underneath in order to fit the upper extremity of the bow hook (fig. 29). The stem’s molded dimension is 15 cm.
Figure 29. Profile and cross section of stem of vessel NZ43. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
Rabbets 4 cm wide by 2 cm deep have been cut into both inboard edges of the stem to receive the strake ends. The dimensions of these rabbets correspond to those of the bow hook. The stem is described as having the same section throughout, but since it is badly preserved above the first 1.50 m, it is possible that the rabbet actually stopped at, or even below, the sheer line. In the wrecks of lot M107 and Bremen, the stems have rabbets only as high as the third and fourth strakes respectively, and then take on triangular to pentagonal cross sections, allowing the strakes to enter at still wider angles and to extend as far as their outboard faces (fig. 30). The stem of Zuyderzee wreck G37 has a rabbet, but the preserved length of the post is not given.50

The stem of vessel NZ43 appears to be concave, the sharpest curvature occurring in its lower part. One could suggest that the post was originally straight, but was bent after the wrecking under the pressure of the overburden; however, such drastic deformation seems unlikely because of the timber's size, and the fact that no trace of strain was recorded by the artist. Nevertheless, the slightly irregular curvature makes it possible that the stem was originally somewhat less concave. A less concave stem would have made the shape of the bow fuller than reconstructed, unless the keel had been less rockeried as well (v. supra, p. 51).

P. Heinsius recognized that some iconographic evidence showed the stems of cog-like vessels as slightly concave.
Figure 30. Bow of Bremen cog under construction, 1975.
(Lahn. ill. 30)
Concave stems are seen on seals from the Netherlands (Harderwijk 1263, Vlaardingen 1312), Flanders (Damme 1309), northern Germany (Kiel 1365, Stralsund 1301), and Denmark (Nykøbing 1556) (Figs. 31 through 36 on pp. 64 and 65). Further, a 14th-century illustration in the Decrees of Gregorius IX shows vessels with heavy concave stems.51

Nearly all this evidence dates to the 14th century or later. Perhaps this reflects an evolution in shipbuilding through time, because a concave stem offers some advantages over a straight post. Not only does it facilitate the fastening of overlapping hooding ends of the strakes, it also provides better protection against bow waves because it acts like a spray deflector.52

About 1 m from its lower end, just outboard of the rabbet, the stem of vessel NZ43 is transversely pierced. With a diameter of 3 cm, the hole may have held a treenail. Two similar holes, higher in the stem, have been found by W. Steusloff in the Ebersdorf boat model. Steusloff does not offer an explanation, but remarks that the holes are situated too low to have served for the belaying of a forestay.53 As the hole in the stem of vessel NZ43 was situated outside the planking, it is most likely associated with the construction phase of the hull. Perhaps the treenail was holding struts supporting the stem, or maybe the hole held a long dowel providing a point of attachment by which the timber could be lifted with tackle.
Figure 31. Oldest town seal of Harderwijk, 1263.
(Ewe, p. 64 and fig. 62)

Figure 32. Town seal of Vlaardingen, 1312. (Ewe, p. 66 and fig. 211)

Figure 33. Second town seal of Damme, 1309. (Ewe, fig. 29)
Figure 34. Oldest town seal of Kiel, 1365. (Ewe, p. 45 and fig. 83)

Figure 35. Third town seal of Stralsund, 1301. (Ewe, fig. 193)

Figure 36. Oldest town seal of Nykøbing, 1556. (Ewe, fig. 132)
A sternpost was not recognized during excavation, but for several reasons I think it may be identified as the heavy beam A7 that was lying in the stern area, between frames S16 (A2) and S17 (A3) and on top of port futtock S17/BB (A4) (fig. 8 on p. 17). This badly eroded beam is curved regularly over its entire length. Its cross section was originally trapezoidal, with the smaller base at the outside of the curve (fig. 37). This cross section bears some resemblance to the sternposts of the Bremen cog and vessel M107 (fig. 38 on p. 68), and suggests that beam A7 may have been the sternpost of vessel NZ43.54 The fact that the curve is convex is unusual for the sternpost of a cog-like vessel, but is not without parallels in iconography. The vessels depicted on the 1263 town seal of Harderwijk and the 1309 seal of Damme boast convex sternposts as well as concave stems, thus approaching in appearance the profile of vessel NZ43, even though they have much higher sides (figs. 31 and 33 on p. 64). The third representation of a convex sternpost is the 1369 seal from the Zuyderzee harbor of Staveren (fig. 39 on p. 68). A fourth depiction, the 1365 town seal from Kiel, shows a concave stem, and a sternpost which runs straight up to the sheer line, terminating in an abrupt convex curve (fig. 34 on p. 65). In my opinion, this indicates that while straight sternposts were the general rule in cog-like vessels, shipwrights occasionally used others shapes as well, perhaps to facilitate the fitting of
Figure 37. Probable sternpost fragment of vessel NZ43. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
Figure 38. Sternpost fragment of wreck M107. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)

Figure 39. Second town seal of Staveren, 1369. (Ewe, fig. 190)
the overlapping strake ends. As with the evidence for concave stems, nearly all representations of convex or semi-
convex sternposts date from after A.D. 1300. These clues are as yet too scanty to allow any conclusions, but they might reflect an improvement in boatbuilding skills, as it is more difficult to fit a stern rudder to a convex post than to a straight one.

The central part of beam A7 is transversely pierced by at least one, and probably two, treenail holes (fig. 37 on p. 67). Near the better-preserved extremity, an oval hole runs from base to base. The transverse holes may have served the same purposes as the hole in the stem, namely holding struts during the construction of the hull, or providing a type of handle for lifting. Since these holes are located within the hull, they may also have held a belaying device for backstays (v. infra, p. 157). The oval hole, on the other hand, might be identified as the hole for a rudder gudgeon of the forelocked eye-bolt type, such as those found in vessel M107 and in the Danish wreck of Vigsø (fig. 40). Since this sternpost would have been convex, the rudder would have turned more easily when attached to only two gudgeons. A second gudgeon might have been located in the now lost or eroded part at the other extremity of A7. Rudders with two gudgeons have been attested, however rarely, in late-medieval iconography. Examples are the seals from Damme, Kiel, and Staveren, which also show convex or
Figure 40. Rudder gudgeons from wreck M107 and the Vigsø find. Above: M107. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.) Below: Vigsø (Crumlin-Pedersen, 1981, fig. 24)
semi-convex sternposts (figs. 33, 34, and 39, on pp. 64, 65, and 68, respectively). The 1312 seal of Vlaardingen that also displays a concave stem has two gudgeons distributed evenly over the length of the sternpost, and a third one oddly placed at the sheer line (Fig. 32 on p. 64). Two gudgeons are also seen on the seals from Polish Golnov (1339) and Danish Stubbekøbing (1367) (figs. 41 and 42), as well as in the Ebersdorf model, dated to about 1400.55

A final indication that beam A7 is the sternpost is the remains of four iron nails running in a row along the outboard edge of its central port side. These can be interpreted as the nails attaching strake ends to the sternpost. The small number of remaining nails may be explained by the fact that beam A7 was apparently too badly eroded over half of its length to leave recognizable traces of nails, while the better-preserved extremity, at the other side of the nails, might have been situated at the level of lower strakes that did not reach all the way to the outboard edge of the sternpost. This explanation conforms to the fact that in shipwrecks the best preserved end of a stem or sternpost is usually the lower one. Furthermore, the reconstructed stern plank of the fifth strake at starboard, even though eroded, reached almost halfway across the sided dimension of the sternpost and may well have extended to the outer edge. To port, all hooling ends have disappeared from the second strake upward. Such a planking arrangement
Figure 41. Oldest town seal of Gølnov, 1339. (Ewe, fig. 57)

Figure 42. Oldest town seal of Stubbekøbing, 1367. (Ewe, fig. 196)
appears to be common in cog-like craft. In the vessels from lot M107 and Bremen, the third and the fifth strakes respectively are the first ones to be nailed at the outer faces of the sternposts.

An alternative identification of beam A7 as a deck beam with crown is less convincing. Not only would it be rather different from the other deck beams, but also the upper face would have been narrower than the lower face, which is not very probable.

The most likely position of fragment A7 was determined mainly on the basis of the oval hole and the iron nails. Medieval artists represented the two rudder gudgeons by distributing them more or less equidistantly over the sternpost length, the lower one being situated at 1/3 to 1/5 from the bottom end and the upper one at 3/5 to 3/4 from the same location (figs. 32, 33, 34, 39, 41, 42 on pp. 64, 65, 68, and 72). This would correspond respectively to the second through fourth strakes and the seventh and eighth strakes of vessel NZ43. As the lowest possible position of the upper gudgeon can be expected to be in the eroded upper part of beam A7, a likely reconstruction would be to place the upper gudgeon at the eighth strake, and the lower one at the third strake. In this way the gudgeons would be situated at 3/4 and 1/4 of the sternpost length respectively, as in the 1339 seal of Golnov (fig. 41 on p. 72). This would place the iron nails at the fifth strake, which at the starboard
side seems to be the first strake to have reached the outboard face of the sternpost. The transverse treenail holes then would be level with the sixth and seventh strakes respectively. Even if fragment A7 were positioned somewhat higher in the sternpost, neither the appearance of the reconstructed post nor the curvature of the stern area would change significantly.

The preserved fragment of A7 is molded 11.2 cm but is badly eroded. On the basis of the 1979 site plan, its molded dimension was reconstructed to about 20 cm, or four-thirds the thickness of the stem (fig. 37 on p. 67). The width of the outboard face had been recorded as 5.3 cm, but since it is eroded on one side, it was reconstructed to about 6 cm wide. The outboard dimension, together with the angle and the width of the sides, indicates that the inboard face of A7 was originally about 16 cm wide. In order to fit the scarf with the stern hook, its lower extremity must have tapered in molded, as well as in sided, dimension. However, it is possible that the sternpost was thinner, which also would have made the inboard face narrower. In view of the evidence from the wrecks of Bremen and M107, it is possible that the sternpost above fragment A7 took on a pentagonal cross section in order to let the strakes enter in ever wider angles (v. supra, p. 66).

The reconstruction of the sternpost height to 2.4 m is conjectural. I merely extended thé post 25 cm above the
sheer line because this seemed reasonable; it still would allow the tiller of the stern rudder to pass over the sternpost, as is seen in all depictions of cog-like vessels. It is likely that in order to protect the hooping ends, an outer sternpost was fitted over them, even though no trace of one has been found (v. supra, p. 58).

4. Hull planking

(a) Strake pattern

Vessel NZ43 had three bottom strakes, two bilge strakes, and four side strakes on each side of the hull. In the bow, the garboard ended in the hook rabbet, and the other strakes apparently ran into the stem rabbet. In the stern, on the other hand, only the first four strakes seem to have stopped at the inboard edge of the sternpost, while the upper five strakes extended to the outboard edge, where they were fastened with iron nails. Presumably all other plank hooping ends were secured with nails as well, as this was common practice (fig. 30 on p. 62).56

Each strake consisted of three to five planks, and each side of the hull originally contained an estimated forty planks (table 2; fig. 43 on p. 77). This illustrates that vessel NZ43 was made out of smaller-sized timber than the Bremen cog, which is almost twice as long and more than three times higher than our vessel; it has only twelve
Table 2. Number of planks per strake and dimensions in cm. Entries marked with asterisks are reconstructed. The 4- to 5-cm-wide overlaps of lapstrake planks are not included in the widths. All thickness values refer to the planks' mid-sections only. Thicknesses given for bow and stern extremities are real values; thicknesses for the remainder of the strakes are averages.

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Figure 43. Strake plan of reconstructed vessel NZ43, 1987. Shaded areas represent substituted parts. (Drawing by author)
strakes with three to four planks per strake, totalling forty-three planks per side.

Almost all strakes of vessel NZ43 taper in width toward bow and stern, while in thickness they are more uniform throughout their lengths, thinning only at the very extremities near stem and sternpost.

Adjacent to the very wide and thick garboard and second strakes, there were three narrower strakes which decreased in width successively. These narrow strakes alternated in thickness, beginning with a thin third strake. The four side strakes alternated both in width and thickness, the narrow strakes being substantially thicker than the wide ones. The sheer strake was the broadest strake of the hull. It appears that these different widths and thicknesses were given to the strakes intentionally as a means of achieving transverse hull curvature without bending the side planks through their widths. The curves of the vessel’s sides appear to be created only by the sculpted inboard or outboard faces of the narrow, thick sixth and eighth strakes; the broad, thin seventh and ninth strakes, with their straight, rectangular cross sections, do not seem to contribute in that regard (fig. 43 on p. 77). As yet, this interpretation can be only hypothetical, because more research on the actual planking remains of vessel NZ43 is needed. Wide side strakes have been reported in other cog-like wrecks and are seen in iconography, but modern literature does not mention
alternating plank widths or thicknesses. The large wrecks from Bremen and Bossholmen have generally thicker strakes, up to 5 cm. No comparable information on smaller cog-like vessels exists.\textsuperscript{57}

Minor differences in width and thickness are found between individual port and starboard bottom strakes, but they seem negligible. The variations in thickness may be due to differential erosion. In general, plank thicknesses are amazingly uniform and show the masterly control of the builders over their craft. The different widths cancelled out collectively, making the starboard bottom no more than 1 cm higher than the port bottom. More significant is the fact that beginning with the garboards, strakes were broader forward than aft. In this way, the bow was gradually built up to rise higher than the stern.

The planks display a wide range of lengths, the longest planks (G1b and G10b) being 4.9 m and the shortest one (Gang x), 1.1 m. It is notable that the widest planks are in general also the longest.

(b) Plank curvature

As in all cog-like craft, the bottom of vessel NZ43 was very broad and almost flat amidships, but was rather sharply peaked in bow and stern (fig. 20 on p. 41).\textsuperscript{58} This caused the planks to curve quite radically, especially in the lower bow and stern quarters. Techniques for bending and twisting
the oak planks are described above (p. 47). In addition, plank shapes, when seen from above, were not rectangular but adapted to the curvature (v. infra, p. 105).

The first through fourth strakes began with a rather hollow curve in the bow and became convex in the bow quarter, in the vicinity of body lines Ch and C, which roughly corresponded to frames S3 and S4, respectively. The bow sections of the fifth through eighth strakes were missing, but on the basis of the rather full curve made by the preserved sheer strake, I reconstructed them as becoming gradually more convex (v. supra, p. 32). In the lower stern, hull lines were slightly hollow, but the actual strakes swept up and retained convex curves (fig. 43 on p. 77).

The garboard determined the curvature of the other bottom planks and displayed the tightest twists, in spite of its heavy dimensions. It started out in an almost vertical position at the hook rabbets, but lay only at a 2° angle beneath the midship frame. Similar garboard curvatures are observed in all sufficiently preserved cog-like vessels. Garboard angles at the body stations of the reconstructed hull of vessel NZ43 are listed in table 3.

The tightest curvatures of the garboard occurred in the bow and stern. The scarfs, situated just forward of station B and just aft of station 2, must have relieved some of the strain on the planks by enabling the shipwright to angle the planks with respect to each other. A considerable amount of
Table 3. Port garboard curvature. Indicated below are the relative curvature differences at each body station of the cardboard model. In reality, stations are spaced 1 m apart; stations 0 and 4 are situated 57 cm from stem and sternpost, respectively.

<table>
<thead>
<tr>
<th>Stations</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>A</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees</td>
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<td>16</td>
<td>3</td>
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<td>11</td>
<td>46</td>
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<td>37</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>35</td>
<td>24</td>
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</tr>
</tbody>
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Twist would also have been avoided if both planks had been made thinner toward the keel; however, there are no data to confirm this.

In the other bottom and bilge strakes, most of the curvature was also found in the bow and stern planks, leaving the midship parts relatively flat. The different treatment of central and end planks was clearly visible when the wreck was uncovered because the central planks, having been affected by torsion only very little, presented much better preserved surfaces than the end planks (fig. 15 on p. 28).

Seen in cross section, the vessel’s bottom planks did not show any flats. The bilge was almost always rounded, except between frames S8 and S12, where the last bottom strake and the first bilge strake were angled in a slight chine of 15°. A similar partial chine is found in the Bremen cog, as well as in all cog-like wrecks from the Zuyderzee that are sufficiently preserved. The three Danish cogs, on the other hand, are reported to have rounded bilges throughout.59
Port and starboard sides may not have been completely symmetrical; on the model, the starboard side seems to curve upward less steeply than the port side. The taper of the garboard hoisting end in the bow is about 5 cm longer to starboard than to port, diminishing in width more gradually, as if the starboard garboard was entering the stern hook under a slightly wider angle. In the stern, the starboard hook rabbet appears to be deeper than at port. Other differences between the two sides, however, are so small that they might well be due to inaccuracies in the research model. A study of the reassembled vessel itself may provide more reliable information in this respect.

(c) Scarfs

In fore-and-aft direction, planks were joined to one another with flat scarfs. In each case, the forwardmost plank lay outboard of the aftmost one. Similar strake scarfs have been found on all cog-like wrecks, and are clearly visible on some detailed iconographic representations (fig. 44, and figs. 33, 34, 35 on pp. 64 and 65). Even though in most of those wrecks plank scarfs have been caulked with moss, only seven scarfs of vessel NZ43 showed possible evidence of such a practice (v. infra, p. 120). Scarf lengths varied between 20 and 31 cm, those on the port side being conspicuously more uniform than the ones on the starboard side (fig. 45).
Figure 44. Plank scarfs in cog-like wrecks from the Zuyderzee. Vessels NZ42 and Q75: side views; dots and crosses represent nails. Vessel N5: longitudinal section. (Reinders, 1985, fig. 8)

Scarf Lengths From Vessel NZ43

Figure 45. Lengths of plank scarfs in vessel NZ43. Strakes 1 through 9 belong to the port side, strakes 10 through 15 to starboard. Lengths are given in mm. Squares with one cap represent two entries, those with two caps three entries. The shortest scarf of strake 6 was more than 20 mm long. (Adapted from plot by D. Carlson, Archaeological Research Lab, Texas A&M University)
All scarfs were secured by iron nails and occasionally also by treenails connecting the planks to frames. Nails were placed in two rows, at the forward and aft edges of the scarfs respectively. In the Bremen cog, all scarf nails have been driven in from the outside and have been clenched so that they are firmly anchored in the wood. No information on this procedure is available from other cog-like wrecks. Only a small number of nails in vessel NZ43 were recorded to have been clenched and hammered in from the outside, the others being perhaps too poorly preserved.

There is no information on the shape or size of scarf nails. Two types of nails are reported from the Bremen cog, one with rounded tips and one with tapering shanks and pointed tips, but no information about their use is given (fig. 46). Textual evidence, on the other hand, might indicate that scarf nails were considered a specific nail type. Dutch accounts from the 14th and 15th centuries mention three kinds of nails used in shipbuilding and other carpentry: *zoespikere* "edge nails," *lasschenagele* "scarf nails," and *tengenagele*. The third term is here less important, and its possible interpretations will be discussed below (p. 115). It seems obvious that the first term should refer to the nails joining the edges of overlapping planks and the second term to nails securing strake scarfs, which is the only scarf type that was primarily fastened with iron nails. Several clues from
Figure 46. Two nail types from the Bremen cog.
(Ellmers, in Kiedel and Schnall, Ill. 56)
shipwrecks suggest, however, that the difference between edge nails and scarf nails must have been minimal at most. Both were clenched, and thus must have been provided with pointed tips. Their lengths were probably similar, because they often had to pierce about the same thickness of planking. Moreover, the fact that in vessel NZ43 artists have recorded cross-sectional dimensions of some edge nails but not of scarf nails suggests that the remains of both nail types looked alike. The only real difference between the two could have been the shapes of their shanks or heads. Therefore, an alternative explanation of the medieval terms might be suggested which, although less evident, is more in keeping with archaeological evidence. If we assume that in the medieval period plank overlaps were considered a type of scarf, we can interpret laasschenagele as referring to scarf as well as plank-edge nails. Zoemspikere may then have been nails fastening hooping ends—also a kind of edge—to stem or sternpost. These nails were not clenched, and thus might have had rounded tips, because nails of such shape are not pulled out of the wood as easily as nails tapering to a point. In this way, laasschenagele would correspond to the pointed nails found on the Bremen cog, and zoemspikere to the round-tipped ones. This second interpretation, however, will remain more hypothetical than the first one until further study of actual scarf nails and edge nails can be completed.
A certain regularity is observed in the number of nails that were employed in the various strake scarfs of vessel NZ43 (fig. 47). It is remarkable that the starboard scarfs appear to have been far more regular in this respect than those at port. On the starboard side, fourteen of fifteen well-preserved nail rows consisted of three nails spaced evenly over the plank widths. On the port side, only seven out of seventeen well-preserved rows had three nails, while most rows had many more. In some, but not all, instances, many nails were apparently needed for the repairs of breaks. A significant relationship between the number of nails employed and scarf width or thickness could not be established. Therefore, the pattern might suggest that two people worked on different sides of the hull, the person to starboard being more disciplined in nailing procedures.

Strake scarfs were loosely staggered in the lower bow and stern areas. In the first two strakes they were situated at places where plank curvature was very tight; probably the scarfs were intended to relieve some of the stress on the planks (v. supra, p. 80). Apparently in order to offset the short bow plank and long stern plank of the second strake, the builder made the third strake with a much longer plank at the bow and a shorter one at the stern, so that this strake did not follow the staggered pattern of the other bottom and bilge strakes. As far as they were preserved, the
Figure 47. Nail distribution in plank scarfs of vessel NZ43. Number of nails is given per nail row. Shaded areas represent nail rows with uncertain number of nails. (Adapted from plot by D. Carlson, Archaeological Research Lab, Texas A&M University)
fourth and fifth strakes had all their scarfs very close together, those of the fifth strake beginning mostly only 8 to 10 cm further aft than the start of the fourth strake scarfs. I did not find a satisfactory explanation for this arrangement. The preserved scarfs of the sixth strake were distributed correspondingly to those of the third strake.

Plank scarfs of the overlapping side strakes were often clustered in larger groups. The first cluster in the bow, at 4.45 m from the stem, was comprised of the forwardmost preserved scarfs of the sixth through eighth strakes, together with the first scarf of the ninth strake (fig. 43 on p. 77). In this group, a higher positioned scarf almost always began just aft of the lower scarf, so that the forward end of the inboard plank of the upper scarf butted against the aft end of outboard plank of the lower scarf (fig. 48). In this way, the builder was able to make the plank seams at the scarfs watertight. An exception was the scarf of the ninth strake, which started just before that of the eighth strake. It is probable that in this and similar cases the upper edge of the outboard plank of the lower scarf had been bevelled so as not to leave a gap between the inboard plank and the overlapping strake. Such bevels have not been reported, presumably because of the rather poor preservation of plank extremities. Clustering so many scarfs presented a major disadvantage as it concentrated weak spots of strakes in one small area. This arrangement must have
Figure 48. Scarf cluster in overlapping strakes. Diagram not to scale. (Drawing by author)
contributed to the loss of the forwardmost planks of the fifth through eighth strakes. Amidships, the seventh through ninth strakes showed a scarf cluster between frames S10 and S11. The upper stern area was too poorly preserved to allow identification of scarf patterns.

Since frames were spaced close together (v. infra, p. 129), scarfs frequently lay beneath them. On the port side this was the case for fifteen out of twenty-seven preserved scarfs.

No scarf distribution studies have been done on other cog-like hulls. Illustrations show that in the side planking of the Bremen cog scarfs are often grouped in pairs (fig. 49), probably for the same reason as the scarfs in the sides of vessel NZ43 were clustered. Strake scarfs in the Ebersdorf model are all placed rather close together, and a major cluster can be seen in the upper stern area at port (fig. 50).

Plank extremities in strake scarfs protruded as much as 2 cm inside and outside the hull. It is remarkable that twenty out of thirty well-preserved scarfs protruded much more outboard than inboard (fig. 51 on p. 93), suggesting that the builder cared less about smoothness on the outside of the hull than on the inside, even though outboard projections increased the resistance of the hull in water (v. infra, p. 199). The smoothing of the inboard scarf
The Hanse Cog of 1380
View of Starboard Side and Bird's Eye View

Figure 49. Sheer and top views of the Bremen cog. (Kiedel and Schnall, back of front cover)

Figure 50. Stern view of Ebersdorf model, c. A.D. 1400. (Steusloff, p. 195)
Figure 51. Scarf protrusion in vessel NZ43. Strakes 1 through nine belong to the port side, strakes 10 through 15 to starboard. Amount of protrusion is given in mm. Small black dots mark two entries; those in strakes 4 and 13 refer to inboard protrusions. (Adapted from plot by D. Carlson, Archaeological Research Lab, Texas A&M University)
protrusions suggests that the inside of the planking has been trimmed; no relationship was found between the amount of protrusion and the presence of overlying frames. Five outboard plank tips were bevelled off, mostly in bottom strakes. This aspect could not be studied at the inboard plank tips because almost all are poorly preserved, undoubtedly as a result of being thinner.

There was also a difference in scarf protrusion between port and starboard sides. On the port side, scarfs in the side strakes jutted out more than those of bottom and bilge strakes. On the starboard side only bottom and bilge strakes were preserved, and their average scarf protrusion was significantly larger than the average of the entire port side. The maximum protrusion to port measured 1.5 cm, and was found in only four of seventeen scarfs, while seven out of twelve starboard scarfs protruded 1.5 to 2 cm. Again, this difference may reflect the activities of two different builders.

(d) Flush and lapstrake planking

The central parts of the bottom and bilge strakes lay flush and were not fastened to one another, in bow and stern, however, the same strakes overlapped. Similarly, the central part of the garboard strake lay flush with the keel plank and was not connected to it, while its fore and aft extremities were nailed to the hook rabbets. The side
strakes were built lapstrake throughout. Similar planking arrangements are found in most other cog-like craft, except in Zuyderzee wreck OZ43 and the Danish wreck from Kollerup. In vessel OZ43, all bottom and bilge strakes remain flush throughout, while in the Kollerup boat not all bottom or bilge strakes were overlapping in bow and stern.62

Iron nails joined the overlapping parts of planks. In vessel NZ43, only about half of these nails were recorded as having been clenched, but we may assume that they all had been clenched because that was the rule on cog-like vessels.63 For the same reason, it may be presumed that all these nails had been driven in from outside the hull. As mentioned above (pp. 84-86), plank-edge nails in the late Middle Ages possibly were considered a specific nail type and must have been similar to scarf nails.

The following data have been compiled concerning the shape and dimensions of the edge nails. Because planks are about 2 to 3 cm thick, and usually 1 cm of the nail shank is clenched, I estimate the nails to have been about 6 to 8 cm long. In plank G6c, nails were recorded as having round heads with a diameter of 2 cm; this probably reflects the size of all plank-edge nail heads. No direct information was given on the shape and size of the shanks, but nails securing the scarf joint of port futtock S12/BB to its floor timber had heads of the same size as the ones in G6c and squared shanks of 4 by 5 mm. Since iron nails are found only
sporadically in frame scarfs, it seems that they were used as temporary fastenings, and one can hypothesize that plank-edge nails were used for this purpose: having pointed tips, they could be removed more easily if the frame scarf needed adjusting. Therefore, it is possible that plank-edge nails had square shanks of about 4 by 5 mm.

Most nails seem to have been driven at approximately right angles, because only rarely is a nail mentioned as being slanted. This must reflect a practice of drilling pilot holes, as is reported in other cog-like vessels.\textsuperscript{64} W. Lahn remarks that the plank-edge nails of the Bremen cog are spaced about a palm width--nearly 10 cm--apart.\textsuperscript{65} The spacing in vessel NZ43 was more erratic, ranging from 5 to almost 30 cm. Nevertheless, most planks' nail spacing was between 10 and 20 cm, and this may reflect the use of a palm width as a measure as well.

Making the transition from flush to lapstrake planking required precise workmanship to prevent the seams from leaking. In vessel NZ43, the builder used two different methods. In most instances he cut an offset in the width of the upper strake so that the strake became 4 to 5 cm wider. With this extra width it overlapped the lower strake (fig. 52). In the bow of the third strake a second method was employed. Here the builder let the transition coincide with the strake scarf and no offset was needed. The forwardmost
Figure 52. Sandwich effect in transition from flush-lying to overlapping planking. The second top view shows an alternative transition, the lower strake being provided with a bevelled notch in its upper edge. Diagram not to scale. (Drawing by author)
plank of the third strake was simply 5 cm wider than the plank aft of it and immediately overlapped the second strake. A similar solution seems to have been used for the now-eroded stern transition of the fifth strake. In the Bremen cog, not all transitions were found within one plank either. No information is available from other cog-like wrecks.66

In the stern area, the boatwright made handy use of the plank scarfs of the first, second, and fourth strakes to facilitate the transition from flush to lapstrake joinery in the second, third and fifth strakes respectively. The forwardmost plank of the scarf always lay outboard, so the builder simply kept the upper strake flush with the outboard plank in the scarf of the lower strake, and cut the offset of the upper strake immediately behind the aft edge of that plank. In this way, the upper plank "hooked" behind the scarf in the lower strake in a way reminiscent of the scarf clusters in the overlapping side strakes (fig. 53; v. supra, p. 89). This method had several advantages. First of all, the edges of lower and upper strakes retained the same thickness throughout the transition, so that the seam was nowhere weakened. Secondly, it reduced to a minimum the number of protruding parts, even though we have reason to believe that the builder was not much concerned about that aspect (v. supra, p. 91). Most importantly, this allowed longitudinal stresses on the hull to be distributed over
Figure 53. Transition from flush-lying to overlapping planking:
upper strake "hooks" behind scarf of lower strake.
Diagram not to scale. (Drawing by author)
both the upper and lower strakes, thereby strengthening the hull.

In the bow, most transitions were located just forward of lower strake scarfs. Since here, too, the forwardmost plank of the scarf lay outboard, the shipwright was unable to apply the same technique used in the stern transitions. Instead, he made the upper strake gradually recede with respect to the inside face of the lower strake until he cut the offset forward of the lower scarf (fig. 52 on p. 97). For the fourth strake, the exact length of the receding part is indicated as 60 cm, and on the basis of the shapes of the overlying frames, I believe that receding parts in other strakes had about the same length. A disadvantage of this method is that plank edges became locally thinner and the seams thus weaker. On the other hand, it seems that by placing the transitions just forward of the bow scarfs in the lower strakes, the builder intended to strengthen the hull by sandwiching the bow plank of the lower strake between the overlying second plank of that same strake and the overlapping edge of the upper strake.

Several planks contained notches and bevels that facilitated and reinforced transitions from flush to overlap. In the upper outboard edge of the garboard bow plank, the builder cut a bevelled notch reaching from the stem to the start of the overlap in the second strake (fig. 54). The second strake was bevelled and notched accordingly.
Figure 54. Bow plank of port garboard. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
Although neither of these two planks was exceptionally thick, the boatwright may have deemed the notch and bevels necessary to make the second strake run in a smooth curve towards the stem. This reduced the amount of plank protrusion and made the hull stronger, as did hooking the stern transitions behind plank scarfs. On the starboard side, a gap was found instead of a notch. It is 60 cm long by 5 cm wide, and covers the entire thickness of the plank (fig. 55). The hole was patched with a repair plank. This gap was most likely the result of a failed attempt to cut a notch similar to the one at port. Perhaps this is another indication that two people were building vessel NZ43, each at one side of the hull.

Lastly, the bow transition in the third strake and the stern transition in the fourth occurred independently of the scarfs in the lower strakes. A bevelled notch was cut in the respective lower strakes, which again facilitated and reinforced the transitions. The reason for this odd location in the third strake apparently was to create a staggered pattern of transitions from the second through the fourth strakes. In the stern, however, the transition of the fourth strake does not follow the pattern of those in the other bottom and bilge strakes (fig. 43 on p. 77).

The notch cut in the upper edge of the garboard at port (v. supra, p. 100) became gradually deeper and wider
Figure 55. Bow plank of starboard garboard. Original edge indicates gap. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
relative to the plank width, so that as garboard and second strake approached the stem, their outboard faces changed gradually from lapstrake to flush again. Unfortunately, the seam was not preserved as far as the post, but I suspect that the hooping ends became completely flush and that the same was true for all other hooping ends on vessel NZ43. This practice was found on many cog-like craft and other lapstrake-built vessels of that time. Even today, it is commonly used in clinker-built craft (fig. 56). It derives this popularity from the fact that it greatly facilitates the closing of the seams between strake hooping ends and posts.67

(e) Sculpting and bevelling

Fore-and-aft curvatures of the strakes were obtained not only by twisting and scarfing but also by cutting them in specific shapes. As described above (p. 75), most strakes tapered in width towards bow and stern.

In several places on the hull, uncommon shapes were cut to meet the requirements of the plank curvature. At port and starboard, respectively 12 cm and 5 cm forward of the bow scarfs, the width of the garboard increased in bottle-neck fashion (figs. 54 and 55 on pp. 101 and 103, respectively). This extra width assured that the twisting planks maintained contact with the keel plank and second strake. In the stern, a slight bevel just forward of the hook rabbet made the
Figure 56. Transition from overlapping to flush-lying planking near stem and sternpost. Above: stern of Ebersdorf model (Steusloff, p. 203). Below: traditional Dutch craft (Sopers, fig. 15).
garboard fit snugly against the keel plank, in spite of its complex curvature (fig. 57). The second strake contained an anomaly as well. At its forward end, the builder placed a short, trapezoidal plank that interrupted the taper of the strake and made it widen again towards the stem. This raised the plank line, which was drooping because of the tight twisting of the garboard (fig. 43 on p. 77).

Strake cross sections were not recorded systematically, but data from several areas on the wreck indicate that transverse curvature of the planking was obtained by sculpting plank faces and bevelling edges in the lapstrake areas, and by merely laying the planks at a slight angle in the flush parts of the planking. Sculpted faces seem to be found only in overlapping planks that are both relatively narrow and thick (v. supra, p. 78). Apparently, planks were never bent in cross section.

In the lower bow, where transverse plank curvature was hollow, the inner face of the third strake was sculpted so that when seen in cross section, it presented a bulge (fig. 58 on p. 108). No bulge was observed in the bow plank of the fourth strake, but this plank was poorly preserved. In the lower stern, where the curvature was convex (v. supra, p. 80), the first strake had straight surfaces, while the cross section of the second and third strakes is not given. The fourth strake had a bulging outer face. The fifth and sixth
Figure 57. Stern plank of port garboard. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
Figure 58. Plank cross sections from vessel NZ43. All lie with inner faces up. For location of strakes: see fig. 43 at p. 77. (Adapted from drawings by Museum Ketelhaven, courtesy R.I.J.P.)
strakes had bulges at their outer faces over most of their preserved lengths. Only the forwardmost preserved plank of the fifth strake was not sculpted, apparently because the transverse hull curvature was still changing from hollow to convex. Unfortunately, the bow planks of the fifth and sixth strakes were lost. The preserved midsection of the very wide seventh strake was recorded as straight throughout, as seems to be the case with the poorly preserved, wide ninth strake. The narrower eighth strake, on the other hand, had a pronounced bulge at its outer face and, in addition, was bevelled over its upper edge, so that it took up most of the transverse curvature.

There was a difference between the port and starboard sides in the beveling of plank edges. To port, seven out of the nine recorded bevels were found in upper plank edges. Only those sections of the second and fourth strakes that fit into the notches of the garboard and third strakes respectively (v. supra, pp. 100 and 102) were bevelled underneath. To starboard, on the other hand, all three recorded bevels of the overlapping bottom planking were in lower plank edges and always presented slight offsets (e.g. Gila and "huid 2 achter:" fig. 58 on p. 108). Even though these data are not complete, they support the contention that different people were working on either side of the vessel.
(f) Temporary fasteners

Throughout the flush part of the planking, and even in some lapstrake sections, small square holes were recorded that often do not reach all the way through the strakes (fig. 59). In bottom and bilge, they vary in section from 4 x 4 to 5 x 5 mm, while the few found in the side planks are slightly larger--6 x 6 mm to 7 x 7 mm. Several holes are grouped in pairs, mostly about 10 cm, or a palm width, apart. Their distribution differed from port to starboard. These holes may have been made by iron nails fastening cleats, and possibly braces, to the strakes (fig. 60). Later, when the frames were put in place, cleats and braces would have been removed and the nail holes stopped with wooden plugs. Several such plugs were still in place when the wreck was excavated.

The use of cleats is considered a characteristic of Dutch shipbuilding. In 1671, Nicolaes Witsen wrote that cleats were employed both on the inside and the outside of hulls; they were spaced 3 to 4 feet apart. They still can be seen in traditional boatyards. The recent discovery of such cleats in the early-15th-century cog-like wreck at lot N5 in the Zuyderzee polders has revealed that they were already in use about 250 years before Witsen (fig. 61 on p. 112).

In all of the above cases, cleats appear as short battens holding only two strakes at a time. One of the
Figure 59. Square nail holes for temporary fasteners. Inboard view model NZ43, between frames S16 (left) and S15 (right). Most square holes are blackened. (Photo by author)

Figure 60. Use of plank braces and ceiling struts during construction. Dutch painting from 16th or 17th century. (Kijk op koggen, p. 32)
Figure 61. Cleats and plank brace. Above: cleats joining garboard to keel in vessel N5. (Reinders et al., s.d., fig. 5). Below: cleats (1, m) and brace (e) in 17th-century Dutch ship. (Witsen, ill. facing p. 168)
cleats in wreck N5 seems to be connected to the lower strake with one nail, and to the upper one with two, while another example apparently has only one nail in each strake. In vessel NZ43, however, nails were found mostly in pairs situated on the same strake (fig. 62). Often, but not always, they were matched by one or two nails in the adjacent strake and appear to have held a short cleat. In many cases, matching nails were missing or they were in the strake beyond. One could suppose that the nail holes have been eroded and were not noticed by the artists, but the over-all good preservation of the bottom planks does not corroborate this assumption.

In my opinion, this nail distribution might suggest that the builder used not only short cleats but also employed some type of longer battens which held more than two strakes at a time. There is textual evidence to suggest that he actually might have employed the boei-tang (planking brace) which is described and depicted by Witsen (fig. 61 on p. 112). The purpose of such braces was to hold the planking and force it into a certain curvature. No archaeological evidence of a planking brace has been found as yet, but a 1423 document from Deventer, a city near the Zuyderzee, may refer to the device. This text, cited by A. Luns, is a repair account for a baardze, a vessel type possibly related to the cog. It mentions the use of three types of nails: zoemspikere, lasschenagele, and tengenagele.
Figure 62. Top view reconstructed vessel NZ43, 1987. Dots represent square nail holes. Substituted parts are shaded. For the sake of clarity, frame heads beneath the clamp are shown in full lines. (Drawing by author)
The first two terms have been discussed previously (pp. 84-86). One could suggest that *tenge* in the third term may have derived from *tengel* (batten) and that *tengenagele* therefore might be the square nails fastening the batten-like temporary cleats. However, such interpretation seems far-fetched. It is more likely that *tengenagele* should be read as *tangenagele* because *tenge* is a common vernacular form of *tangle*, and that *tange* refers to the brace mentioned by Witsen or to the related verb *tangen* (to brace). *Tangenagele*, therefore, might be translated as "brace nails," or "bracing nails," meaning nails fastening a brace to the planking. Interpreted in this way, the Deventer text would indicate that planking braces were used already in the early 15th century, and it would seem rather likely that they were used in the 14th century as well. Whether they would have had the same shape as the one depicted by Witsen is not known.

(g) Caulking

The seams between strakes were filled with moss, covered with moss-laths, and fastened by rows of overlapping iron butterfly clamps called *sintels* in written documents (fig. 63 and fig. 64 on p. 117). On many other wrecks, moss was mixed with animal hair and/or pitch. These ingredients are also mentioned in several medieval Dutch accounts, although no such mixture was reported in wreck NZ43.74 The
Figure 63. Caulking of flush and lapstrake planking in vessel NZ43. Above: flush strakes G13b and G1b. (Adapted from drawing by Museum Ketelhaven). Below: rows of caulking clamps covering caulking at the inside of overlapping strakes. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
Figure 64. Caulking of flush and lapstrake planking in cog-like vessels from the Zuyderzee and the Bremen cog. Above: caulking methods with caulking clamp from vessel NS. (Reinders, 1985, fig. 8). Below: from Bremen cog. (Ellemers, in Kiedel and Schnall, ill. 56)
moss-laths in our vessel have ellipsoidal cross sections, unlike the triangular shapes found in most other wrecks. In some cog-like vessels, as in wreck M107, laths were omitted.

Caulking clamps are not sufficiently preserved to be reconstructed in their original shapes, but those of other wrecks are basically elliptical plates with lips at both long sides (fig. 64 on p. 117). The caulker would bend the lips and drive the clamp, as a staple, into the wood on either side of the plank seam. Only twice were references to the sizes of butterfly clamps found for vessel NZ43. In the stern areas of the second and fourth strakes on the starboard side, the hearts of the clamps were spaced 5.5 to 6 cm apart. As these clamps overlapped one another about half of their lengths, their longest diameters may be estimated as also 5 to 6 cm. This corresponds exactly to data from the Bremen cog. Clamp lips in vessel NZ43 have left slots of 0.9 by 0.2 cm in the wood. In the Swedish cog-like wrecks from Bossholmen and Helgeandsholmen, clamps did not overlap but were placed 5 to 8 cm apart. About 8000 butterfly clamps were counted in the Bremen cog.

This caulking method was known as early as Roman times, and elements of it have been recognized in many parts of central and eastern Europe. B. Arnold reports the use of moss and butterfly clamps on the 1st- or 2nd-century−A.C. lake barges from Bevaix and Yverdon in Switzerland.
Butterfly clamps were found on land in Novgorod, Russia, in strata ranging from the 11th through 14th centuries. In the southern Baltic they were discovered in medieval context, moss being found in vessels from the 9th century on. They were also employed in late-medieval river craft from Elbing (Elblag), Poland, even though the rest of the caulking method differed somewhat. Furthermore, clamps were widely used in late-medieval vessels along the rivers Rhine, Meuse, and Yssel, surviving along the upper Rhine until the early 20th century. Medieval Dutch accounts show that they were not only employed in cogs but in other boat types as well, such as baardze and schole. In the Zuyderzee wrecks, clamps are confirmed no later than the 16th century. The success of this caulking method can be explained by the easy availability and durability of the caulking moss (v. supra, p. 44). In the Scandinavian tradition, on the other hand, animal hair or cloth mixed with tar was preferred for caulking. 78

In the flush parts of the hull planking of vessel NZ43, caulking was applied from the outside, even in places where the upper plank was gradually receding with regard to the lower plank prior to making the transition from flush to lapstrake (v. supra, p. 100). Often the angled seams left sufficient space for caulking, or else the planks would be slightly bevelled underneath over part of their thicknesses (Fig. 63 on p. 116).
Lapstrake planks were caulked at the inside of the overlap, even though in eight planks there was additional caulking on the outside. In some places it was noted that the outer edge of the lower plank was bevelled in order to hold the caulking. Similar practices were found in other cog-like vessels (fig. 64 on p. 117).79

Many cracks in the hull planking were caulked in the same way (fig. 14 on p. 28). Caulking in cracks was usually found on the outside of the hull, undoubtedly because on the inside the presence of the frames would have hindered the repair work. Moss was also found in five strake scarfs, and moss was mixed with pitch in the scarf of the bow hook and triangular chock. Black colorations observed in two other strake scarfs may also be remains of caulking. Finally, moss was discovered between strake G7 and frame S11/BB.

(h) Hull finishing

No information on the smoothness of plank surfaces exists. Patches of what may be tar or pitch have been recorded at several places, mostly on the inside of the hull planking but in two instances on the outside (fig. 14 on p. 28). Inboard, all patches covered areas of planks situated between frames, and were never found on the frames themselves. Furthermore, they occurred mostly in the lapstrake parts of the hull; only once, in the stern area of the fourth strake, did they extend into the flush section.
Analysis of the substance will reveal whether it is tar or pitch.

Contemporary Dutch accounts list both tar and pitch among hull-finishing materials, as well as animal fat, tallow, and harpuls—a mixture of resin and linseed oil. Evidence of the use of such substances dates from the 16th to the 20th centuries, but it is possible, as A. Luns suggests, that they were used in the same way in the late Middle Ages. Below the waterline, pitch was smeared only over the caulked seams, while tar covered the strakes. Harpuls, sometimes mixed with pitch, was specifically used for coating deck planking and spars. Animal fat probably served to protect the metal parts on the vessel.

5. The clamp

From the stem to at least frame S17, and perhaps all the way to the sternpost, a timber ran inboard over the frame heads along the upper edge of the sheer strake (v. supra, p. 16; fig. 62 on p. 114). On the basis of fragments and of notches in eight of the frame heads, the timber’s dimensions can be determined as varying from 7 cm wide by 3 cm thick in the extreme bow, 14 by 9 cm at frame S7, 15 by 8 cm at frame S13, and probably 15 by 9 cm at frame S17.

The function of the timber was, without doubt, to add longitudinal stiffness to the upper part of the hull. In addition, it served to protect the frame heads. Although it
did not support deck beams, which seem to have run at a lower level, it is best referred to as a clamp. In modern wooden vessels, a clamp is a thick strake running along the interior frame faces and parallel to the wales; its primary function is the longitudinal stiffening of the hull. It is commonly found in Dutch shipwrecks from later periods, but in other cog-like vessels clamps have not been found at the sheer line. The Bremen cog has merely a ceiling plank running along the sheer, and other wrecks have not been sufficiently preserved to provide data in this respect (fig. 65). However, the beams found in the bilges of the Danish wrecks of Kollerup and Kolding seem very similar to the clamp of vessel NZ43. In each case, the timber runs on top of the last flush strake, apparently over most of the length of the hull (fig. 66 on p. 124). It is unusual that these beams are situated underneath the frames, which are notched to let them pass. In the Kollerup wreck, floors and futtocks stop at the level of the timber, and a second futtock is placed above the first one. Obviously, those timbers served as longitudinal reinforcements of the hull, and therefore they can be considered clamps.

The clamp of vessel NZ43 was fastened to the sheer strake with large, close-set trenails, their diameters ranging from 3.5 to 5 cm. At one instance, under frame 58, the clamp was in addition pierced by an iron bolt with a diameter of 3 cm. Over most of its length, the clamp had one
Figure 65. Midship section of the Bremen cog. Ceiling plank along sheer is indicated by number 18. (Lahn, p. 40-41)
Figure 66. Sketch of cross sections of three Danish cogs.
(Crumlin-Pedersen, 1979, fig. 2.12)
treenail at each frame and one between frames, so that on the average, treenails were spaced only about 12 cm apart. In the bow, however, the fastening was more robust. At the half frames as well as at frame 81, two treenails were found, of which one was aligned with the frame. Forward of the half frames, two groups of two treenails each were placed very close together. Undoubtedly, the size and distribution of the treenails reflect the function of the clamp as a stiffener, and point out the areas of greater stress along the upper hull.

6. Frames

The hull of vessel NZ43 was reinforced with twenty full frames and probably a pair of half frames in the bow. These half frames and one full frame in the stern quarter were missing (v. supra, p. 16-18). In the bow and stern, most frames were slightly curved toward the vessel’s extremities (fig. 62 on p. 114). All frame parts covering overlapping strakes had offsets cut into their outer faces in order to fit better to the planking.

The full frames consisted of floors and futtocks. Because of variations in hull shape, cog-like vessels had three different kinds of floor timbers (fig. 67). In bow and stern, where the sides rise quite steeply, floors were V-shaped timbers designated in Dutch as wrangen (wringing pieces). Floors in bow and stern quarters were called
Figure 67. Frame sections of vessel NZ43. Treenail holes are marked by centerlines. Dashed lines represent substituted parts. (Drawing by author)
krommers (curved pieces). In the flat central part of the hull, floor timbers were almost straight beams referred to as leggers (laid pieces).

The first four frames in the bow of vessel NZ43 were heavy wrangen, shaped slightly asymmetrically in accordance with the shape of the lower bow (v. supra, p. 82). Their molded dimensions, measured at the vessel’s centerline, gradually diminished from 35 cm at the first floor to c. 21 cm at the fourth. Sided dimensions, on the other hand, increased from 13 to 20 cm. After the four wrangen came three heavy krommers averaging 20 cm in molded and 23.5 cm in sided dimensions. Krommer S7 had a very long leg at the port side, reaching all the way to the sheer strake. Floor timbers S8 through S13b were leggers that supported the ceiling area. Their extremities were slightly upturned to follow the curve of the bilge. Dimensions averaged 13 cm in molded and 16.5 cm in sided dimensions. Then followed a pair of smaller krommers with an average molded dimension of 15 cm and a sided dimension of 16.5 cm. In the stern, finally, lay four more wrangen. The first three increase in molded dimension from 14 cm at S16 to 27 cm at S18 and have an average sided dimension of 15 cm. Frame S19 is only fragmentary. Like krommer S7, floors S16 and S17 each have one long leg, but this time on the starboard side; both are preserved up to the seventh strake but may have reached all the way to the sheer strake.
Without the **wrangon**, the average molded dimension of the floor timbers is 15 cm, or five times the thickness of the strakes. This ratio is much higher than the 3:1 frame-to-plank thickness ratio on the Bossholmen wreck. No information on this aspect is known from other cog-like craft. Most futtocks are slightly lower but broader than the floor timbers. Others have dimensions similar to the floor timbers or are slightly smaller. They stopped short of the sheer line or were notched on top in order to fit over the clamp (v. supra, p. 121).

Watercourses were cut in most floor timbers, except for the first three in the bow and the last four in the stern. The absence of watercourses in the hull extremities may be explained by the fact that those parts of the keel line were raised well above the midship elevation (v. supra, p. 51). The fourth floor had a triangular-shaped limber hole, positioned at the port edge of the keel plank. Floor timbers S5 through S13 had as a rule four triangular watercourses, two at either seam of the keel plank and two in the bilges, the latter ones mostly over the third strake. The watercourse in the starboard bilge of floor S7 has been omitted, apparently because of the futtock scarf (fig. 67 on p. 126). The average height of the courses was 5 cm, the base 3 cm. As a rule, those over the keel plank were somewhat larger than those in the bilges. Krommers S14 and
S15 had only one limber hole each, square cuttings sized 5 by 5 cm and located at the starboard edge of the keel plank. While the average sided dimension of the frames was 17.5 cm, their average spacing was 24.5 cm. Exceptionally large intervals were observed between frames S3 and S4, S7 and S8, S14 and S15. These exceptions seem to have been functional. The first and the last one might have been related to the supposed existence of fore and aft decks. Frame S14 was situated just aft of the ceiling area and probably provided foot space for the people loading and unloading the cargo. The extra large interval between frames S7 and S8 occurred just forward of the ceiling area, and may have served a similar purpose. At the same time, it offered sufficient space to place the rectangular chocks in the bilges (v. infra, p. 144). Moreover, the interval was situated at or near the location of the mast and, judging by its wear pattern running from the starboard garboard to the third port strake, I think it also may have been used for storing mast or tackle gear (fig. 68).\textsuperscript{83}

As in other cog-like vessels, frames were connected to the keel plank, hooks, and strakes primarily by means of cylindrical treenails. Seventy-six of these treenails were secured with wedges at their outboard ends. A distinct pattern existed in the number and position of the treenails, which was generally similar on both sides of the hull.
Figure 68. Inboard view of midship part of reconstruction model. Seen from stern. Fourth and fifth frames from the top are S7 and S8, respectively. Line running through center of third starboard strake indicates an uncaulked crack. (Photo by author)
Krommers and leggers were fastened to the keel plank and hooks with one treenail. In the first four strakes, as well as in the seventh strake, they had as a rule two treenails, even though the third and fourth strakes were quite narrow and the seventh strake was exceptionally wide. In most other strakes, only one treenail was used. Rarely were three treenails found, and then most often when the frame covered a plank scarf, in which case two of the treenails were usually found very close together. The wrangen in bow and stern, on the other hand, were held by only a few treenails and iron nails (fig. 67 on p. 126).

Iron nails were also employed to fasten frames to planking. They have been recorded in ten floor timbers and six futtocks, their numbers ranging from 1 to 3. These nails most likely held the frames in place temporarily before they were fastened with treenails. They might also have reinforced some weak connections between frames and planks.

Along the surface of the frames, treenails were only slightly staggered; in two frames, major portions have broken off along the line of treenails. Almost all treenails were driven in perpendicularly to the curvature of the hull; seldom was a treenail angled as much as 45°. In some cases two treenails met in the same hole or partially overlapped one another. Usually this was seen on the inner faces of frames, occurring only once on an outer face. The few blind treenails found in frames were located in the outer faces,
suggesting that most treenails were driven in from the outside of the hull, according to common practice.

Treenail diameters have not been recorded systematically for all frames and strakes, and often a single measurement was taken as representative of all treenails in a plank or frame. Consequently, a pattern cannot be established. There are treenail measurements for six floors, eight futtocks, and several strakes. Their diameters in the bottom and bilge seem very consistent, ranging from 2.3 to 2.5 cm, and averaging 2.4 cm. Treenails in the side planking tended to be somewhat smaller, from 2.2 cm to 2.4 cm, with an average of 2.23 cm. In three areas of the hull side, however, treenails were conspicuously large. Those in futtock S2/BB (A28) and in the upper part of floor S7 measured 3 cm in diameter, the ones in the upper part of S17 as much as 4 cm. Both S7 and S17 were long-legged floors, and the difference in treenail size at the bottom and bilge (2.5 cm) versus the side of the vessel are therefore more striking. These larger treenails may have served to counter extra pressures on the hull. We know that frame S7 was carrying, above the bilge, a wooden chock supporting a mast or lifting arrangement (v. infra, pp. 144 ff.). Futtocks S2/BB and S17, on the other hand, may have supported partial decks (v. infra, p. 140).
Futtocks were joined to floors by long flat scarfs. Some of these scarfs were slightly curved, and sometimes the upper face of the floor had a small recess to receive the futtock. The lengths of the eighteen well-preserved scarfs varied from 20 cm to 100 cm, with an average of 38 cm. On the port side, futtocks started at the fifth or sixth strakes. Most scarfs on the starboard side cannot be reconstructed with certainty, but seem to have presented the same pattern. This placing of the frame scarfs in almost one line must have weakened the bilge of the vessel, and we see that the starboard side has indeed broken off in that area. Frame scarfs in other cog-like vessels are not situated in one line but are otherwise similar.84

Floors and futtocks were connected with treenails, which usually penetrated the planking. In eleven scarfs iron nails were driven from the inboard side of the futtock. Their numbers ranged from 1 to 4 per scarf, averaging 1.81. Four nails fastening the port scarf of frame S12 are recorded as having square shanks of 4 mm by 5 mm, and round heads with a diameter of 20 mm. The other nails may have had similar dimensions. Because of their small number, these iron nails must have served either a temporary or auxiliary function.
7. Deck beams and knees

On several cog-like wrecks, through-beams are found which must have played an important role in the transverse reinforcement of the hull, often replacing futtocks. They were fastened to the upper hull planking by heavy standard knees. Wreck M107, on the other hand, did not have its deck beams protruding through the planking, and its knees are of modest sizes.85

As described above (p. 18), three deck beams have been found, all with one extremity preserved (fig. 69). The largest beam, labeled A37, is sided 17 cm and molded 17.5 cm, tapering to 14.5 cm at the extant extremity and to 13.5 cm at the broken end. Its large size and crown correspond to deck beams found in other cog-like vessels.86 The shape of the preserved extremity and the direction of the two treenails piercing it in a downward angle towards outboard indicate that this beam, like the ones of wreck M107, did not protrude through the planking. It ran perhaps level with the seventh or eighth strake, in the vicinity of frame S17. It may have supported the presumed after deck. However, an iron bolt fragment found just forward of the wooden chock at frame S7 fits into one hole of the deck beam’s extremity. For that reason, the excavators suspected that beam A37 belonged to that area of the hull. If that is true, the highest part of the beam would not be situated over the keel, and thus might not be the crown, but a result of
Figure 69. Deck beam remains from vessel NZ43. (Adapted from drawings by Museum Ketelhaven, courtesy R.I.J.P.)
differential preservation. A shallow cavity on the under
face of the preserved extremity suggests beam A37 was
running over a now lost gangway or flat plank placed along
the inner faces of the frames to provide walking space along
the cargo area. Such a gangway has been found in wreck M107
(Fig. 70). Since the deck beam extends at least 15 cm beyond
this cavity, it is likely that it ended between two frames.
The rather poor preservation of the beam’s extremity, as
well as that of the upper hull, does not allow further
speculation about the original location of the beam.

Both smaller beams have maximum molded dimensions of 10
cm, decreasing to 9 cm at their preserved ends. The sided
dimension of beam A23 is c. 11 cm throughout, and that of
beam A27 is about 10 cm, decreasing to 8 cm at the extant
extremity. Each beam has one vertical treenail hole piercing
its preserved extremity, and beam A23 seems to have one at
the opposite end as well, which might mean that it has lost
only a small part to erosion. Near one edge of its central
part this timber has a group of three nail holes, perhaps
remains of fastenings for deck planking or a stanchion. The
upper face of beam A27 also has one iron nail a short
distance from its treenail. Both beams were found in the
bow, and might belong there, A23 perhaps around frames S2 or
S3. Because of their small sizes, however, it is also
possible that they did not run in a transverse but in a
fore-and-aft direction as carlings. Such an arrangement is
Figure 70. Deck beam and gangway in vessel M107. Above: ship section, seen from the bow. (Reinders, 1985, fig. 4). Below: Wreck M107 in situ, seen from the stern. (Photo by Museum Ketelhaven, courtesy R.I.J.P.)
found in the Bremen cog, and probably also in the Ebersdorf model (fig. 65 on p. 123). Both, however, represent much larger seagoing vessels, and a small boat like ours may not have needed them. This reconstruction is also less likely because it does not explain the presence of the treenail hole in each beam’s extremity. A third possible suggestion is that they served as transverse beams of a tabernacle mast structure (v. infra, p. 150). However, there is not sufficient evidence to prove that vessel NZ43 possessed a mast of such type.

Beam fragment A25 is similar in size to beams A23 and A27, although slightly flatter. It tapers at the preserved end. Too little has remained to allow its reconstruction.

One small and two large knees that were excavated could not be relocated (fig. 71). One large knee, A20, is sided 19 cm, and molded 19 cm, its short leg tapering in height to 16 cm, and its long leg to 10 cm. The other one, labelled A26, was not drawn. The smaller knee has a sided dimension of 12.5 cm and a maximum molded dimension of 15 cm, tapering in height to 7 cm in the short leg and 14 cm in the longer leg. Comparing these with knees in other cog-like vessels, I think the longer legs were lying horizontally.87 In most of those vessels, standard knees are placed on top of deck beams. In larger craft, these knees look almost like bulkheads and support the upper strakes. In small wrecks,
Figure 71. Knee remains from vessel NZ43. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.)
knees are smaller and sit quite close to the sheer line. Unfortunately, the vertical legs of those knees are damaged so it cannot be known whether they supported a washboard or some type of superstructure. The knees of vessel NZ43 were found in the bow area, but the curvature of their vertical legs suggests rather that they belonged amidships.

Because of its high sides in the stern, this vessel must have had at least a partial deck aft from which the helmsman handled the rudder. A likely starting place for this deck would be somewhere between frames S15 and S17, aft of the ceiling area. The heavy treenails in the upper part of S17, and the possible location there of heavy deck beam A37 suggests the deck began near S17. A row of five iron nails in the inner face of frame S18 might be related to this deck (fig. 62 on p. 114). A second partial deck in the bow would have been useful for heaving the lead or handling the anchors. Navigation with the sounding lead was characteristic of shallow water sailing in the late Middle Ages, and in the shallow Zuiderzee this operation must have been of prime necessity. Perhaps vessel NZ43 also had a gangway running along the sides, connecting the decks fore and aft (v. supra, p. 136).
8. Ceiling area

Three large and two smaller parts of ceiling planks remain, together with a bulkhead. According to the excavators, they must have covered the area from frames S8 through S14 (fig. 11 on p. 22). These planks ran in fore-and-aft directions and formed a closed ceiling at least over its bottom section. They vary in thickness from 1.5 to 3 cm, averaging 2.4 cm. Their widths range from 32 cm to 42 cm, with an average width of 37 cm. Along the edges of their upper surfaces are iron nails, which are recorded as extending only halfway through the thicknesses of the planks, as if the ceiling planks were not connected to the underlying frames but to some structure on top. Yet, because it is more likely that the planks were fastened to the frames, it is possible that on their under faces the nail holes were so small that they were closed by the swelling of the wood after the sinking of the vessel and became invisible. Such a phenomenon is not uncommon in shipwrecks. Some nail holes found in the upper surfaces of frames S12 and S13 may be evidence of ceiling plank fastenings.

Because of the scarcity of nail holes and the small number of ceiling planks found, it is impossible to determine how high the ceiling extended up the sides. Plank A18 was found on top of the bulkhead, and therefore must have originated at the fifth strake or higher (fig. 8 on p.
Frame S13 has one blind nail at the level of the sixth starboard strake, but this evidence is too scanty to conclude that the ceiling reached to that point. All other cog-like vessels seem to have had an open ceiling, reaching as far as the sides are preserved, with the planks fastened mostly by treenails. Only in wreck M107 were the spaces between the fixed ceiling strakes filled with loose-lying planks. 90

A low bulkhead, which must have stood on top of frame S8, closed off the forward end of the ceiling area (fig. 72). It was 40 cm high over the keel and, on the average, 4 cm thick. Two nail holes, 3.5 cm from the upper edge and 1.65 m apart, might have fastened wooden uprights or cleats supporting the bulkhead and perhaps other partitioning timbers. No other fastenings were found on the bulkhead itself. The upper face of frame S8 has a blind treenail that also may have formed part of the bulkhead fastening. Evidence for a bulkhead closing off a ceiling area also has been found in the Danish Kollerup wreck. The bulkhead was located in a notch on top of a large floor timber, just aft of the mast step which was cut in the floor. This wreck yielded evidence for a second bulkhead in the stern. 91

Ceiling strakes served to reinforce hulls longitudinally and to keep the cargo out of the bilge. Since the ceiling planks of vessel NZ43 were not strongly connected to the frames, it seems that they were primarily
Figure 72. Bulkhead and ceiling area of vessel NZ43. Above: bulkhead. (Adapted from drawing by Museum Ketelhaven, courtesy R.I.J.P.) Below: inboard view model NZ43, seen from bow. Dark ceiling plank more likely belongs higher up the port side. (Photo by author)
intended to support the cargo. The closely lying planks and the presence of a bulkhead made it possible for the vessel to hold bulk goods or cargo stored in bags or wickerwork baskets. The possibility that the ceiling planks formed the lining of a living floor as in the 16th- and 17th-century Dutch waterschepen, is less likely because of the small size of the vessel. 92

D. Rigging

1. Mast step

Heavy wooden chocks were fastened over frames S7 and S8 at the level of the port and starboard sixth and seventh strakes. Only the port side chock is preserved (figs. 10 and 11 on pp. 21 and 22, respectively, and fig. 73). It has a slightly irregular shape, with a maximum length and width of 108 and 47 cm respectively and an average height of 22 cm. Its outboard side is chamfered and notched in order to fit over the two frames. It was fastened to frame S8 with one large treenail and to frame S7 with two. These treenails had a diameter of 3.5 cm. A fourth treenail seems to have joined it to the sixth or seventh strake, but no treenail hole is recorded in either strake.

In the center of the chock's top face, a square cavity with sides 18 cm long and a depth of 9 cm has been cut. The
Figure 73. Heavy wooden chock in vessel NZ43. Probably mast step. Top left: seen from starboard. (Reinders, 1985, fig. 9) Top right: seen from starboard; below: seen from upper port side. (Photos by Museum Ketelhaven, courtesy R.I.J.P.)
upper face of the chock and the bottom surface of the cavity were positioned more or less horizontally in the wreck. Inside this cavity, an off-center circular hole has been drilled through the block, apparently as a drain hole. The upper edges of the cavity were reinforced with iron strips on all but the inboard side. A strip of iron found along the starboard side suggests this was also true for the starboard chock. In the corner formed by frame S7, the seventh strake, and the chock, a shallow round wear mark was recorded. It does not seem to be related to the structure but rather resulted from shipboard activities, such as the stepping of a fishing line, a stanchion, a lifting boom, or simply from erosion. The 1979 site plans show at that location a rectangular object that can no longer be identified (figs. 8 and 11 on pp. 17 and 22, respectively).

The function of the heavy chocks is uncertain, and no such timbers were found in other shipwrecks. R. Hulst suggests they were steps for a boom to hold the yard in a slanted position, so that the square sail could be used as a type of spritsail when the wind was coming abeam. Hulst’s hypothesis is partially based on the difference between a cog’s center of effort and center of lateral resistance. The center of effort is the point through which the aerodynamic forces on the exposed hull and rigging can be considered to operate; it is estimated to be the center of the sail. The center of lateral resistance, on the other hand, is the
point through which the resultant of the total hydrodynamic force can be considered to act, and which is located about amidships, at the widest part of the hull (fig. 74). A vessel sails most efficiently when the centers of effort and lateral resistance are aligned. The more the center of effort moves forward with regard to the center of lateral resistance, the more the bow will drift when the wind is not astern. Since the mast on a cog-like vessel is placed somewhat forward from amidships (v. infra, p. 152), the center of effort is quite far away from the center of lateral resistance. Hulst believes that if the mast was placed farther forward than a third of the keel length from the stem, the sail must have been used as a spritsail in order to prevent the bow from drifting when not running before the wind. He refers to the 1365 town seal of Kiel as a portrayal of this sailing method (fig. 34 on p. 65). On the basis of the same seal, D. Ellmers has suggested a similar use of the sail, but without a boom. Even though the mast position of vessel NZ43 might have been so far forward that such a sailing method would have been useful (v. infra, p. 152), the cavity seems to be too large for this purpose, and its surface is flat and appears ill-suited for a pivoting boom.

It seems more likely that the chocks served as steps for some sort of heavy uprights. The massive size of the preserved timber, the iron strips around its cavity, and the
Figure 74. Centers of effort and lateral resistance. (Adapted from Matthews, fig. 74)
long longitudinal cracks in the seventh strake indicate that these uprights exerted considerable pressure upon the hull. Perhaps they were two independent lifting devices, rigged with a pivoting boom placed in a small step in the worn corner of the chock. The maximum angle of the boom would have been about 55°, which is sufficient to hoist goods outboard. Such a lifting device would have been useful on a local vessel of the time, because it is known that in the Middle Ages most small ports and farmsteads on shallow shores had only primitive landings without cranes. If the chocks carried such lifting devices, the mast would have been placed in a now-lost step over the centerline of the vessel. It is indeed not uncommon for mast steps to disappear from shipwrecks, because often they are only lightly fastened to the floor timbers, if at all. However, on cog-like vessels it is unlikely that mast steps would have disappeared because they are usually heavy timbers, notched underneath and connected with treenails to the frames and sometimes even to the keel. Furthermore, the use of two independent lifting devices would have caused enormous pressure on one side of the hull or the other. For these reasons, this hypothesis is not very convincing.

It rather may be assumed that the chocks carried a mast structure: either the shear legs of a bipod mast provided with vertical tenons underneath that fitted into the cavities of the chock, or short vertical uprights that were
connected by a transverse beam forming a tabernacle upon which a mast was mounted (fig. 75). Bipod and, to a lesser degree, tabernacle masts have been found in many parts of the world from Predynastic Egyptian times to the present. Usually they appeared in association with a craft that had a relatively weak bottom. Both masts are favored for heavy lifting, because they distribute pressures over a larger area of the hull than conventional masts do. It would have made good sense to employ either of these mast types on vessel NZ43 because this boat has a rather weak bottom without a true keel (v. infra, pp. 204-205). It is unknown whether tabernacle masts existed in the Zuyderzee region at the time, but a bipod mast is shown on a 1399 seal from Kuisne, a small port on the northeast shore of the Zuyderzee (figs. 5 and 25 on pp. 13 and 53, respectively). Therefore, the chocks from vessel NZ43 are reconstructed most convincingly as bearing a two-legged mast.

In order to use the mast for lifting loads, a pivoting boom would have been placed in a small step over the centerline and handled by a rope passing through a block hanging from the mast. The distinct wear pattern found on the first strakes, between frames S7 and S8, could have been made by the boom step or by the heavy tackle that would have been stowed there, but it could also be a result of bailing, because this is the deepest accessible part of the vessel. If vessel NZ43 was also used for fishing, as is
Figure 75. Hull section at frame S7 with bipod and tabernacle masts. Projected sail area shown. Above: bipod mast; below: tabernacle mast. (Drawing by author)
suggested by its low midship sheer (v. infra, p. 177), the bipod mast would have been a sturdy device for towing nets.

0. Crumlin-Pedersen compared the Danish cog-like wrecks with the Bremen cog in terms of the relative positions of their masts.101 His study was expanded by Hulst to include five other wrecks and thirty iconographic representations dating mostly to the 13th and 14th centuries.102 Hulst describes the mast position as the proportion of the keel length that is taken by the distance of the mast from the start of the stem. The masts in representations are located a little forward of amidships on the average, but this evidence is quite different from that of the wrecks, and therefore may be regarded as a product of artistic license. On shipwrecks, mast steps were found at .23 to .42 of the keel length from the stem, averaging .34 or about 1/3 of the keel length (fig. 76). Crumlin-Pedersen sees a historical evolution in the position of the mast, moving gradually toward amidships, but R. Reinders thinks the differences in mast location are rather functional, reflecting adaptations to sailing conditions.103

If the mast of vessel NZ43 was stepped in the two wooden chocks between frames S7 and S8, it would have been situated at .38 of the keel length of 9.125 m, which is just aft of 1/3 of the keel length. The same proportion is reported on the 15th-century Kalmar II wreck, a cog-shaped
Figure 76. Mast positions in cog-like wrecks.
(Reinders, 1985, fig. 14)
vessel with Scandinavian construction features. If vessel NZ43 carried a conventional mast placed at the centerline, in keeping with the range of proportions calculated by Hulst, it would have been located somewhere between frames S9 and S5. A mast stepped far forward is very efficient when the vessel is running before the wind but makes the bow drift when the wind is not astern. To overcome this disadvantage, the sail may have been used as a spritsail (v. supra, p. 147).

2. Sail

Pictorial and textual evidence indicate that late-medieval vessels carried one square sail. In Dutch accounts of that time, sails are described as being made from linen or hempen canvas. Their length-to-width ratio is still open to discussion. P. Heinsius cites the mid-15th-century Venetian merchant Timbotta da Moda, who wrote that in Mediterranean craft the length of the mast should be four times the beam of the hull and the yard 4/5 the length of the mast. Heinsius found identical proportions of masts and yards on several cog representations (e.g. figs. 34 and 42 on pp. 65 and 72, respectively). Such proportions, however, cannot be applied to vessel NZ43 because the mast would be about 17 m long, or more than ten times the height of the hull amidships. A. Luns found three late-medieval shipbuilding accounts specifying the length of the canvas
purchased for Dutch rowing vessels, called *heerkoggen* and *baardzen*, which may have been related to cogs. He estimates that the width of the canvas roll was two cubits, which was, in the drapery industry of The Hague, the width of cloth of inferior quality—one cubit being about 70 cm long. Assuming that the sail was made of eight strips, as can be seen on some cog seals (e.g. figs. 34 and 42 on pp. 65 and 72, respectively), Luns calculates that the sail area of those war vessels was 5.5 to 6 m² per meter keel-line length.106

This reconstruction would give the sail of vessel NZ43 the rather large size of 50 m².

I prefer, however, to reconstruct the sail area of vessel NZ43 by taking as an example the one calculated for the Kalmar 1 wreck, a 14th-century Scandinavian-built merchantman. With its 12 m length, 5 m beam and draft exceeding 1 m, this boat is only slightly broader and deeper than vessel NZ43. Its sail area is estimated to have been 270 sq.ft., or 25 m².107 For the sake of simplicity, when calculating the stability and speed of vessel NZ43, I will assume that it had the same sail area (v. infra, appendix A, pp. 290, 293, and 297). It is remarkable that Luns' calculation would yield this result if he would take the width of a canvas strip to be one cubit (70 cm), the width of better-quality cloth.

Cog sails are mostly represented as having a greater width than length. A sail width of 5.6 m, or eight one-cubit
strips, for vessel NZ43 seems reasonable because it would make the sail project about 70 cm at either side of the hull, which at the location of the wooden chocks is about 4.22 m wide. The sail height then would have been 4.46 m, or just over 6 cubits. From pictorial evidence we know that cog sails could be enlarged by attaching bonnets at the foot, or shortened by reef points. They were also dyed or painted to protect them from rotting. 108

With a sail height of 4.46 m and a sheer height of about 1.2 m, I assume the mast would have risen about 6 m above the baseline of the hull. If the mast was two-legged and stepped in the chocks at 0.5 m above the baseline, both shear legs would also have been about 6 m long. This would make the mast length about 5/4 the length of the yard, which is a proportion recommended by Timbotta and found on several cog representations (v. supra, p. 154).

3. Ropes

Luns cites interesting textual evidence concerning rigging lines. 109 Ropes were made out of hemp, wool, and also of bast (phloem), the fibrous layer found between the bark and sapwood of a tree. Even though none of the late-medieval accounts contains complete lists of all lines on board ship, these records inform us about the use of some types. Accounts from 1343/6 distinguish between standing and running rigging. From iconography we know that standing
rigging consisted of fore- and backstays as well as shrouds. R. Unger states that cogs had two backstays. Perhaps the one or two transverse cylindrical holes recorded in the reconstructed sternpost of vessel NZ43 are related to the belaying of these backstays (v. supra, p. 69). One account lists hoofdtouwe (lanyards), and houten naelden (wooden needles) with which the shrouds were belayed to the sides of the hull. These needles might be belaying pins set at a sheer plank. On vessel M107, as well as on the Bremen cog, shrouds were belayed to a channel rail attached on the outside of the vessel. No such channel rail was found in wreck NZ43.

Of the running rigging listed in the accounts, only sheets and bowlines can be recognized. The interpretation of the other terms is not certain and, as they are not important for the interpretation of wreck NZ43, I will not discuss them. Pictorial evidence shows that cog-like vessels also had braces, and probably a halyard as well.

E. Rudder

At the end of the 12th century, the stern rudder appeared in northern Europe and, by the 14th century, it was used on most vessels in Britain and the Continent (v. infra, p. 224). Almost all cog-like wrecks bear evidence of a stern rudder. In vessel NZ43, the narrow shoe found under the stern hook, as well as the probable gudgeon hole in the
reconstructed sternpost, point to the former existence of a stern rudder that would have extended to the bottom of the hook. Iconographic evidence shows that the rudder ran all the way to the top of the sternpost, and that a tiller was fitted over the rudder blade, passing inboard over the sternpost (e.g. figs. 24 to 26, 31 to 36, 39, 41, and 42, on pp. 53, 64, 65, 68, and 72). Unlike on the Bremen cog or on vessel M107, the turn of the stern hook on vessel NZ43 does not present a projection to protect the rudder sole (figs. 28 and 49 on pp. 55 and 92, respectively).

As described above (p. 69), the rudder of vessel NZ43 may have had only two gudgeons. They must have belonged to the same type as the one found on wreck M107. This gudgeon resembles an eye-bolt, which passes through the sternpost and is forelocked with a key on the inside (fig. 40 on pp. 70). On several other cog-like vessels, the gudgeons seem to have been attached with iron straps around the sternpost.\textsuperscript{113}

The accounts mention the use of pintles by which the rudder blade was hung in the gudgeons.\textsuperscript{114} Representations show that pintles were attached to the rudder blade by means of metal straps that often reached over the entire width of the blade.
F. Construction sequence of vessel NZ43

My findings concerning the sequence in which the hull of vessel NZ43 was assembled conform in general to established scholarly opinion, and in some instances provide more detail (fig. 77). 115

As was customary, the shipwright must have begun by setting up stocks and laying out the centerline members of the hull. He probably positioned the hooks first, because the keel plank seems to have been put on top of the hooks in both keel scarfs. At this stage, the keel plank was held to the stern hook by two iron nails at most. The original arrangement of the bow scarf is unknown. Perhaps the stem and sternpost already were set up and supported by struts, because the inner faces of their lower extremities are very narrow; after the garboard strakes had been brought in place there would have been little space left between the garboards for hammering in the treenail connecting the post to the hook.

The shipwright then proceeded to assemble the bottom of the vessel. Port and starboard planking are overall similar, and might have been built up simultaneously. As described above (pp. 105 ff.), most bottom and bilge planks in the bow and stern are rather elaborately sculpted and bevelled in order to achieve transverse hull curvature. For that reason, planks probably were built up one by one, and were not
Figure 77. Hypothetical construction sequence of a cog-like vessel. (Klik op koggen, p. 18-22)
preassembled. Throughout the hull, the aftmost planks of strake scarfs lay inboard of the foremost planks. In the flush part of the planking, it is likely that the innermost plank of a scarf was brought in after the outermost plank, but the reverse is not impossible. In lapstrake sections, on the other hand, the innermost plank must have been laid first. Therefore we know that the overlapping planks were installed from stern to bow. The flush planks may have been assembled from bow to stern, but for reasons of simplicity they probably followed the same sequence as the overlapping planks. Perhaps it was easier for the builder to begin each strake from the stern, because the curvature of the strake was simpler in the stern than in the bow (v. supra, p. 80). 116

The shipwright provisionally fastened the planking in the required shapes with short blocks called cleats and perhaps also with braces. In addition, he must have supported the planks with struts underneath, and perhaps with struts locked between the inboard planking and the ceiling of the workshop, as shown by a later painting (fig. 60 on p. 111). A few unexplained treenail holes located sporadically on the planking surfaces could be traces of those inboard struts.

An often-asked question is whether the builder of a cog-like vessel would have set up some frames before or at
an early stage of the planking process as a guide in
determining the hull shape and in order to keep the bent
planks in the desired shape.\textsuperscript{117} The practice of pre-
erecoting frames is not attested for that time, and the
reconstruction of the Bremen cog shows that they are not
needed to assemble the bottom planking of a cog-like
vessel.\textsuperscript{118} Nevertheless, some scholars assume that one or
more floors may have been laid over the keel before the
planking was assembled.\textsuperscript{119}

The presence of cleats or braces in vessel NZ43 does
not necessarily preclude the use of frames to shape and hold
the planking, because in the late 17th century they were
employed together for the building of a ship.\textsuperscript{120} More
revealing is that square nail holes are found beneath most
of the floor timbers. In this way we know that floors S8 and
S9 were installed after the third strake at the earliest.
Floors S13 through S15 were not set up before the fourth
strake, and S5, S6, S7, S10 and S12 were not brought in
before the fifth strake—the last flush strake—was in
place. Only under and around floor S11, no square nails have
been recorded, so that in theory this frame could have been
erected before the planking. However, since frame S11 is not
as wide as main frame S10, it would make little sense to use
it instead of S10 for determining the hull shape. Therefore,
it is quite likely that floor S11 was not set up before the
planking. The absence of square nails underneath this frame
might be explained by the fact that the bottom planking in that area curved very little (v. supra, pp. 80-81), so that it had less need of cleats or clamps.

We know for certain that the floors and futtocks in the overlapping planking portions were brought in after the planking, because they covered the fasteners of the overlaps as well as the strake seam caulking, which ran inboard in those areas. Moreover, the offsets in their under faces were fashioned to match the configuration of the underlying planks.

Most scholars believe that for reasons of simplicity and strength, floors were put in place after the completion of the bottom planking before the overlapping side strakes were attached. This proved to be the easiest way to reconstruct the Bremen cog because of the size and weight of the floor timbers. If the builder of vessel NZ43 held the bottom strakes only with cleats, he did not have to take them out at this point, and consequently he did not really need floor timbers. However, if he used braces, he must have removed them at this stage and brought in at least some floor timbers in order to preserve the curvature of the bottom planking. Floors that may have been set up after the fifth strake are S1 through S4, S8 through S10, as well as S12, S18, and S19, because they did not reach as high as the overlapping strakes. These floors, however, seem not to have contributed too much to the rigidity of the bottom planking,
because they could not yet have been connected definitively to the strakes that were covered by the frame scarfs. This regards the fourth and fifth strakes amidships, and the second and third strakes in bow and stern. For the treenails of the frame scarfs are found to run also through the futtocks, and thus can only have been brought in after the side planking was finished. At most, they may have been fastened with temporary iron nails.

Treenail holes in the first three strakes at port and starboard between frames S12 and 13 indicate the builder started to set up a frame here, but later changed his mind. Further, this temporary frame has square nails underneath, and must have been installed after the fifth strake.

The clamp—the timber running along the sheer line—probably was put in place before the futtocks, because it would have been easier to notch the frame heads according to the shape of the clamp, rather than vice versa. The sequence of the remaining hull members cannot be traced and is less important to the development of the hull design.
CHAPTER IV

HULL ANALYSIS

A. Hull design

The shape of vessel NZ43 displayed several characteristics that seem typical for cog-like vessels of that time. As described above (p. 37), the overall length of the hull was reconstructed as 11.815 m, the overall beam as 4.26 m, and the sheer height amidships as 1.2 m above the bottom line of the keel. With such dimensions, vessel NZ43 belonged to the smaller-sized range of cog-like craft. Its length-to-beam ratio of 2.8:1 was rather low, and the beam-to-height ratio of 3.6:1 was high. Both ratios indicate that the central part of the vessel was very beamy with respect to length and height. The graphs in fig. 78 illustrate that the hull proportions of vessel NZ43 are similar to those of even larger cog-like vessels. It is remarkable that seagoing craft like the Bremen cog, the Danish vessels and the wreck of Bossholmen have more slender hulls (fig. 79 on p. 167).

In view of the above-mentioned proportions, the c. 10:1 length-to-height ratio of wreck NZ43 indicates a low sheer amidships. This ratio is exactly the same as the one measured on wreck M107, and very close to those on the vessel from Emmeloord. It is still found on traditional Dutch craft today.122 Four other wrecks on which
Figure 78. Geometrical properties of cog-like vessels. Above: length-to-beam ratios; below: beam-to-height ratios. (Reinders, 1985, fig. 13, B and C)
Figure 79. Longitudinal profiles and cross sections of cog-like vessels. (Hulst, fig. 41)
sufficient information is known have relatively higher sheers. The difference may indicate that those vessels were built to carry more cargo, and probably to sail waters less protected than the Zuyderzee. Almost all of the 34 cog representations allowing such measurements, however, yield average length-to-height ratios that are twice as high as those of any wrecks. Since their sheer heights seem realistic (v. infra, p. 175), these vessels must have been depicted as shorter than they actually were, probably because they were confined within the narrow space of city seals or book illustrations.123

Typical for cog-like craft seems the radical difference in the lower hull between this broad midship area and the sharp bow and stern. It appears that the vessel was intended as a spacious cargo box to which pointed extremities were added for sailing purposes. Because of this beamy midship, vessel NZ43 appears to have been designed as a cargo carrier. However, as will be seen below (p. 177), the hull also shared some characteristics with fishing craft. It is not impossible that our vessel served both purposes.124

The comparative sharpness of both bow and stern can be described through various coefficients of form used by modern naval architects. These values are necessarily approximate because they are based on reconstructed dimensions, but the error margin seems very small, for after
some recent adjustments of the hull lines that make the bow at places almost 20 cm lower and more than 20 cm wider, I found that the coefficients had hardly changed. Therefore, form coefficients appear as a dependable means of comparing the hull designs of relatively well-preserved wrecks.

The midship coefficient, or the ratio of the immersed midship section area to a rectangle with an area of beam times draft, was 0.79 (fig. 80; appendix A, p. 267). Compared to modern cargo ships, which range from 0.75 to about 0.996, the midship coefficient of vessel NZ43 was rather small.\textsuperscript{125} This can be explained by the fact that modern freighters have more box-like hulls. On the other hand, the block coefficient, or the proportion of the total immersed body to the prism formed by the length between perpendiculars (Lpp), beam, and draft, was only 0.45 (fig. 81; appendix A, p. 267). This ratio is much lower than that of any modern cargo carrier, and approaches the block coefficients of modern high-powered yachts or destroyers.\textsuperscript{126} It is thus clear that the difference in volume between midship and extremities was much higher in vessel NZ43 than in present-day vessels. No sufficient information is available to calculate block coefficients for the other coglike wrecks.

Bow and stern were rather full in their upper parts, but became very fine lower down, in the fashion of modern fast craft. This is illustrated by the waterplane
Figure 80. Midship coefficient. (Adapted from Rawson and Tupper, fig. 2.10)

Figure 81. Block coefficient. (Adapted from Rawson and Tupper, fig. 2.11)

Figure 82. Waterplane coefficient. (Adapted from Rawson and Tupper, fig. 2.9)
coefficient, or the ratio of the design waterplane area to the rectangle formed by Lpp and beam (fig. 82 on p. 170; appendix A, p. 267). The value for vessel NZ43 was 0.67 and, like the block coefficient, fell within the lower limit of modern sharp-ended fast vessels. Since no lines drawings are available for other wrecks, their waterplane coefficients cannot be calculated. However, as their proportions and general shape are similar, their waterplane coefficients must be quite similar as well.

By making the central vessel very wide, and bow and stern sharp, the shipwright managed to combine the different advantages of beamy as well as sharp ships with respect to the physical conditions of the Zuyderzee.

Wide vessels allow for a shallow draft in relation to capacity, and are thus very well suited to the shallow waters of this inland sea. Furthermore, they are very stable, and their flat bottoms prevent them from capsizing when running aground. As mentioned above (p. 51), small merchantmen must have beached often in order to load or unload cargo in small late-medieval Zuyderzee ports and farmsteads. The builder of vessel NZ43 made its bottom planks flush, and not completely flat but slightly rounded transversely as well as in fore-and-aft direction, so that it could be set afloat again more easily after running aground. The partial chine along the ceiling area, on the other hand, enlarged the capacity of that part of the hull.
Finally, a compact, tubby shape improves the speed of slow vessels, because it reduces skin friction, which at low speeds forms the major resistance component (v. infra, pp. 199-200).

Its sharp extremities enabled vessel NZ43 to cut more smoothly through the water and hold a better course than a plain tubby hull would. Also the relatively heavy lower stern would have contributed to course holding (v. infra, pp. 173-174). This would have been especially important if the mast was stepped significantly forward of the center of lateral resistance, because then the bow would have tended to drift when the wind was not dead astern (v. supra, p. 147). No model research has been conducted yet to test the maneuverability of cog-like craft; therefore we must rely on indirect evidence. According to R. Hulst, the good sailing capabilities of the cog are indirectly visible in the historical and archaeological evidence, because from the 13th century on, at a time when vessels with the typical "cog" shape are found, we have the first written and archaeological evidence of ships trying routes with dangerous and adverse winds, such as the sea-route between the North Sea and the Baltic.128 This quality of cog-like vessels must have been useful also in the open Zuyderzee, where strong winds could come up and change directions very suddenly (v. supra, p. 1).
A second striking characteristic of vessel NZ43 is the fact that in the lower part of the hull the bow was sharper than the stern, while higher up, the bow became fuller than the stern (fig. 20 on p. 41). At the load line, both hull ends were of about equal volume. The Bremen cog is reported to have a drop-shaped waterplane, with a fuller bow than stern (fig. 49 on p. 92). It is possible that only the upper hull is being described, however, and that the lower hull has a reversed drop shape.\textsuperscript{129} No information on this aspect is known from other cog-like wrecks. The change of relative fullness between bow and stern of vessel NZ43 is illustrated numerically by the different positions of the longitudinal centers of buoyancy (LCB) at each waterline of the lines drawing (fig. 20 on p. 41). A longitudinal center of buoyancy represents the center of effort of the uplifting hydrostatic forces of the water seen in longitudinal section (fig. on p. 197). These forces are engendered by the immersion of the hull in water, and their magnitude is directly related to the volume of the immersed body. Consequently, the greater the volume of bow or stern, the more fore or aft, respectively, the position of the LCB will be. At waterline 1 of vessel NZ43, the LCB was situated 7 cm aft of the main frame, while it was only 4 cm aft at waterlines 2 and 3. At the design waterline, LCB was 3 cm aft of the main frame, meaning that the aft half of the hull
up to this waterline was still slightly fuller than the forward half (appendix A, pp. 278-281).

It appears that the boatwright consciously created this hull shape, because in order to make the lower bow sharper, he had to force the strakes in the bow to curve inboard more abruptly than in the stern. By making the lower bow so sharp, the builder probably tried to make a boat which would cut more smoothly through the water. He may have left the stern fuller, and thus heavier, to prevent drifting.

The fuller bow above the waterline also offered advantages. N. Witsen wrote in 1671 with regard to 16th-century craft that small boats always had broader bows to facilitate the frequent raising of the anchor. More importantly, a wide upper bow must have reduced the heave, or up-and-down motion, of the bow in heavy waves, because its fullness provided extra buoyancy, preventing the bow from sinking too deeply. Secondly, with its flaring bodylines, the bow must have acted as a spray deflector in rough seas. As an additional protection against heavy seas, the bow was built up almost 20 cm higher than the stern. As described above (p. 79), this was done gradually, by making the strakes in the bow generally wider than in the stern. As R. Huist remarks, such protection against incoming water is important for vessels sailing in colder climates, and can be seen in the later waterschepen, a boat type that might have descended from cogs.
I compared the relative sheer heights of the bow, midship, and stern of vessel NZ43 with data from iconographic and archaeological evidence (fig. 79 on p. 167). With respect to hull proportions, medieval cog representations should be considered only to approximate reality. Manuscript illuminations are often less accurate than city seals.\textsuperscript{132} Furthermore, even though the makers of city seals were well-qualified craftsmen—usually goldsmiths\textsuperscript{133}—it seems obvious that they did not base their drawings on actual measurements but rather conveyed overall impressions of hull shapes. Artistic conventions and the restricting shapes of the seals may have forced them to alter their hull designs somewhat. Moreover, since the drawings were done on such a small scale, minor mistakes by the artist would yield large differences if the vessel were projected to life-size dimensions.

Even though most representations seem to portray hulls as quite short with respect to their heights, they can still be used in comparative studies of sheer heights if the real values are not taken but rather the proportions of the sheer heights at bow, midship, and stern relative to one another. The results of this study are listed in table 4. Depictions which do not show keels of vessels were omitted, as were those of which the sheer strakes did not reach the posts. In addition, some seals display craft that seem to be large
Table 4. Sheer height ratios of cog-like vessels. Actual dimensions were measured from the baseline of the hull. Ratios preceded by an asterisk are based on reconstructed heights.

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<thead>
<tr>
<th>Illustration</th>
<th>Bow:Stern</th>
<th>Bow:Mid</th>
<th>Stern:Mid</th>
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<td>Ebersdorf c. 1400</td>
<td>1.26</td>
<td>1.40</td>
<td>1.11</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Wreck</th>
<th>Bow:Stern</th>
<th>Bow:Mid</th>
<th>Stern:Mid</th>
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<tbody>
<tr>
<td>Nijkerk c. 1300</td>
<td>*1.03</td>
<td>1.42</td>
<td>*1.37</td>
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<tr>
<td>NZ43 13th-15th c.</td>
<td>1.08</td>
<td>1.88</td>
<td>1.74</td>
</tr>
<tr>
<td>Bremen 1380</td>
<td>1.13</td>
<td>1.44</td>
<td>1.01</td>
</tr>
<tr>
<td>Emmeloord 15th c.</td>
<td>1.09</td>
<td>1.60</td>
<td>1.47</td>
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</table>

Seagoing ships with obviously higher sheer lines amidships (fig. 79 on p. 167). Of these, only the seals from Harderwijk and Damme are listed (figs. 31 and 33 on p. 64), because these boats have concave stems and convex sternposts.
like vessel NZ43. In spite of their higher midship sheers, the Harderwijk and Damme boats have sheer height ratios at bow and stern similar to that of vessel NZ43.

Four other representations display sheer-line ratios similar to that of vessel NZ43. The 1461 town seal of Genemuiden (fig. 26 on p. 54), a fishing town at the northeast shore of the Zuyderzee, shows a boat with nearly the same sheer line and perhaps of the same size category. Such deep sheer amidships would be useful for a fishing vessel, because it facilitates the handling of the nets in the water.\textsuperscript{134} The values from two Baltic cog seals—Elbing 1242 (fig. 83) and Golnov 1354 (fig. 84)—differ less than 20% from our vessel. Bow and stern have a quite similar ratio on the 1265 Stralsund seal (fig. 85), even though its sheer is higher amidships. The 1399 seal of Kuinre (fig. 25 on p. 53) has a similar bow and stern height, but a much lower midship sheer. Such a low midship would be ill-suited for sailing the Zuyderzee, but this might be the artist's way of indicating the tubbiness of the vessel. A likewise deep-curving sheer was found on the 1339 seal of Golnov (fig. 41 on p. 72). The other illustrations, as well as the Ebersdorf model (fig. 86 on p. 179), have quite different sheer lines. Four depictions not included in the table display vessels with higher bows than sterns: Stralsund 1329, Staveren 1369 (fig. 39 on p. 68), Elbing 1367, and an early-15th-century graffito from Roskilde.\textsuperscript{135}
Figure 83. Oldest town seal of Elbing, 1242. (Ewe, fig. 41)

Figure 84. Secret seal of Gollnow, 1354. (Ewe, Fig. 58)

Figure 85. Oldest seal of Stralsund, 1265. (Ewe, fig. 191)
Figure 86. Sheer view of Ebersdorf model. Seen from the port side. Steusloff, p. 191)
The ratio of bow to stern height is very similar on all reconstructed wrecks, while their midship sheer appears generally higher. These data confirm previous conclusions regarding the length-to-height ratios (v. supra, pp. 165-168).

With regard to the shape and rake of the posts, vessel NZ43 fits within the limits of the cog-like type. Comparative evidence for its concave stem and convex sternpost is listed above (pp. 63 and 66). In our vessel, the rake of the stem was 55° at its lower extremity, and 49° at the top. The reconstructed sternpost rake progressively increased from 50 to 59 degrees. Even though in the lower hull the stem began at a greater angle than did the sternpost, the top of the stem was placed at a lower angle. Vessel NZ43 thus follows the tendency of cog-like craft to have lower stem than sternpost rakes. Further, these values are just within the lower limits of 14th-century iconographic and archaeological evidence. Comparative studies done by Hulst reveal that posts of 13th-century vessels have somewhat higher rakes. However, not enough data have been gathered to allow the dating of our vessel on the basis of these characteristics. In addition, it should be remembered that the rake of the upper sternpost is a result of reconstruction and may have been somewhat different in reality. Its rake was slightly lower than that
of the Bremen cog (63°), which is the lowest value found in
the wrecks. The stem rake of vessel NZ43 was most similar to
those of the Kalmar II wreck (49°) and the boat from lot N5
(54°).

B. Hydrostatic properties

All calculations of hydrostatic properties are based on
the assumption that the vessel was operating in fresh water,
because it was found among fresh-water sediment layers. The
characteristics discussed in this chapter relate to the
reconstructed hull shape and are probably somewhat different
from those of the original hull when newly built.

1. Design waterline

The maximum safe draft of a vessel is indicated by the
design waterline (DWL), also called the load line. Since the
19th century, the DWL has been officially regulated for all
craft according to type and function. It is known that by
the end of the 12th century, Venetian, Genoese, and
Sardinian ships were required to display a maximum load
mark. Shipowners of Hamburg, Lübeck, and Visby also adopted
a load line.137 Those regulations regarded seagoing craft,
however, and it is likely that Zuyderzee vessels were more
heavily loaded.
The DWL of a wrecked ship can be reconstructed on the basis of the weight of the cargo. However, no cargo was present in wreck NZ43. Iconographic sources are not helpful either, because they do not necessarily display vessels at maximum load. Therefore, I decided to estimate the DWL of vessel NZ43 by using as a guide a similar study done by E.J. Metz on a 17th-century Zuyderzee barge that had carried mud.138 On the basis of written and archaeological evidence, Metz believes this 16.3 m long flat-bottomed craft could have had a minimum freeboard of 12 cm. Vessel NZ43 was smaller and less flat-bottomed, but being a bulk cargo carrier, it served a somewhat similar function as the mud barge. Therefore it is reasonable to estimate its minimum freeboard as 20 cm, and to place the DWL at hull waterline 4 (fig. 20 on p. 41). The molded draft, measured from the top of the keel plank, was then 0.93 m, and the hull’s reserve buoyancy a comfortable 5.7 tonf (ton force) (appendix A, p. 272).139

Amidships, this DWL was located in the middle of the sheer strake, but because of the sweeping sheer line it ran only through the third and fourth strakes in bow and stern, which to me seems very low. The DWL could have been higher if the vessel were carrying a washboard amidships. The Bremen cog has a washboard nailed lightly on top of the sheer strake (fig. 49 on p. 92).140 On vessel NZ43,
however, no fastenings have been found that might have indicated the former presence of such a board.

2. Tonnages

Hull displacement at each of the four waterlines was calculated by means of Simpson's first rule, as it is done in modern naval architecture. Formulas and results are given in appendix A, pp. 268-271. The results are also represented on the sheer plan as Bonjean curves (fig. 20 on p. 41), which makes it possible to read the displacement tonnage of the hull at different trim angles. Because it is not known with certainty which unit of measure the shipwright himself was using (v. infra, pp. 210 ff.), all calculations are done in metric units.

At the DWL, the volume of displaced water was 17.8 metric tons, which means that the total weight of vessel and contents would have been 17.8 tonf. The weight of the boat itself is calculated as 8.130 tonf, so the deadweight tonnage—the maximum weight a vessel may carry in cargo, stores, and crew—amounted to approximately 9.670 tonf (appendix A, pp. 283-284). Of this, about 9.2 tonf would have been occupied by cargo alone. These values, obtained by estimating or calculating the volume and weight of each item on board ship, yield a much lower deadweight tonnage than the standard formula for 13th to 17th-century ships:
keel length x maximum breadth x depth in hold (cu.ft) \[\times 100\]

which yields 15.36 long tons, or 15.6 tonf. A reason for this difference must be the low block coefficient of vessel NZ43 (v. supra, p. 169).

Vessel NZ43 belonged to the smaller cog-like wrecks from the Zuyderzee. The ratio of capacity to keel length was about 1 tonf per meter, which is more than five times less than the 5.13 tonf/m calculated for the 80 tonf Bremen cog.\[\text{143}\]

I converted these tonnages into old Dutch volume and weight measures in order to obtain some indication as to the size category to which vessel NZ43 might have belonged in its time. Included are measures from cities bordering the Zuyderzee as well as from cities more inland that were important for late-medieval Zuyderzee trade.\[\text{144}\] The results of this study can only be approximate, not only because the tonnages of vessel NZ43 are based on reconstruction, but also because the preserved old measures date from several centuries after the wreck: the Amsterdam grain last (v. infra, pp. 187-188) from the 16th century, and the others from the late 18th or early 19th century. Volume measures in particular seem to have been susceptible to sudden and drastic changes.\[\text{145}\] Furthermore, we do not always know all the measures of a city, and we have no information on
several Zuyderzee cities that were important in the late Middle Ages.

Before the introduction of the metric system in the early 19th century, different types of goods had their own units of weight or volume. For large cargo ships, the unit of capacity reflected the commodity it predominantly carried. In medieval Europe, the two most common measures used to express the stowage capacity of ships were the last (load) and the ton, derived from measures of grain and wine respectively. For the Zuyderzee region, however, I found a ship measure that might have expressed an average of the measures of different cargo items: the scheepsvracht "ship load" of the city of Groningen in Frisia. Its metric equivalent is 17.7 tons, almost twice the estimated cargo capacity of vessel NZ43. It could be suggested that our boat was actually intended to carry one-half of a Groningen scheepsvracht, and hence was built in a city using this Groningen ship measure. Yet, it is equally possible that slightly larger units of ship measures existed elsewhere, according to which our vessel would have been built.

The last was a wholesale measure used for dry goods, grain in particular, but also fish and some other commodities. It was mostly employed in northeastern Europe, where grain was the predominant cargo item. Originally it was only a weight unit, often defined as the weight of a cartload that could be pulled by four horses. As
carts and horse power are relatively constant givens, it is assumed that the last as a measure of weight did not differ much from city to city and did not change much through time. In the trade of goods with low specific gravity, such as grain, salt, and fish, the last became a volume measure, as quantities of such goods were more adequately described by volume than by weight, and a ship's capacity for carrying light-weight goods was limited in volume more than in weight. As a volume measure, however, the last had a different value for each commodity because of differences in specific gravity. So the grain last, salt last, and fish last of a city were equal in weight but not in volume. Moreover, a last denoted different volumes for the various types of grain and fish. Therefore, the term "ship last" found in medieval documents, when referring to lightweight goods, must have represented an average value of the volumes of the most important cargo items. In order to make this ship last comparable to modern measures of cargo capacity, one must convert it into an approximate weight unit by multiplying it with the average specific gravity of the presumed cargo goods.

For the Zuyderzee region, the oldest ship last known is the Groningen last. It is not a volume but a weight unit of 1.770 tonf, and represents one tenth of the scheepsvracht. The estimated 9.2 tonf capacity of vessel NZ43 equals 5.2 Groningen ship last, but if the boat had
been built according to this measure, it is more likely that its maximum capacity was intended to be 5 last (8.85 tonf).

Values seem to have been higher in northern Germany. W. Vogel estimated the Lübeck ship last of c. A.D. 1400 to be 1.933 tonf, and the Danzig ship last to be 2.257 tonf. He based his calculations on the grain last (volume) of the respective cities and on the specific gravities of wheat and rye. Using Vogel's method, I calculated for 16th-century Amsterdam a ship last of 2.246 tonf on the basis of its grain last of 3.010 m³. The Zuyderzee harbor of Muiden, which borrowed the 3.040 m³ grain last of Naarden, must have used a slightly heavier ship last of 2.268 tonf. Today, however, when calculating the weight of a quantity of grain as ship's cargo, one does not use specific gravity but a value called the stowage factor, which signifies the specific volume of cargo a vessel can hold per unit of displacement. The modern stowage factor of bulk wheat is 47 cu.ft. per English ton. This modern factor was calculated for long voyages, and allows for shifting boards, stanchions, deck gratings, pipe covering, and other devices to prevent rotting. Little is known about medieval stowage practices, but perhaps a more realistic stowage factor for our purposes would be 50 cu.ft. per English ton, or 1.44 m³/tonf. Employing this factor, the weight of the Amsterdam ship last could be estimated as 2.090 tonf and that of the Naarden and Muiden last as 2.111 tonf.
Because we lack information about medieval stowage practices, many modern scholars prefer to work with an average value, and take the ship last to be 2 tonf, the value assigned to the last in the early 19th century when the metric system was introduced in the Netherlands.\textsuperscript{153} Referring to this average value, we can say that the capacity of vessel NZ43 was 4.6 or perhaps 4.5 last.

The other widely used medieval ship measure was the ton, a wholesale measure for wine. Since wine was not a common item in local Zuyderzee trade, I will not discuss this measure.

The reconstruction of the tonnages of vessel NZ43 reveals something about the way the cargo might have been stowed. As mentioned above (p. 12), no trace of the cargo was found. It seems likely that the cargo was either perishable or floated away, because it was probably not valuable enough to have warranted complete salvage. The fact that no cargo containers were found, and that part of the hold was lined with ceiling planks and closed off by a bulkhead, suggests the vessel carried bulk cargo or goods packed in perishable materials. It is also possible that the vessel was being used for fishing when it sank. In the Zuyderzee region, common examples of cargoes that could have disappeared by shipwreck would be grain, peat, and cattle. Another common cargo item our vessel might have carried
during its lifetime was bricks. In the 14th century, many wooden buildings in the Netherlands were being replaced by brick, which spawned a busy trade as is shown by cargoes of bricks found in some of the Zuyderzee wrecks. In those wrecks, bricks were lying on closed ceiling planking.154

The bottom of the hold portion covered by ceiling planking has an average area of 6.9 m² and the sheer height amidships is 1.13 m, so that the volume of that part of the hold was about 7.8 m³. Using the above-mentioned stowage factor for bulk grain, one can estimate the weight of the bulk grain filling the ceiling area at 5.4 tonf. A cargo of wheat carried in bags would have weighed 5.2 tonf, because the modern stowage factor in that case is 52 cu.ft. per English ton, or 1.496 m³/tonf.155 For peat I did not find a stowage factor, but worked instead with a specific gravity of 0.825 tonf per cubic meter, used by E.J. Metz for calculating the cargo capacity of a 17th-century Zuyderzee peat barge.156 The weight of 7.8 m³ peat is about 6.4 tonf.

Weight calculations reveal that a cargo of wheat or peat could represent only about one-half to two-thirds of the hull's capacity, and would have made the vessel sink to about halfway between the third and fourth waterlines, creating a draft of about 85 to 90 cm. If the skipper wanted to fill the boat to its maximum capacity, he had to store additional cargo outside the ceiling area. For the same
reasons, it is clear that the 40 cm high bulkhead cannot have marked the height of the cargo area.

Additional cargo would have been stowed fore and aft of the ceiling area, possibly in sturdy containers such as barrels. This cargo must have been about 3 to 4 tonf. A proviso when using a modern stowage factor in calculating the volume of medieval packed goods is that the size of the medieval and modern containers should be approximately equal. One such comparable example seems to be salt, which in Amsterdam was stored in barrels of 184 l or 0.184 m³.\textsuperscript{157} Since the modern stowage factor for salt tons is 52 cu.ft./Eng. ton, or 1.496 m³/tonf,\textsuperscript{158} the volume of 3 to 4 tonf cargo of salt barrels would be almost 4.5 to 6 m³, the number of barrels being 24 to 33. The total volume of the hold up to the sheer line amidships was 23.5 m³ (appendix A, pp. 271–272. If we subtract 7.8 m³ of the ceiling area, we have 15.7 m³ left. Space for partial decks, rigging and gear should be subtracted as well, but even so we can state safely that salt barrels did not reach higher than the midship sheer line when the boat was filled to maximum weight capacity. The secondary cargo probably was distributed over the hold in order to make the vessel ride on a more or less even keel.

If vessel NZ43 was carrying at some time a maximum load of bricks, no secondary cargo would have been needed.
Assuming such bricks weighed 4 kgf like those of wreck M107, I calculated that vessel NZ43 needed to carry 2300 bricks to reach its maximum 9.2 tonf cargo capacity. If the size of these bricks was 2.366 dm³ as well, their total volume would have been 5.442 m³. Since the bottom area of the ceiling is about 6.9 m², they would have reached 79 cm high, or about 40 cm below the midship sheer height. That this vessel may have carried so many bricks is suggested by the much larger cargo of 5000 bricks found on the c. 16-m-long vessel M107.

If 2300 bricks were located in the celled cargo area of vessel NZ43, 52% of the total weight of the vessel would have rested on one-fourth of the keel length, which would have induced the hull to sag. The irregular sagging curve of the ceiling area recorded on the wreck might have been caused by such heavy loads during the vessel’s lifetime (v. supra, p. 51). The brick cargo would also have made the hull sink 4 cm deeper aft (v. infra, p. 196).

3. Transverse stability

I calculated the stability of vessel NZ43 assuming its draft was at the design waterline, and all its cargo concentrated in the ceiling area, which means that the cargo consisted of 2300 bricks. Since hull stability increases with draft, a cargo heavier than the estimated maximum cargo capacity of 9.2 tonf would have made the vessel still more
stable. On the other hand, less cargo would make the hull ride higher in the water and decrease its stability.

Important components of transverse or cross-sectional stability are the relative heights of the centers of gravity and buoyancy, and the metacenter (fig. 87). The vertical center of gravity (VCG) is the point on the hull’s cross section through which the total weight of the body may be considered to act with a downward force normal to the waterline. In order to find VCG, one has to take the total moment about the baseline of the weight of vessel and contents, and divide that moment by the sum of their weights (appendix A, pp. 282-284). Buoyancy of a vessel, on the other hand, is an upward force normal to the waterline, and the vertical center of buoyancy is the center of volume of the water displaced by the vessel. Its vertical position (VCB) is determined by calculating the total moment of the displaced water about the baseline, and dividing it by the volume of displacement (appendix A, pp. 273-277). Gravity and buoyancy forces of a floating body are equal. In order for the floating body to be stable in an upright position, VCG and VCB should be vertically aligned, and not too far apart. I calculated that VCG of vessel NZ43 was situated at 0.7 m above the baseline, and VCB at 0.63 m.

When a ship heels, or rotates about its longitudinal axis, VCB shifts to the submersed side (fig. 87). The intersection of the vertical line of action through VCB of a
Figure 87. Transverse hull stability. ▽ indicates displacement volume; G and B stand for VCG and VCB, respectively. (Adapted from Rawson and Tupper, fig. 4.7)
hull in an inclined position, with the vertical axis through VCB and VCG in an upright position, is called the metacenter (M) of the transverse plane. The heeling motion is caused by the force of water and wind. A vessel is called positively stable if a righting force of equal magnitude causes it to return to the upright position. This righting moment is a couple that results from the fact that VCG and VCB of an inclined hull are out of alignment. Its force is the total weight of vessel and contents, symbolized by Δ. Its lever is the distance $\overline{GZ}$, or the normal extending from VCG to the action line of VCB in the inclined position. The larger $\overline{GZ}$ is, the larger is the righting moment. The distance of $\overline{GZ}$ in any inclined position can be calculated by multiplying the sine of the inclination angle $\theta$ by the metacentric height $\overline{GM}$, or the height of the metacenter M above VCG. Therefore, transverse stability is directly related to metacentric height. In order to find $\overline{GM}$, we need to know the transverse moment of inertia about the design waterplane, or the horizontal hull section at DWL. These calculations are given in appendix A, pp. 288-289. Vessel NZ43 had a large metacentric height of 1.46 m, indicating that the hull was very stable.

In order to qualify this high stability somewhat, I calculated the maximum heeling moment that vessel NZ43 would have been able to withstand when fully loaded (appendix A, p. 290). That heeling moment was equal to the righting
moment at the hull’s maximum inclination angle, which was 5.4°. The sine of this inclination angle multiplied by the metacentric height yielded a righting lever $\bar{G}Z$ of about 0.14 m, and a righting moment of 2.5 tonf m. To make this more concrete, I estimated the transverse wind force that would be needed to cause the hull to capsize. If one assumes that the vessel is anchored in calm water, that its 25 m² sail area is slightly billowing so that the projected plane is 24 m² and that only half of this projected plane is exposed to the direction of the wind, the hull would be overturned only by a wind having a transverse component of 80 knots. In reality, an even stronger wind would be required, because as the boat starts heeling, its exposed sail area becomes smaller, and so does the effect of the wind. Moreover, if the vessel were not anchored, it would start moving in a lateral direction, which would also decrease the wind’s effect on the hull.

The large metacentric height and relatively low transverse moment of inertia, on the other hand, meant a disadvantage for the crew, because it must have caused vessel NZ43 to roll—or rotate around the longitudinal hull axis—very rapidly. The frequency of the roll motion is calculated to have been 3.66 radians per second, and its period only 1.72 seconds (appendix A, p. 294). This is about three times faster than the roll motion of modern high-speed craft. The actual motion of vessel NZ43 must have been
somewhat slower, however, because of the damping that would have been caused by the overlapping strakes. In addition, the uncomfortable effect could have been mitigated if more weight were shifted toward the vessel’s sides, away from the centerline, so that the transverse moment of inertia about the design waterplane would have increased.

4. Longitudinal stability

As in the transverse plane, the stability of a vessel in its longitudinal plane is determined by the couple created between the action lines of gravity and buoyancy when the vessel pitches, or rotates along a transverse axis (Fig. 88). The pitching axis runs through the longitudinal center of flotation (LCF) of the hull. LCF of vessel NZ43 was computed to be only 2 mm aft of midships, which means that the pitching movement caused an almost equal angle of trim fore and aft (appendix A, p. 287).

The righting lever $\bar{G}_2$ is about equal to the horizontal distance from the longitudinal center of gravity (LCG) to the longitudinal center of buoyancy (LCB) (appendix A, pp. 278-281, 285-286, 291-293). If all 9.2 tonf cargo of vessel NZ43 were placed in the ceiling area, $\bar{G}_2$ would have been 5.7 cm, and the stern would have had 4 cm additional draft. This trim may have been corrected if some of the cargo were placed further forward in the hold, or if the vessel were appropriately ballasted.
Figure 88. Longitudinal hull stability. GI stands for LCG.  
(Adapted from Rawson and Tupper, fig. 3.16)
Since the moment required to change the trim was 1.015 tonf m, and the largest possible trim was 0.87 m and 0.64 m fore and aft, respectively, the maximum moments vessel NZ43 could have resisted without being flooded would have been 20 tonf m at the bow and 15 tonf m at the stern. If one assumes that the vessel was lying still in calm water, with its entire 24 m² projected sail area exposed to the wind, it would have taken a wind of at least 147 knots from the stern, or 127 knots from the bow to tip over the hull. Again, pitching motion and lateral movement of the vessel in the direction of the wind would in reality require a still stronger wind to obtain this result. It is more likely that the mast would break, or that the vessel would sail itself under water before it would tip over.

The pitch motion of vessel NZ43 had a frequency of 3.36 radians per second, and a period of 1.87 seconds. This is somewhat shorter than the average 2 to 3 second period of fast craft today appendix A, p. 294). Again, the actual motion of vessel NZ43 would have been somewhat slower because of the damping effect of the overlapping strakes. On modern craft, sea sickness is largely caused by the pitching motion because the frequency of pitching is about double that of rolling. In vessel NZ43, however, the periods of rolling and pitching were about equal, so that the roll motion would have also contributed to sickness.
C. Resistance and speed

In order for the wind to move a sailing vessel, it must first overcome the vessel’s resistance in the water. Basically, the total resistance of a boat can be subdivided into frictional and residual resistance. Frictional resistance (Rf), or skin friction, is the resistance that is encountered by an equivalent flat plate moving through the water. Rf is a function of speed, wetted surface area, and roughness of surface, as well as water density and viscosity. Residual resistance encompasses all other factors, such as form of the vessel, appendages, and wave action.

A major component of Rf is the area of wetted surface. Since this area is quite well known for vessel NZ43, I believe that the skin friction values calculated are quite reliable, and would be suitable for comparison purposes (appendix A, p. 295). Still more accurate results could be obtained by the model-towing method, which has been perfected to a high degree in modern naval architecture.

In modern slow cargo carriers, Rf accounts for 80 to 85% of the total resistance, especially if the surface is rough. For several reasons, however, it may be assumed that this percentage was less for vessel NZ43. Cog-like vessels were built to carry bulk goods, and speed was less important than cargo capacity in this type of trade. Today, if speed is not important, a ship hull is made very
tubby, so that the area of wetted surface and thus also RF is smaller per ton cargo. It is clear that the rounded shape of cog-like vessels must have reduced their RF. On the other hand, residual resistance components such as form drag can be as much as 40% or more of the skin friction if the vessel is very tubby.163 The resistance caused by appendages must have been considerable in the case of vessel NZ43 because of its overlapping planking. Therefore it seems reasonable to assume that the frictional resistance of our vessel would have accounted for only 50% of the total resistance (v. appendix A, pp. 296-298).

Ship resistance is overcome by the force of the wind acting on the exposed sail and hull areas. The forces of resistance and wind are expressed in effective horse power (EHP). If the vessel moves in the direction of the wind, effective power is exerted only by that part of the wind velocity that surpasses the speed of the vessel.

In table 5, effective wind power and total hull resistance have been plotted against wind and ship velocity. From the graph it is clear that for each additional 3 knots of wind, the ship speed increases only 1 knot. This input/output ratio is called hull efficiency. One can thus say that vessel NZ43 had a hull efficiency of 3:1.

Since 10 to 15 knots is a normal wind velocity, the cruise speed of vessel NZ43 must have been 3 to 5 knots. This is fairly close to its hull speed of 5.7 knots. The
Table 5. Effective wind power and total hull resistance versus ship and wind velocity.

Hull speed is the ideal speed a vessel should make to reach the ratio $V_s/V_L=1$, whereby $V_s$ is the ship speed in knots, and $L$ the length between perpendiculairs, expressed in feet.
One can see that from about 7 knots of ship speed upward, the full line on the graph becomes quite straight, reflecting a linear relationship between speed and resistance. Such a linear relationship is impossible, and must be due to the fact that our calculations did not take into account that at these speeds, the residual drag became much higher in relation to skin friction. The dashed line, therefore, represents a more likely continuation of the curve, as a vessel of this type and size probably did not exceed 10 knots.164

D. Structural analysis

Today, Dutch shipwrights building traditional craft consider the hull an assembly of two parts: the flat bottom and the sides. They refer to a ship’s bottom as het vlak (the flat), and to the sides as de boorden (the boards).165 If a smooth transition from bottom to sides is desired, the last bottom strakes are given some rise and form the bilge strakes. The hull of vessel NZ43 seems to correspond to this basic concept.

The primary structure of a vessel consists of those members that account for most of the shaping and supporting of the hull. In vessel NZ43 this role is without any doubt played by the planking. Not only were the strakes assembled before frames were brought in, but also the elaborate
sculpting of the strakes indicates that they were considered the principal shaping elements of the hull (v. supra, pp. 104-109). The lapstrake sections of the planking also provide considerable rigidity.

A distinction should be made in this regard between the planking of bottom and sides of vessel NZ43. Clearly, the central parts of the bottom strakes give little support to the hull, as they are lying flush and are not connected to one another. Nevertheless, these planks were among the biggest and sturdiest found in the hull. The fact that during construction they were most likely held together by cleats or perhaps braces, not by frames, suggests that they can be considered the primary structure, the frames being purely for reinforcement afterwards. Structural problems such as the transitions from flush to lapstrake were solved within the planking itself, independently of the frames. The flush planks defined the shape of the hull, making it as broad as possible amidships. The overlapping parts of the bottom planking, on the other hand, not only achieved the complex curves of bow and stern towards the posts, but provided in addition considerable strength. This is illustrated by the fact that several floor timbers installed later in the lower bow and stern were not fastened to every strake. The side planking is built lapstrake throughout and thus shapes as well as supports the hull. While the sixth and eighth strakes account for most of the transverse
curvature, the seventh and ninth strakes, consisting of only a few big planks, must have provided more reinforcement.

In the center of the flat bottom lies a keel plank, and in bow and stern, port and starboard sides of the hull planking are closed off by hooks and posts. Stem and sternpost are sizeable timbers holding together the sides of the hull. The keel plank, on the other hand, is only slightly thicker than the strakes, and is not even connected to the garboards, so it does not provide much support to the structure. Its function is rather to determine the rise of the bottom at the outset of construction. Of the centerline members, the hooks appear to be most important, because they join the main shaping members of the hull: stem, sternpost, keel plank and garboards. Their significance is reflected in their large size and elaborate sculpting. I agree with R. Huist that by using hooks the builder avoided connecting the relatively heavy posts immediately to the weak keel plank, which otherwise would have exerted a lot of strain on the keel plank.166 As one-piece transitions between the horizontal and vertical planes of the vessel, hooks could be considered a type of keystone. Because of the weak scarfs with keel plank and posts, however, their support in the longitudinal direction remains limited as it is only partially transmitted to the other centerline pieces. More important is their transverse stiffening function, because
they firmly hold the curving garboards in shape, which in turn lay out the shape of the hull.

One can thus hypothesize that, unlike in modern craft, the centerline members of vessel NZ43 were not considered to be one unit serving as the backbone of the hull, but that keel plank, hooks and posts were intended to act as separate entities. This concept is most clearly illustrated by the weak and awkward way in which the bow scarf has been repaired (v. supra, p. 57).

Frames transversely reinforced the "shell" of planking. Also the frames show a division into bottom and side sections, as they consist of floors and futtocks scarfed together in the bilge area. The location of the frame scarfs in almost one line at the bilge, however, forms a weakness of that transverse support. The fact that the treenails securing the frame scarfs continue into the planking suggests that a frame was not considered as one unit, but as two parts, one part reinforcing the hull bottom and one the sides.

Some longitudinal stiffening of the bottom is provided by the ceiling strakes, which are fastened to the frames. This support was only partial, because the ceiling planking covers only about one fourth of the keel line amidships and in the stern quarters. We do not know how high up the sides they went.
The upper hull was stiffened by deck beams, which probably did not protrude through the planking. They must have been held to the upper planking by standard knees. Even though not as effective as the through beams found on several large cog-like craft, the deck beams of vessel NZ43 must have stiffened the upper hull considerably in transverse and longitudinal directions, as they provided resistance against shear stresses. The large sizes of one cross-beam and two knees suggest their importance. Perhaps the smaller beams found in the wreck are carlings, longitudinal stiffeners which were also present in the Bremen cog and in the Ebersdorf model.

Apart from the plank overlaps, the only longitudinal stiffener running over most or perhaps the entire length of the hull was apparently the clamp. This beam, joined to the sheer strake with many large treenails, must have given the upper hull considerable resistance against shear stresses.

One can thus say that only the upper hull of vessel NZ43 is longitudinally reinforced throughout, while the bottom is only partially supported in that direction. This lack of concern for the longitudinal stiffening of the lower hull can also be observed in the other cog-like vessels, although some boasted long keelsons over the centerline.167

Perhaps because the longitudinal strength of the hull was taken mostly by the planking, many strakes display long
cracks in the fore-and-aft direction (fig. 14 on p. 28).
Since these cracks have been repaired, they cannot have been caused by the shipwreck. Most repairs are on the outboard sides of the planks, which suggests they were made after the frames were in place. The longest breaks occurred in the garboard and the seventh strake. The garboard cracks may also have been caused by the abrupt twisting of the planks. Those of the seventh strake seem related to the presence of the heavy chocks which probably served as steps for a mast or for a lifting device. This very wide and relatively thin strake appears ill-suited for the heavy pressures which such a mast or lifting device would exert. An interesting split occurs in the third strake at starboard. It runs from at least frame 56 to 513b (fig. 68 on p. 130). This break seems related to the water courses in the under sides of the frames, as it begins and ends with these courses. Perhaps it was caused by the bilge water collecting there each time the vessel rested with its starboard side on the sand. The break was not repaired. It is unlikely that the crack developed after the wreckage, however, because the vessel was found lying on its port side.

The longitudinal rigidity of the planking was somewhat weakened by the clustering of scarfs in the bow and stern quarters, as is illustrated by the fact that after the wrecking the hull planks had broken off forward or aft of these scarf clusters (v. supra, p. 91).
Some sections of the hull appear to have been built stronger than others. It is obvious that frames S1 through S7 are heavier than the other frames. This suggests that the bow was liable to more stresses. Part of that excess stress would have been caused by the mast structure and eventually the lifting devices (v. supra, pp. 147 ff.). Also, the bow's higher sheer and more complex curvature may have induced the builder to use heavier frames than in the stern area. Furthermore, the bow must have suffered more shocks than the stern because these vessels probably beached bow first, as the stern carried the rudder. On the other hand, the sternpost seem to have been much heavier than the stem, probably because it had to carry the rudder. In several places, iron nails connecting overlapping strakes had been placed very close together. In the foremost garboard plank at port, this was obviously done to counteract the tension caused by the tight plank curvature. Elsewhere the reasons for doing so are not always obvious. Treenail sizes are in some places conspicuously larger than in others. These larger treenails could be related to the mast structure and partial decks fore and aft (v. supra, p. 132).

Differences in hull strength also exist between the flush and lapstrake areas. By using both flush and lapstrake planking, the builder combined the advantages of these
techniques. The flush bottom made the vessel more suitable
to operate in shallow water, and would have been easier to
replace than lapstrake planking if the strakes had worn out
by frequent running aground. The overlapping parts were
inherently stronger. Yet, the combination of these planking
types in a hull with this design may have presented a
disadvantage, in that the broad and weaker central part of
the vessel was more buoyant than the peaked and stronger bow
and stern, which must have increased the tendency of the
hull to hog. Of course, when the vessel was loaded, the
central part of the hull, the ceiling area in particular,
became much heavier, so that the hull then tended to sag.
These differences in buoyancy and weight must have caused
great pressures on the lower quarters, and the breaking of
the bow scarf may have resulted from these strains. Perhaps
the builder made the keel of vessel NZ43 rockeressed in an
effort to counter the hogging pressures, but in this way
made the hull more prone to sagging.

A similar combination of flush and overlapping planking
is found on all cog-like wrecks. On the basis of the Danish
wrecks, O. Crumlin-Pedersen suggests that cog-like vessels
gradually evolved from flush-planked flat-bottomed river
craft with a few extra lapstrake side planks, to boats that
were almost completely clinker-built and had only a few
bottom strakes lying flush (fig. 66 on p. 124).\textsuperscript{168} Some
wrecks from the Zuyderzee seem to corroborate this
hypothesis, as the oldest wreck, OZ43, has seven flush strakes that do not change into lapstrake in bow or stern, while on the other hand the most recent cog-like wreck, M107, has only three partially flush strakes. Also the data from the Bremen cog fit this thesis, because this vessel is slightly older than wreck M107 and has one more flush strake. Unfortunately, only a small number of cog-like wrecks have yielded information in this respect.

E. Analysis of hull dimensions

1. Standard measures

In the late Middle Ages, when vessel NZ43 was built, virtually every town in the Netherlands used its own measuring units, and different measures often were used for different commodities. We know that in later times shipbuilding had its own units, and so it is possible that this was also the case in the medieval period. By comparing known medieval measures with various dimensions of a wreck, one may establish the specific unit used by the builder. In this way, it might be possible to determine in what town the vessel was built.

There are still several problems in this regard, however, and the results of such a study can only be tentative. As with the weight and volume measures mentioned above (p. 184), the earliest known length measures date from
the late 18th century. Moreover, measures of all towns could not be found. Furthermore, for most units given, the use was not specified by the author, so there is a possibility that these units may not have been used in shipbuilding. An additional difficulty arises from the fact that differences between the measures are minor. The various inches differ by a maximum of 4 mm, the feet by 3 cm. It is clear that inches require too much accuracy to be useful for determining the place of construction. Not only does it seem unlikely that the builder would have worked with such a degree of accuracy, but hull parts may have been distorted by the water. Further, most of our hull dimensions are based on reconstruction, and the estimated error is 3 cm at the most (v. supra, p. 32).

The best approach to these problems, in my opinion, is to use statistics. All dimensions likely to have been measured by the shipwright should be divided by all known units. In addition, they should also be divided by all other integers up to a reasonable number, so that standard measures could be found that are not yet known to metrologists. The measure which provides the most correlations to important ship parts, would be the one used by the builder. Such a project, however, was beyond the scope of the present study.

Instead, I chose from a list of old measures published by J.M. Verhoeff (v. supra, n. 142), four sets with values
representative of the range units used in the Zuyderzee region. First of all, the Amsterdam measures include an inch of 2.35 cm and a foot of 28.3 cm that were specifically used in shipbuilding and in the wholesale wood trade. These measures had been adopted by other cities as well. The second pair of measures are the Frisian inch of 2.46 cm and foot of 29.6 cm. They were used for wood in general, also outside of Frisia. 170 Both the Amsterdam and the Frisian inches are the smallest inches listed, while the feet are among the highest. Thirdly, the 2.68 cm inch from Utrecht represents an intermediate value; its 26.8 cm foot is the smallest foot known from the Netherlands. 171 The inch of Hoorn, finally, is at 2.77 cm the longest inch of the list, and the city foot of 27.7 cm is intermediate. 172 The Utrecht and Hoorn measures were city standards of which no specific use is stated. Not all feet contain an equal number of inches. The Amsterdam and Frisian feet comprise 12 inches, while the Utrecht and Hoorn feet contain only 10 inches. This fact provides an additional clue for the identification of standard measures, in that a value of 6 inches would be significant in the Amsterdam and Frisian system as being a half foot, while in the other systems values equalling 5 inches would be more meaningful.

The cubit is not included in the ship units of Amsterdam or in the wood measures of Frisia. The city cubit of Utrecht measured 68.5 cm, which is rather short. The
Hoorn cubit of 70.8 cm is the longest one on the list. Both cubits measure 25.5 inches. To these I added an Amsterdam city cubit which measures 68.8 cm and is divided into 29 inches.

All useful dimensions were listed and divided by the values given above. The Hoorn and Utrecht standards, as well as the Amsterdam cubit, yielded only a few correlations and could be eliminated. Table 6 lists the dimensions that yielded equivalents in Amsterdam or Frisian standards.

Several important hull dimensions can be expressed either in Amsterdam or in Frisian measures, and some in both. With regard to the inches, this was to be expected, because their values differed by only 1 mm. The conversions into feet give more significant results. One can see that most important dimensions are multiples of the Frisian foot. The bottom width, overall beam, as well as bow sheer height could not be converted into Frisian measures, but they may have been derived from proportions of other hull parts, as is explained below (pp. 217-219). For these reasons, the foot used for building vessel NZ43 seems to have been close to the Frisian "wood foot" of 29.6 cm. Apparently the shipwright did not use cubits, because none of the three investigated cubit lengths correlates to the vessel's dimensions.

When studying the dimensions, I noticed that many of them are either multiples of 3.5 cm or differ by exactly
Table 6. Hull dimensions in Amsterdam and Frisian measures. Dimension marked with asterisk is reconstructed.

Amsterdam Inch = 2.35 cm Frisian Inch = 2.46 cm
foot = 28.3 cm foot = 29.6 cm

<table>
<thead>
<tr>
<th>Hull member</th>
<th>Metric (cm)</th>
<th>Amsterdam</th>
<th>Frisian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keel plank fore</td>
<td>15</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>width</td>
<td></td>
<td>(inches)</td>
<td></td>
</tr>
<tr>
<td>mid</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>height</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Keel line rise</td>
<td>14.5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Bow hook - hor.</td>
<td>92</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>length</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- molded in</td>
<td>14</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>out</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>- sided</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Stern hook - vert.</td>
<td>28</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- molded in</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>out</td>
<td>10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Hook rabbets - width</td>
<td>2-2.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Posts - inner faces</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Garboard - width</td>
<td>37</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Second, port - width</td>
<td>32</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Strakes - scarf lengths</td>
<td>23-25</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>- overlaps</td>
<td>4-5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Clamp - molded</td>
<td>7</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- sided</td>
<td>15</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Frames - average dist.</td>
<td>24.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>- molded (1 ex)</td>
<td>21</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>(3 ex)</td>
<td>20</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>(2 ex)</td>
<td>15</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>(1 ex)</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>(1 ex)</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- sided (1 ex)</td>
<td>20</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>(1 ex)</td>
<td>15</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>(3 ex)</td>
<td>23.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>(9 ex)</td>
<td>16.5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Treenail diam. - bottom</td>
<td>2.4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- sides</td>
<td>2.23</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ceiling - length</td>
<td>234.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>- av. width</td>
<td>37</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>- av. thickness</td>
<td>2.4</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Deck beams (1) - molded</td>
<td>17.5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>- sided</td>
<td>17</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>(2) - molded</td>
<td>10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>&quot;Mast step&quot; - length</td>
<td>108</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>- molded</td>
<td>22</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>- sided</td>
<td>47</td>
<td>20</td>
<td>19</td>
</tr>
</tbody>
</table>
Table 6 (continued)

<table>
<thead>
<tr>
<th>Hull member</th>
<th>Metric (cm)</th>
<th>Amsterdam</th>
<th>Frisian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall</td>
<td>1181.5</td>
<td></td>
<td>40 (feet)</td>
</tr>
<tr>
<td>Length on the ground</td>
<td>912.5</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Keel plank length</td>
<td>650.5</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Stern hook - hor. 1.</td>
<td>76</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>- vert. 1.</td>
<td>28</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Stem + hook length</td>
<td>272</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>* Sternpost + hook 1.</td>
<td>242</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Bottom width</td>
<td>198</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Beam overall</td>
<td>426</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Midship - height</td>
<td>120</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>- molded h.</td>
<td>113</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Sheer height - fore</td>
<td>225.7</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>- aft</td>
<td>208.5</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Ceiling area length</td>
<td>234.5</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

3.5 cm. This length does not correspond to any known Dutch inch, and I do not know an explanation for this phenomenon.

In addition, as mentioned above (pp. 96 and 110), a palm width of about 10 cm may have been used for the location of the edge nails of overlapping strakes as well as for the square nails holding temporary cleats or braces during construction.

2. Hull proportions

As far as we know, medieval shipwrights did not use building plans in which the shape of the vessel was determined beforehand, but developed the hull as they went along, working at the most with traditional canons of proportion or experimental formulas.173
By comparing various measurements from vessel NZ43, I found several meaningful proportions, and it seems now possible to hypothesize the way in which the shipwright may have determined the principal dimensions of the hull. The value of this hypothesis is of course limited, as it is based on a reconstruction model. Nevertheless, it would be interesting to search for similar proportions in other cog-like vessels.

The length on the ground, or keel line length, of 9.125 m (30 Frisian wood feet) seems to have been fundamental in developing the hull of vessel NZ43. From this length, various other important dimensions can be derived. Yet, the builder’s reason for choosing this keel line length is not clear. We know that a shipwright in later times received an order to build a ship of a specific capacity, not dimensions. Since the capacity of vessel NZ43 approaches so closely one-half unit of a known Groningen measure of ship capacity, this may have been the case also with our vessel (v. supra, p. 185). The length on the ground may have been a function of the capacity. It is likely that the builder was a small shipwright producing vessels of only a few sizes, who knew from experience which ground length was required for each desired cargo capacity.174 Perhaps he employed an experimental formula.

The keel line is made up of the keel plank and the horizontal legs of the hooks. Because the hooks played such
an important structural role, their dimensions must have
depended on the choice of available heavy timbers. This
would explain their different sizes. The keel plank may have
been trimmed down to fit the determined keel-line length.
The keel line was given a rise of 14.5 cm, equal to 6
Frisian wood inches, or one half foot.

Exactly in the middle of the keel line length, the
builder located the midship section. By taking one ninth of
the keel line length measured to the inside of the hooks, he
would have obtained the distance from centerline to chine
for each side of the vessel. The transverse rise of the
bottom planks is only 2° and may have been obtained by eye.

Neither the lengths nor the vertical heights of the
posts fit well into this scheme. The stem together with the
vertical hook leg is 9 Frisian wood feet long, and the
reconstructed height of sternpost and hook is 8 Frisian wood
feet. However, it seems possible to me that the builder was
not so much concerned about the lengths of the posts, but
with the vertical heights of the sheer line; it would have
been easy to let the posts rise somewhat above the sheer. In
the bow, the vertical height of the sheer line is found by
dividing the keel line length by four, or the length from
bow to midship section in half. The height of the
reconstructed sheer in the stern measures 9/10 of the height
in the bow, and is 7 Frisian wood inches lower. The rake of
the posts is determined by the angles of the upright hook
legs. These angles are 55° and 52° in bow and stern respectively. The builder may merely have wanted to make these angles slightly steeper than 45°, and more so in the bow than in the stern, because the stem was to be concave and the sternpost convex. Or perhaps he determined the rake by calculating its vertical and horizontal components. In that case, he must have found first the overall length of 11.815 m by taking 5/4 of the length on the ground. This overall length was 2.69 m longer than the keel line length. By taking 3/5 of this difference and projecting it forward of the bow hook, the horizontal distance of the stem rake would have been obtained. The remaining 2/5 was taken by the sternpost rake. The vertical component of the rakes would have been formed by the heights of the sheer line in bow and stern, which are described above.

Midship height from the bottom of the planking to the sheer strake was equal to 1/10 of the over-all length. It is interesting that exactly the same proportion was prescribed by N. Witsen for the building of a 17th-century pinnace. The builder may also have determined the molded midship height by taking 1/8 the keel line length, or 1/2 the sheer height in the bow. The angle of the bilge amidships is inclined 27° from horizontal, or 25° when measured from the rising bottom planks. It may have been obtained by taking about 1/2 of the bow or stern rake, or even by taking about 1/4 of a 90° angle. The length of the maximum beam, 4.26 m
overall and 4.22 m molded, did not form any simple proportion of the larger dimensions. One possible way the builder could have determined it is by dividing the keel line length into half and subtracting one Frisian wood foot. The result is 4.26 m, or exactly the reconstructed overall beam.

Most surprising was the proportion found with regard to the location of the chocks that may have served as mast steps. The distance of the chock's center to the stern hook, taken to the inside, is related to the distance of the chock to the turn of the bow hook as 1.613, which is almost exactly the so-called golden proportion of 1.618. So the builder may have determined the location of the chocks by taking the golden mean proportion from the keel line length. The way in which this can be done is illustrated in fig. 89.176 One constructs a right triangle of which the height is half the length of the base. With a compass placed in the upper corner of the triangle the height is projected onto the hypotenuse. With the compass placed at the other corner of the hypothenuse, the length of the hypotenuse less the height of the triangle is projected onto the base line, and this projection point marks the golden mean of the base, the ratio of the longer to the shorter line section of the base being 1.618:1.

Information on mast positions of eight cog-like and related wrecks is given by O. Crumlin-Pedersen and R. Hulst
Figure 89. Method for finding the golden mean. (Drawing by author)
(v. supra, p. 152; fig. 76 on p. 153).\textsuperscript{177} The mast location of the 15th-century wreck Kalmar II, described by Hulst as having a cog design and Scandinavian construction,\textsuperscript{178} happens to yield the same proportion as in vessel NZ43. Wreck OZ43 from the Zuyderzee gave a quite close ratio of 1.857, as did the Bremen cog with 1.439. The proportions found in the other wrecks differed more.

F. Provenience and date

At this point in the analysis, we have gathered several clues regarding the possible provenience and date of wreck NZ43. First of all, we can say that the vessel belonged without doubt to the cog-like type, because its shape and construction features are similar to the ones of the Bremen cog: it has a beamy midship and rather sharp lower bow and stern; the bottom is almost flat, with a keel plank and mostly flush-lying strakes; the side strakes overlap and are joined with clenched nails; the bottom is drop-shaped in plan view; hooks make the transitions from keel plank to stem and sternpost; caulking moss is held in the seams by laths and butterfly clamps; deck beams and knees play an important role in reinforcing the structure.

Cog-like craft were built along the southern coasts of the North Sea and the Baltic, from Flanders to Poland. Having a nearly flat bottom with little dead rise, vessel NZ43 was intended to sail shallow waters. Its high bow and
stern suggest it sailed the sea, while the low midship sheer leads one to think that the waves of the sea were not very high. Within the territory of the cog-like craft, both the Zuyderzee and the Waddenzee fit that profile. We can therefore say that our vessel might have been built anywhere from the northern Netherlands to northern Germany. The location of the wreck site does not necessarily indicate that vessel NZ43 was a local Zuyderzee craft, because Frisian merchantmen of that size sailed both seas.  

German scholar P. Heinsius has distinguished on the basis of iconographic data several regional cog types. I was unable to fit the outward appearance of vessel NZ43 into any of these. Some individual seals, however, do show close similarities to our boat. The profile of vessel NZ43, with its concave stem and probably convex sternpost, as well as the probable rudder attachment by means of only two gudgeons are found on the 1309 cog seal of the Flemish port of Damme (fig. 33 on p. 64). The boat on the seal also has the same relative difference in height between bow and stern. More similar to the sheer line of vessel NZ43 is the one seen on the 1461 seal of Genemuiden, a fishing town on the east coast of the Zuyderzee (figs. 5 and 26 on pp. 13 and 54, respectively). Also in size the Genemuiden boat seems to correspond to our vessel.

The relative dimensions and shape of the boat depicted on the 1399 seal of Kuinre, a Zuyderzee harbor north of
Genemuiden, also resemble those of vessel NZ43, and in addition the seal shows the only example of a bipod mast, which might have been the mast type on our boat as well (fig. 25 on p. 53). The boat represented on the Kuinre seal was perhaps a so-called Kunrencogghe, a boat type mentioned in a 1343 Deventer account. Kunre seems to me merely an alternative spelling of Cunre, the medieval name of Kuinre written on the seal. The Kunrencogghe, according to A. Luns, appears in written documents as a special type of cog used for carrying peat. In my opinion, some of its special features might have been a beamy hull for carrying the peat load, and a bipod mast for lifting the heavy cargo in and out the boat, as can be seen on the Kuinre seal. It is tempting to identify vessel NZ43 with the boat of the Kuinre seal and the Kunrencogghe not only in view of the hull shape and the possible bipod mast, but also because a function as a peat carrier would explain the presence of the closed ceiling area as well as the absence of cargo on the wreck. The evidence is nevertheless too hypothetical to allow yet such identification.

Iconographic evidence might suggest that vessel NZ43 was built along the Zuyderzee rather than along the Waddenzee, but we should keep in mind that we do not have any cog seals from the Frisian towns along the Waddenzee. The vessel's tonnage of about one-half of a Groningen scheepsvracht might point to a provenience in Frisia, and so
does the fact that a unit of measurement close to the Frisian wood foot may have been used by the shipwright. Also these clues are dubious, however, not only because the correlations are quite weak, but because it is possible that these measures were used outside Frisia as well.

Shipwrecks are usually dated on the basis of their contents. This criterion cannot be used for vessel NZ43 because the wreck was found virtually empty, but the stratigraphy of the site indicates that vessel NZ43 sank before the 17th century. Further, since cog-like craft appear in the iconographic and archaeological record from the 13th century on, a likely terminus post quem for our vessel is A.D. 1200. This lower limit is supported by the evidence for a stern rudder. The earliest representations of stern rudders come from late 12th-century England and Flanders, and this rudder type is therefore thought to have originated in either of those regions.\(^{182}\) A cog carrying a stern rudder first appears on the 1242 seal from Elbing, Poland. Since it is reasonable to believe that the stern rudder may have come to the Netherlands before it was used in Poland, A.D. 1200 seems an acceptable terminus post quem for the construction of our vessel. If it were possible to analyze the iron remains on the wreck and establish the original degree of purity, one could determine if the vessel
was built after A.D. 1400, when newly introduced technology yielded purer metal than before.

The date of vessel NZ43 nevertheless can be narrowed down tentatively on the basis of some construction features. The rake of stem and sternpost, and the possible presence of only two rudder gudgeons are found in iconographic representations only from the 14th century on. The concave stem and convex sternpost are attested only once in the 13th century, and more frequently from the 14th century on. Leaving a margin for possible delay between a technical innovation and its appearance in iconography, we could thus raise the *terminus post quem* to the late 13th century.

Additional clues are suggested by O. Crumlin-Pedersen. He hypothesizes that the number of flush strakes in cog-like vessels decreased through time. Seeing that the earliest cog-like wreck, of the late 13th century, has seven flush strakes, and the latest, from around A.D. 1400, only two, we could say that our vessel with its five flush strakes should be dated rather in the early than late 14th century. It must be kept in mind, however, that the value of this dating criterion is not yet substantiated by sufficient evidence. Crumlin-Pedersen also sees a chronological evolution in the location of the mast, moving gradually from the bow toward amidships. I prefer not to use this criterion, because the position of the mast on vessel NZ43 is not known with certainty. Moreover, in the Zuyderzee wrecks, the mast
location appears to be functional rather than the result of an evolutionary process.

Therefore, we may conclude that vessel NZ43 was built almost certainly between A.D. 1200 and 1600, probably before A.D. 1500, and perhaps in the late 13th or early 14th century.

G. Socio-economic environment

Since vessel NZ43 is only approximately dated to the late Middle Ages, socio-economic conditions in northern Europe will be discussed from the 13th through the 15th centuries. Only those aspects reflected in the construction of this vessel will be covered.

1. Profitability of cogs

As mentioned above (pp. 168 and 177), vessel NZ43 might have been used for carrying cargo as well as for fishing. In both aspects, the boat was an economic tool, and subject to the laws of cost and profit. Costs resulted from building and operating the vessel, profits were derived from selling cargo or fish, or from hauling cargo. Naturally the owner wanted his vessel to be as profitable as possible.

Profitability calculations for large merchant cogs were done by W. Vogel on the basis of 14th- and 15th-century written documents from cities on the southern Baltic
Vogel deals with cogs from 45 to 150 last, which were involved in long-distance trade between the Baltic regions, Flanders, England, and western France. Smaller cogs have not been studied in this regard.

Vogel's first calculation relates to a cog of 45 last, built around 1330. This vessel must have been slightly larger than the Bremen cog of about 40 last. The building price was 19,125 g silver. Assuming the ship made only one round-trip voyage a year, Vogel estimates its yearly gross earnings as 20,000 g silver, and its operating costs as 10,060 g silver, which would leave a profit of 9,940 g silver, or 52% of the original building expenses. Thus the owner needed a little less than the profits of two years to recover the building costs completely. If, however, 10% amortization a year is included in the calculation, as Vogel suggests, the yearly profit of the ship could be estimated at 8,028 g silver. Vessels of such size were usually owned and operated by partnerships of merchants; a half share would have yielded 4000 g, and a fourth 2000 g silver. As annual earnings these profits are very high. For the sake of comparison, Vogel mentions that the yearly wages of the chancellor of Lübeck were only 3600 g silver, while a carpenter in 1344/5 earned 1846 g a year.

The second cog discussed by Vogel dates to A.D. 1403, and carried 150 last. It is estimated to have yielded a yearly profit equal to 41% of its original construction
costs. A 1450 cog, finally, carried 120 last and might have yielded 48% of its building price yearly. According to Vogel, these differences in profit rates may be due to the time period, the size of the vessel, or the nature of the cargo. In general, he concludes that investments in these large cogs could be paid back fully in two to three years, and that long-distance shipping was a very profitable business. These conclusions are confirmed by numerous merchant accounting books of the time.

Concerning local shipping along the North Sea coast and in the Zuyderzee, the relation of profits to expenses may have been similar. Certainly, the earnings of one voyage must have been much less, but on the other hand, many more voyages per year were made, and less must have been paid for the living expenses of the crew. During the late Middle Ages there was a growth in the coastal trade carried on by small vessels from the Baltic to England. Also the active Zuyderzee trade in that time suggests local shipping was an attractive occupation. 186

2. Organization and duration of the construction

Before we discuss the relative costs of labor and materials for the building of a cog, it is worthwhile to describe first how the production of our vessel might have been organized and how long it might have taken. An interesting study on this subject was made by German scholar
K.-F. Olechnowitz. Even though his work concerns mostly the later Hanseatic period from the 15th century on, his findings may reflect some basic practices that existed earlier. In general, the history of Hanseatic shipbuilding suggests that shipbuilding was increasingly regulated through time, which enables us to assume that rules in the 13th and 14th centuries may have been less strict than here described. Olechnowitz' data refer mostly to German Hanse cities, but it is thought that the situation in the Netherlands was similar.

From the late 14th century on, shipbuilders organized themselves in guilds consisting of masters, journeymen and apprentices. The master shipwright can be considered the head of a production unit. He rented a city shipyard and had a storage cabin, bought the necessary wood, and either possessed or rented from the guild necessary tools and heavy equipment such as lifting devices. The master made an oral agreement with a customer for the construction of a vessel and was responsible for the final product. His main task was to inspect the fastening of the hull members and the closing of the hull. If the quality of the produced ship was inadequate, he was required to pay all costs himself. Master shipwrights apparently enjoyed a quite high social status.
Training of skilled shipwrights was strictly regulated by the guilds. In Hamburg, apprentices had to be at least 18 to 20 years old, because of the arduous work. It is not known how many apprentices a master could take in the late Middle Ages, but in the 16th century, under pressure exerted by the journeymen, the number was limited to two. After two to four years and the fulfillment of some requirements, the apprentice graduated and became a journeyman. In several cities one of the graduation requirements was to make a long journey abroad on board ship in order to learn new techniques.190 In 16th-century Lübeck, the graduation test in addition consisted of making a mast, yard, and rudder. At the end of the 17th century, graduating apprentices in Königsberg (Kaliningrad) were required to join a crotch onto a ship, to cut a 30 foot plank, and to close a seam between carvel planks.191

A journeyman was not bound to a master but to the shipbuilders guild of the city. Every morning he would go to the eldersmen of the guild and be assigned for that day to a specific master. The eldersmen were compelled by law to inspect the work of the journeymen daily. Journeymen carried their own tools but were not allowed to possess major gear such as lifting devices. Doing private work was forbidden to them, and punishment of violators was severe.

There seems to have been little or no difference in skill between journeymen and masters. In Bremen, where
shipbuilding was done on a modest scale, not even a masterpiece was required, but only admission by the eldermen or other masters. The same was true in 16th-century Lübeck. In other cities, masterpiece requirements were minimal. In 16th-century Danzig the examinee had to make a ship’s rudder and a winch, and was required to cut a plank correctly. The masterpiece in 16th-century Königsberg was somewhat more demanding. It included making a rudder with six hooks and a winch with six slots, as well as fastening a 30 foot plank in a curved part of the hull, or even building a new boat.192 Wages of masters and journeymen seem to have differed little or not at all. Other evidence that journeymen were nearly as skillful as masters, can be seen in the frequent disputes between journeymen and masters with regard to the part of the work each was entitled to do. Documents also testify that when there was no master available, guilds assigned a journeyman to oversee a job. On the other hand, masters who were out of a job would work occasionally as journeymen. The main difference between master and journeyman appears thus to have been the master’s responsibility for the quality of the finished ship, and his right to possess or rent major production equipment.193

It seems thus that in the 15th century, a boat the size of vessel NZ43 would have been built by a small number of about equally skilled craftsmen of whom one bore the responsibility of the final product. The work of the others
would have been inspected daily. These craftsmen were likely to have experience in other shipbuilding traditions as well. In addition, there must have been one or two apprentices. A 1285/6 shipbuilding account from the Dutch city of Dordrecht—the shipbuilding center of the county of Holland—indicates there were specialized sawyers, as it lists separate entries for workmen who sawed the timbers.194

The Dordrecht account and Olechnowitz's studies also give us some insight into the duration of the building process. Counting the work days of all men listed, I obtained a minimum of 99 man days, or a little over three months for one person alone. Olechnowitz mentions that in summers, working days consisted of 14 hours, including three to four breaks of about 2 hours total. Winter days consisted of about 11 hours. No information exists on the length of breaks in winter. Therefore, if the Dordrecht cog was built in summer, it would have required 1,188 man hours. If built in winter, it would have taken only about 990 man hours. Shipbuilding in that time may not have been efficiently organized, however, because as late as the 17th century, van Yk complains about craftsmen having many idle moments.195

Even though vessel NZ43 differed from 15th-century and later vessels, its construction may have been organized in a similar way. In the late-medieval Zuyderzee regions, the initiative to build a small vessel may have come from a city, but rather from a skipper, a merchant, a farmer, or
even a monastery. It is known that many farmers had boats, not only to carry their own products to the market, but even to practise carrying-trade for part of the year. It is possible that just as in earlier times, a farmer would build such a vessel by himself in his back yard, with the help of a few others. However, because of the quite elaborate hull design and plank curvature, it is more likely that this vessel was built by skilled boatwrights. As described above (pp. 87, 94, 102, 109), several striking differences in constructional details suggest that at least two craftsmen of basically equal skills worked on either side. The fact that at port the trimming of planks and the cutting of notches happened more carefully, and that the lengths of the scarfs were more regular, while at starboard the scarf nails were hammered in with more regular patterns might suggest that the more skilled builder worked mostly on the port side of vessel NZ43, but that he sometimes may have changed sides.

3. Labor and material costs

A. Luns cites several late-medieval building accounts from the Netherlands dealing with small war cogs and related craft. Two documents include entries of material and labor, and thus can be used to study the relative expenses of each with regard to the total price of the hull. Because these war vessels were rowed as well as sailed, they may
have looked somewhat different from merchantmen. But as their sizes were not too different, the ratio of labor versus material costs may have been similar to the one on our boat.

The source most useful for our purposes is the Dordrecht account of 1285/6. It is a detailed list of building expenses for a new cog. Since this cog required two hundred planks, it must have been larger than vessel NZ43, which had a skin made up of about eighty planks. On the basis of the number of oars listed, Luns estimates that its keel was at least 12 m long. I calculated that 40% of the total cost was claimed by labor, 44% by wood, 10% by ironwork, and 6% by pitch, grease, saws, and minor supplies.

A second useful document is a 1361 building account of a heerkog for Deventer, a city on the river Yssel that had close contacts with the Zuyderzee. Only one hundred planks were ordered for this war vessel, and therefore it may have been about the same size as vessel NZ43. This account is not as detailed as the previous one, and lists several items that are not directly related to construction. After omitting all entries which were not directly comparable to those of the first document, I found that of this reduced sum 35% went to labor, 45% to wood, and 20% to an anchor and tholes. In reality the percentage of labor expenses may have been even smaller, since commodities like
pitch, grease, and nails were not listed and probably should be added.

From these accounts it appears that in the late 13th and 14th centuries, labor costs amounted to about 35 to 40% of the total cost of the hull, always a little less than the wood cost. The Deventer account even allows us to figure that when the price of the sail is added to the total cost, labor expenses constitute only 25%, equalling the percentage of rigging costs, while wood still accounts for 36%.

Even though we have information from only two sources, we may tentatively conclude that in the late 13th and 14th centuries, labor expenses were less than material costs in the construction of a ship. Since the organization of the work might not have been very efficient, the main reason for the low labor costs must be the low wages of the workmen.200

Several reasons can be suggested to explain the difference in labor cost percentages in the two documents. We know that in the 75 intervening years shipwrights' wages increased,201 but perhaps the prices of materials went up faster. Or the difference may be a result of how the work was organized. The Dordrecht cog was built by more than 18 people, each entered individually in the account. They worked for periods of 3 to 10 days, with an average of 4 to 5 days, including the master shipwright. This peculiar organization may reflect the concept of the war cog as a vessel of the community, built by a number of skilled
craftsmen of the city. The master seems to have come by only occasionally to inspect the quality of the work. Labor costs for the Deventer heerkog, on the other hand, had been entered as one sum, which was paid to a master shipwright. This corresponds to the way the building of merchant cogs was organized: the master taking the responsibility for the entire building process (v. supra, p. 229). This form of organization might have kept labor costs down, because construction was more centralized and thus perhaps more efficient, or maybe as a result of competition between masters to get orders.

Evaluating labor-consuming techniques in vessel NZ43 is not straightforward, because what may seem difficult to us might have been easy for trained shipwrights of that time. In my opinion, it was not so much the bending or connecting of planks that was labor intensive, but the cutting of the planks in the required shapes. For planks were not straight but individually modelled in top view as well as in cross section (v. supra, pp. 104-109). The transitions from flush to lapstrake planking, with their bevels and notches, must have required especially accurate work. This is also suggested by documents showing that plank cutters were paid per piece.202 If we assume that quality of the product was a condition for payment, we can conclude that the purpose of this regulation was to make time unimportant with regard to
cost, so that quality planks would be delivered. Other pieces that required careful sculpting were the hooks. Finally, the use of closely set butterfly clamps to cover the caulking seems also time-consuming to me (v. supra, pp. 115 ff.). If however, as van Yk suggests, this work was done by unskilled labor, caulkers would have been paid less.203

On the other hand, the fact that the side planks reached to the outer edges of the sternpost is considered by modern authors to be a time-saving technique, because the builder did not need to fit the planks exactly, as in a rabbet, but could have them pass the post, and then saw them all off at once. Fitting these side planks may even have been done by less skilled labor.204

The builders of this vessel must have worked very carefully, because few tool marks were found on the hull. The relatively minor variations in thickness throughout the planks show the craftsmanship of the sawyers.

Wood was a major part of the building expense, accounting for about 45% of the total cost of the hull (v. supra, p. 234). In both medieval building accounts, transport costs were minimal, so the wood must have been bought from local merchants. Since the oak type used in vessel NZ43 has not been sufficiently studied, its provenience is not known. But because of the small size of
the vessel, I assume it was built from local oak. We know that at least in 15th-century German Hanse cities, shipwrights were required by law to use only good wood. 205 This also must have kept the relative cost of wood high.

The few data available on wood use in the construction of vessel NZ43 reflect the high price of the wood, in that it was used quite efficiently and economically. Cracks were carefully caulked, and several large knots in the planks were patched with a plug and by nailing a short plank on top (fig. 90). Different cutting techniques and various parts of trees were used. Planks were flat-sawn or quarter-sawn. Even though they were bevelled and sculpted, they seem to have received their shapes primarily from bending, so that little wood was wasted. All frames but one were made of big branches or small trunks, and in many instances sapwood was included in the timber. The V-shaped floors and the hooks were grown pieces, and for some floors even asymmetric timbers were employed.

Vessel NZ43 appears to be a sober, purely functional, but carefully made hull, built from timbers of various qualities. The shipwright seems to have maximized the use of the wood, with relatively little concern for labor expense. Similar findings were done on the Bremen and Kollerup wrecks. 206 As such, the construction of these three vessels might reflect the high prices of materials and the low costs of labor.
Figure 90. Repair of a leaking knot in vessel NZ43. Plank G10b. (Adapted from drawing by Museum Ketelhaven, courtesy R.IJ.P.)
4. Operating expenses

The main constituents of operating expenses were maintenance, crew wages and supplies, as well as river and harbor taxes. The shape of the hull suggests vessel NZ43 carried cheap bulk goods. Unlike in the trade of luxury items, transport costs in bulk trade must be as low as possible in order for the cargo to bring a good price at the market.\textsuperscript{207}

According to A. Luns, maintenance of the bottom parts of late-medieval vessels was done by careening; he does not say how often this was necessary.\textsuperscript{208} The flush-lying bottom planks of vessel NZ43 must have been quite easy to replace, because they had rather simple configurations, and were not connected to one another. This feature might be related to the fact that the frequent beaching in primitive harbors for loading and unloading undoubtedly caused the bottom planks to wear out faster than the side planks (v. supra, p. 51).

The Dordrecht document from 1285/6 included a second account for the repair of an old cog. The total cost was 26\% of the building price of the new cog.\textsuperscript{209} This ratio corresponds to Vogel's estimate that the maintenance of large Baltic cogs cost about 25\% of their original price per year.\textsuperscript{210}

Crew wages for large cogs during the 13th and 14th centuries are estimated by W. Vogel at probably less than 40
g silver a month. In one such cog of 150 last, the hiring of 30 sailors for eight months accounted for about 52% of the operating costs, excluding taxes.\textsuperscript{211} I did not find data on the costs of hiring crews for small vessels. Our vessel probably could do with two or at the most three sailors. The fact that vessel NZ43 was built very round as a slow-speed vessel suggests that speed and thus crew wages were not as important as a large cargo capacity in keeping transport costs per unit of cargo low.

Skippers on late-medieval river craft had to pay a lot of tolls, because they crossed the possessions of many small lords who had the rights of exacting taxes.\textsuperscript{212} It may be assumed that every Zuyderzee harbor required the payment of taxes as well. According to Olechnowitz, taxes were calculated on the basis of the skipper’s declaration of keel length and a rough estimate of the cargo capacity.\textsuperscript{213} In tidal harbors, the keel length seems to me easier to verify, because it could be measured if the vessel lay dry at low tide. A reflection of these tax regulations could be the quite low rakes of stem and sternpost, which reduced the keel length per unit of cargo capacity, and thus also eventual taxes. C. van Yk mentions two methods used in the late 17th century for measuring a vessel’s cargo capacity. The first one was to load the vessel until it had reached a certain draft, and measure the amount of cargo needed in
tons or last. The second was to multiply overall length, molded beam and molded depth, and divide the product by the number of last cargo the hull could contain. The ratio obtained in this way could be applied to other vessels of similar size and shape. These capacity calculations were done by special inspectors of weights and measures. If a similar system existed at the time vessel NZ43 was built, the strict control of cargo capacities by the inspectors may be reflected in the fact that its capacity might have constituted one-half unit of a ship measure (v. supra, p. 185).
CHAPTER V

CONCLUSION

Vessel NZ43, found in the reclaimed land off the southern coast of the former Zuyderzee, is a small cargo carrier that may have been used for fishing as well. It undoubtedly belongs to the type of cog-like craft that during the 13th and 14th centuries dominated seafaring in the North Sea and the Baltic. Seaborne trade at that time was flourishing, and vessels the size of ours are known to have sailed the coastal waters between the Baltic and England. While large cogs carried trade goods between the relatively few deepwater harbors of eastern and western Europe, small merchantmen like ours were indispensable for distributing goods to the smaller ports.

Like all cog-like boats, our vessel has a tubby hull with sharp lower bow and stern, and was thus designed for maximum capacity as well as for good sailing qualities. It may have been constructed anywhere along the coasts of the northern Netherlands and northern Germany, but likely in the Zuyderzee region. It dates probably from sometime in the 13th through 16th centuries, perhaps to the late 13th or early 14th century.

The reconstruction of the well-preserved and meticulously recorded wreck NZ43 shows that this small, ordinary boat was extremely well built, in spite of a
limited supply of good shipbuilding wood. Evidence of the scarcity or high cost of the wood is abundant. Timbers were cut or sawn in different ways to avoid waste. Sapwood was often included, and knots and cracks were carefully mended. The high level of craftsmanship among the workers is still more apparent. The sawyers produced long, wide planks which over their entire lengths varied a few millimeters in thickness at most. Almost no tool marks were left on the wood by the builders, despite the elaborate sculpting, bevelling, and notching of the planks. The shipwright also impresses us by his cleverness. He used the available supply of large and small planks in such a thoughtful way that he maximized their usefulness. Flush-lying and overlapping planking techniques were combined so as to exploit the advantages of both. The builder devised ingenious solutions to constructional problems, such as the transitions from flush to lapstrake planking in bottom and bilge. He even seems to have turned these potentially weak spots into points of some reinforcement for the planking.

The good preservation of vessel NZ43 has allowed us to expand our knowledge about the design and construction of cog-like craft. For the first time, a concave stem and probably convex sternpost are found on a cog-like wreck, thereby confirming the evidence given by some iconographic representations. The presence of heavy steps in the sides is also unique among cog-like vessels, fueling our idea of the
variety that might have existed among the smaller craft of the time. Moreover, they suggest how a bipod mast arrangement like that shown by a seal from the Zuyderzee port of Kuinre might have been constructed.

Not only does wreck NZ43 enable us to reconstruct the building sequence in more detail than before, it also provides evidence of the use of cleats to hold the planks together during construction, and perhaps of braces to keep the strakes in their curved shapes, thus pushing back by about 250 years the date for the employment of these techniques in shipbuilding. This vessel may also provide the first illustration of the shipwright's use of proportions for developing the cog-like hull shape. Especially interesting is the location of the possible bipod mast steps at the golden mean of the keel line, suggesting that the builder was well schooled in the secrets of medieval architecture. Comparing the hull's reconstructed cargo capacity of 9.2 tonf with old ship measures reveals that merchantmen this size may have been intended to carry the weight of one-half unit of ship measure.

Moreover, the good preservation of vessel NZ43 allows us to evaluate in concrete terms the quality of the cog-like design. The reconstructed hull was apparently very stable, and sailed at a cruising speed of 3 to 5 knots, which was nearly the ideal speed with regard to its hull length. Its maximum velocity was probably 10 knots. As in other cog-like
vessels, the possible location of the sail somewhat forward of amidships and the sharp lower bow and stern suggest the vessel could maneuver very well, thus being well suited for coastal sailing.

As such, vessel NZ43 has given us some long awaited insight into the construction and the qualities of cog-like craft. Since this small and modest boat was so carefully planned and built, we may assume this was also true for large cogs, which had to sail far more dangerous waters, and carried much larger values in cargo. Cog-like vessels thus can be seen as products of the high level of craftsmanship that was typical for medieval guilds. At the same time, they appear as the exponents of a long shipbuilding tradition.
NOTES

1. The Zuyderzee has changed names several times. In the Roman period it was a small fresh-water lake called Lake Flevo. The water expanded during the Middle Ages and became known, from the 8th through the 12th centuries, as Almere. Toward the end of the Middle Ages, the lake became increasingly saline because of the widening of its opening to the North Sea, which turned it more and more into a sea-arm. The chronology of the salinization process is not yet well-established. Neither do we know the name used in the late 12th and 13th centuries. The term Zuyderzee (South Sea) appears for the first time in 1340, and remains in use until the 20th century. In 1932 a dam was constructed closing off the entrance to the North Sea, so that the Zuyderzee became again a lake, now called IJsselmeer, which is translated as Lake Yssel. As a result of land reclamation, Lake Yssel is much smaller than the former Zuyderzee, and most shipwrecks are not found in the lake but in the reclaimed lands, which are called IJsselmeerpolders: P.J.R. Modderman, Over de wording en de betekenis van het Zuiderzeegebied (Groningen 1945) 27-28; J.C. van Triest, "Omme noetsz will der zee" (Amsterdam 1981) 69-70. In this thesis I adopt the term Zuyderzee, because it is likely that vessel NZ43 sailed when that name was in use.


4. F. Moll, Das Schiff in der bildenden Kunst (Berlin 1929); H. Ewe, Schiffe auf Siegeln (Rostock 1972).

5. B. Hagedorn, Die Entwicklung der wichtigsten Schiffstypen bis ins 19. Jahrhunderts (Berlin 1914); W. Vogel, Geschichte der deutschen Seeschifffahrt (Berlin 1915); P. Heinsius, Das Schiff der hansischen Frühzeit (Weimar 1956) 6-8.


7. Crumlin-Pedersen, "Danish Cog-Finds," in McGrail ed. (supra n. 6) 17-34; I prefer not to use Crumlin-Pedersen's terms "carvel" or "clinker," because "carvel" carries the connotation that the vessel is built frame-first, and "clinker" denotes that the overlapping strakes are joined with roves and rivets; neither is true for cog-like vessels. Instead, I follow Reinders' suggestion and use the neutral terms "flush" and "lapstrake," respectively. Reinders (supra n. 2) 17. With "flush" or "flush-lying" strakes I refer to strakes of which the outer faces are aligned.

8. Ellmers, "The Cog of Bremen and Related Boats" (supra n. 6) 11, 14; and "The History of the Cog as a Ship Type." In Kiedel and Schnell eds. (supra n. 6) 60-68.

9. Reinders (supra n. 2) 31.


11. Ellmers, "The Cog of Bremen and Related Boats" (supra n. 6); "The History of the Cog as a Ship Type" (supra n. 8) 60-68; and "Frisian and Hanseatic Merchants Sailed the Cog," in A. Bang-Andersen, B. Greenhill and E.H. Grude eds., *The North Sea* (Stavanger 1985) 79-96.

12. Reinders (supra n. 2)

13. A. Luns, *Item van den cogghen ... Een onderzoek naar oorsprong, uiterlijk en functioneren van een middeleeuws scheepstype* (Leiden 1985) Rijksuniversiteit Leiden, Doctoraalscriptie Middeleeuwse Geschiedenis; I thank the author for allowing me to use his unpublished work.


16. Y.N. Ypma, *Geschiedenis van de Zuiderzeeversterii*
(Amsterdam 1962) 1; Reinders, written communication, July 1987.

17. Reinders (supra n. 15).

18. The term "hook" was first used by: Ellmers, Frühmittelalterliche Handels schiffahrt in Mittel- und Nor deuropa (supra n. 6, 1st ed. 1972) 292. It has been adopted by most cog scholars and will therefore be used in this thesis. In later English shipbuilding, however, this member is called "gripe" in the bow, and "heel knee" in the stern: The Visual Encyclopedia of Nautical Terms Under Sail (London 1978) 03.04, 03.07. I owe this observation to J.R. Steffy. Lahn (supra n. 6) 53, refers to both pieces as "keel ends." Lahn's terminology may be closest to the designation used in the late Middle Ages, because a Schwerin manuscript, probably dating to the second half of the 16th century, contains a drawing of this hull member and calls it merely voor stuk tot de Kiel (the forward part of the keel): K.-F. Oiechnowitz, Der Schiffbau der hansischen Spätzeit (Weimar 1960) 188, 201.

19. Reinders (supra n. 15).

20. In modern vessels, a clamp is a thick horizontal strake running along the inner frame faces and parallel to the wales; its primary function is the longitudinal stiffening of the hull: J.R. Steffy, Glossary of Ancient Ship Terms (s.l. 1979) 2. It is used here to refer to the heavy inboard plank along the sheer line because it serves a similar purpose, even though it is not located inboard of the frames but runs either over the frame heads or through notches cut in the outer edges of the frame heads. I am indebted to J.R. Steffy and F.M. Hocker for suggesting this term.

21. Reinders (supra n. 15).

22. Reinders (supra n. 15).

23. Molds were cut by F.M. Hocker in the Ship Reconstruction Laboratory at Texas A&M University; his help is much appreciated.


25. Heinsius (supra n. 5) 141; Luns (supra n. 13) 48; Hulst (supra n. 14) 54-55.

26. Wood imports from Norway and upper-Rhine region: J.A. van Houtte, Economische en sociale geschiedenis van de Lage


28. C. van Yk, De Nederlandsche scheeps-bouw-konst open gestelt (Amsterdam 1697) 52; R. Reinders, Mos, moslat, sintels en prikken (Lelystad 1978) 3.

29. Unger (supra n. 2) 144; W.L. Goodman, The History of Woodworking Tools (London 1964) 172-73, describes the breast auger.

30. Lahn (supra n. 6) 53, 57.

31. J.R. Steffy, oral communication.


33. Luns (supra n. 13) 61.

34. P.J.V.M. Sopers, Schepen die verdwijnen (Amsterdam 1974) 43-44; Olechnowitz (supra n. 18) 114; Hulst (supra n. 14) 34; Lahn (supra n. 6) 56.

35. R.W. Unger, Dutch Schipbuilding before 1800 (Assen 1978) 75; for Bremen cog: Lahn (supra n. 6) 57.

36. Olechnowitz (supra n. 18) 2, 69.

37. Olechnowitz (supra n. 18) 115; Lahn (supra n. 6) 53; Kijk op koggen (supra n. 26) 17.


39. Sopers (supra n. 34) 19; Hulst (supra n. 14) 33, 38-39, 47; Reinders (supra n. 2) fig. 4; for Ebersdorf model: W. Steusloff, "Das Ebersdorfer Koggenmodell von 1400," Deutsches Schiffahrtsarchiv 6 (1983) 194, 197; for Bremen cog: W. Lahn, "A Cog Shipyard in the 20th Century," in Kiedel and Schnall eds. (supra n. 6) 40-41; for Bossholmen
wreck: J. Rönny, **Bossholmen. En medeltida vrakplats.** Historiskt sammanhang och undersökningsmetodik (Stockholm 1986) Stockholm University, Thesis Archaeology, 41, fig. 18—
-I am grateful to J. Rönny and the Archaeology Department of Stockholm University for allowing me to use this 
unpublished work; the keel plank of the Helgeandsholmen 
wreck was a very thick (13 cm) strake: B. Varenius, written 
communication, 3 April 1986—-I thank B. Varenius for sending 
me a detailed, unpublished description as well as 
photographs of the wreck.

40. Unger (supra n. 2) 146; Ellmers, "The History of the Cog 
as a Ship Type" (supra n. 8) 62; and Frühmittelalterliche 
Handelsschifffahrt in Mittel- und Nordeuropa (supra n. 6) 
263; for a history of beaching: D. Ellmers, "Warenumschlag 
zwischen Schiff und Wagen im Wasser," Deutsches 

41. Sopers (supra n. 34) 19, fig. 1.

42. R.M. Rose, "The Anti-Hogging Hull of the Cog of Bremen," 

43. R. Reinders et al., Drie schepen uit de late 
middleleeuwen (R.I.J.P. Opgravingverslagen 2, 3, 4, Lelystad s.d.) 8, 19.

44. Ellmers, "The History of the Cog as a Ship Type" (supra 
n. 8) 62; Hulst (supra n. 14) 34, 67.


46. Hulst (supra n. 14) 38-39, 59; Reinders (supra n.2) 15, 
33; M. Audy et al., Summary of Field Research Conducted in 
1980 at Red Bay, Labrador, on the underwater Remains of the 
"San Juan" and of the Basque Whaling Station (Research 
Bulletin No. 163, Parks Canada 1981) 6—-I am indebted to T. 
Oertling and M. Gringas for bringing this to my attention; 
for the use of the term "hook": supra n. 18.

47. Heinsius (supra n. 5) 112; Hulst (supra n. 14) 41, 45, 
67, appendix, p. 61; Lahn (supra n. 6) 59; Reinders (supra 
n. 2) 15.

48. Hulst (supra n. 14) 38.

49. Hulst (supra n. 14) appendix, pp. 41-43; Lahn (supra n. 
6) 53.

50. Hulst (supra n. 14) appendix, pp. 41-43; Lahn (supra n. 
39) 33, 111. 30; and (supra n. 6) 53.
51. Hulst (supra n. 14) appendix, pp. 2-27; the concave stem of the Hardewijk vessel is clearly visible on the photograph of the 1263 seal imprint (Ewe [supra n. 4] 24), but is not rendered on Ewe's drawing of the same imprint (Ibid., 132).

52. J.R. Steffy, oral communication.

53. Steusloff (supra n. 39) 194.

54. Lahn (supra n. 6) 53. I thank C. Pulak for suggesting this possibility.

55. Steusloff (supra n. 39) 196. Also for this observation I am indebted to C. Pulak.

56. Reinders (supra n. 2) 17.

57. Ellmers, "Frisian and Hanseatic Merchants Sailed the Cog" (supra n. 11) 79; Hulst (supra n. 14) 39, 68; Lahn (supra n. 6) 58; Rönnby (supra n. 39) 41.

58. Hulst (supra n. 14) appendix, pp. 43-45; Steusloff (supra n. 39) 193.

59. Crumlin-Pedersen (supra n. 7) fig. 2.12; Hulst (supra n. 14) appendix, p. 43, 50-52.

60. Hulst (supra n. 14) 39, appendix, p. 50; Reinders (supra n. 2) 18, fig. 8; Steusloff (supra n. 39) 195.

61. Luns (supra n. 13) 30-31.

62. Crumlin-Pedersen (supra n. 7) 29; Hulst (supra n. 14) appendix, pp. 44-45, 68; Reinders (supra n. 2) 16; Varenius (supra n. 39).

63. Hulst (supra n. 14) 39; Reinders (supra n. 2) 17.

64. Hulst (supra n. 14) 39; Lahn (supra n. 6) 57.

65. Lahn (supra n. 6) 57.

66. Lahn (supra n. 6) 53-54.

67. Hulst (supra n. 14) 91, n. 7, fig. 45; Sopers (supra n. 34) 33, fig. 15; Steusloff (supra n. 39) 197, 203.

68. R. Oosting, oral communication, May 1985.

69. The possible employment of cleats was brought to my attention by F.M. Hocker.

71. Reinders et al. (supra n. 43) 11, fig. 5.

72. Witsen (supra n. 70) 169.

73. Luns (supra n. 13) 30.

74. Hulst (supra n. 14) 37, 63; Lahn (supra n. 6) 57; Reinders (supra n. 2) 18; Rönby (supra n. 39) 50; for textual evidence: Luns (supra n. 13) 31.

75. Lahn (supra n. 6) 57.

76. Rönby (supra n. 39) 50, 54; Varenius (supra n. 39).

77. B. Arnold, "Some Remarks on Caulking in Celtic Boat Construction and Its Evolution in Areas Lying Northwest of the Alpine Arc," *IJNA* 6 (1977) 293-97, describes moss caulking in Switzerland from Roman times to 20th century; for Novgorod and the Baltic: Ellmers, *Frühmittelalterliche Handelsschifffahrt in Mittel- und Nordeuropa* (supra n. 6) 310-312; C. Franklin, *Caulking Techniques in Northern and Central European Ships and Boats: 1500 B.C.-A.D. 1940* (College Station 1985) Texas A&M University, M.A. Thesis Anthropology, 66 deals with southern Baltic, and appendix III gives an overview of caulking materials used in northern and central Europe from 1500 B.C. to present times; Hulst (supra n. 14) 56, 59; for written sources: Luns (supra n. 13) 31-32; for Rhine, Meuse, and Yssel: Reinders (supra n. 28) 3; Reinders et al. (supra n. 43) 45 deals with the Zuyderzee wrecks; Sopers (supra n. 34) 33 for 20th-century Germany.

78. Hulst (supra n. 14) 54.

79. Lahn (supra n. 6) 57; Reinders (supra n. 2) 18.

80. Luns (supra n. 13) 45-46.


82. Crumlin-Pedersen (supra n. 7) 30-31.
83. This possibility was suggested to me by F.M. Hocker.

84. Hulst (supra n. 14) 40, 46.

85. Hulst (supra n. 14) 42-44; Reinders (supra n. 2) 21-22.

86. Hulst (supra n. 14) 40; Varenius (supra n. 39).

87. Hulst (supra n. 14) appendix, pp. 53-55; Lahn (supra n. 39) 40-41; Steusloff (supra n. 39) 199.

88. U. Schnall, "...wäh scheident aber die wege sich ...?" in Kiedel and Schnall eds. (supra n. 6) 69-73 describes late-medieval navigation techniques in North Sea and Baltic.

89. I thank C. Pulak for discussing this aspect with me.

90. Hulst (supra n. 14) 40, 46-47, 59-60; Varenius (supra n. 39).

91. Crumlin-Pedersen (supra n. 7) 30, fig. 2.11.

92. Hulst (supra n. 14) 83.

93. Reinders (supra n. 15).

94. I owe these suggestions to J.R. Steffy.


96. Ellmers (supra n. 44) 63-64; Hulst (supra n. 14) 93-95, n. 5.

97. Ellmers (supra n. 77) 123-48 gives an overview of medieval landings; Unger (supra n. 2) 146-47.

98. These possibilities were suggested to me by J.R. Steffy and F.M. Hocker.


100. J.R. Steffy, oral communication.

101. Crumlin-Pedersen (supra n. 7) 30, 32, fig. 2.13.

102. Hulst (supra n. 14) appendix, pp. 72-74, fig. 41; Reinders (supra n. 2) fig. 14.
103. Reinders (supra n. 20) 23.

104. Luns (supra n. 13) 41-43.

105. Heinsius (supra n. 5) 78, 136, fig. 43.

106. Luns (supra n. 13) 41, 51-53.


108. Heinsius (supra n. 5) 139; Luns (supra n. 13) 51; Unger (supra n. 2) 140.

109. Luns (supra n. 13) 42-43.

110. Unger (supra n. 2) 140.

111. Lahn (supra n. 6) 59; Reinders, written communication, May 1985.


113. Hulst (supra n. 14) 40-41, appendix, pp. 65-66; Steusloff (supra n. 39) 196.

114. Luns (supra n. 13) 40.

115. Klik op koggen (supra n. 26) 17-22; Hulst (supra n. 14) 33-41, 62; Lahn (supra n. 6) 52-59.

116. I thank J.R. Steffy for suggesting this explanation.


118. Lahn (supra n. 6) 54.

119. Hulst (supra n. 14) 36.

120. Timmerman (supra n. 70) 26.

121. Lahn (supra n. 6) 57.

122. Hulst (supra n. 14) appendix, p. 77; Reinders (supra n. 81) 42; Rönnby (supra n. 39) 4; for present-day Dutch traditional craft: Sopers (supra n. 34) 19.
123. Hulst (supra n. 14) 71.

124. I owe this suggestion to J.R. Steffy.


126. Owen and Niedermair (supra n. 124) 42.


128. Kijk op koggen (supra n. 26) 30.

129. Elmers, "The Cog of Bremen and Related Boats," in Mcgrail ed. (supra n. 6) 11, mentions that the bow of the Bremen cog is wider than the stern; in my opinion, he may be referring to the upper hull only, which is visible in top view of the strake plan.

130. Witsen (supra n. 70) 93.

131. Hulst (supra n. 14) 74-76, figs. 60 and 61; M. Gringas, oral communication, informs me that a higher bow is also a striking characteristic of modern Canadian fishing craft, which equally operate in cold, rough waters.

132. Hulst (supra n. 14) 8.

133. Ewe (supra n. 4) 8.

134. Hulst (supra n. 14) 72-73; Reinders (supra n. 2) 24 considers the Genemuiden vessel to belong to the category of the smallest cog-like vessels.

135. Hulst (supra n. 14) 69.

136. Hulst (supra n. 14) 74, 77, Tables D and E.


139. In this thesis I will use tonf to designate the weight unit of a metric ton; tonf is the scientific denotation of
the popular "ton" that in fact refers to a mass, not a weight; in the same way I will use kgf (kilogram force) instead of the popular kg. British authors often write "tonnef" when referring to the weight unit of a metric ton, and "tonf" for the English unit.

140. Lahn (supra n. 6) 58.
141. Owen and Niedermair (supra n. 124) 13-15; Rawson and Tupper (supra n. 127) 24-30.
142. Reinders (supra n. 2) 24.
143. Ellmers (supra n. 57) 79 states the Bremen cog's capacity as about 80 tons or 40 last, which is much lower than the earlier published capacity of over 130 tons; Ellmers (supra n. 77) 257; I determined the keel length of the Bremen cog as 15.6 m on the basis of the stereoptic depiction: Kiedel and Schnall eds. (supra n. 6) back of front cover; see fig. 49 at p. 92 of this thesis.

144. For these calculations I used: J.M. Verhoeff, De oude Nederlandse maten en gewichten, Amsterdam 1983, who lists the measures per city and alphabetically.

145. Verhoeff (supra n. 144) x.
146. Verhoeff (supra n. 144) 30.
147. Hagedorn (supra n. 5) 16; Vogel (supra n. 5) 555-60; Heinsius (supra n. 5) 82-84.
148. Verhoeff (supra n. 144) 30.
149. Vogel (supra n. 5) 556-558 uses as specific gravity of rye: 0.727 kgf/l, and of wheat: 0.765 kgf/l.
150. Verhoeff (supra n. 144) 5.
151. Verhoeff (supra n. 144) 55.
152. Owen and Niedermair (supra n. 124) 51.
153. Vogel (supra n. 5) 558; Heinsius (supra n. 5) 84; Verhoeff (supra n. 144) 112.
154. Kijk op koggen (supra n. 26) 29; Reinders, written communication, May 1985.
155. Owen and Niedermair (supra n. 124) 51.
156. Metz (supra n. 138) 20.
157. Verhoeff (supra n. 144) 5.

158. Owen and Niedermair (supra n. 124) 51.


160. J. Lou, oral communication.


162. Unger (supra n. 2) 140, 146.


164. I am grateful to J. Lou for suggesting this correction to me.

165. Sopers (supra n. 34) 19.

166. Hulst (supra n. 14) 41-42.

167. Hulst (supra n. 14) 38, 44, 77.

168. Crumlin-Pedersen (supra n. 7) 30-31.

169. Hulst (supra n. 14) 43-45, 50-52; Reinders (supra n. 2) 14-16.

170. Verhoeff (supra n. 144) 24.

171. Verhoeff (supra n. 144) 80, 130.

172. Verhoeff (supra n. 144) 39.


174. This possibility was suggested to me by J.R. Steffy; Olechnowitz (supra n. 18) 99 believes that the contract might have established the ship type, capacity, as well as the dimensions.

175. Witsen (supra n. 70) 104.

177. Crumlin-Pedersen (supra n. 7) 30, 32, fig. 2.13; Hulst (supra n. 14) appendix, p. 74; Reinders (supra n. 2) fig. 14.

178. Hulst (supra n. 14) 49.

179. Unger (supra n. 2) 168.

180. Heinsius (supra n. 5) 58-63.

181. Luns (supra n. 13) 54-55 also mentions in this regard the term *koeynre cogh*, designating a cog used in 1396 Gelderland for carrying cattle over the Zuyderzee; the etymology of the term *koeynre* is not yet established. Luns suggests it might be related to the name Kuinre. In my opinion it might refer to *koelen* (cattle) as well.

182. Ewe (supra n. 4) 16; Unger (supra n. 2) 141-43.

183. Vogel (supra n. 5) 432-34.

184. Eilmers (supra n. 57) 79.

185. Vogel (supra n. 5) 435.

186. Unger (supra n. 2) 149, 168.

187. Unger (supra n. 35) 70, for increasing regulations and restrictions during the 14th and 15th centuries.

188. Alberts (supra n. 26) 203, 238; Olechnowitz (supra n. 18) 75-94.

189. Olechnowitz (supra n. 18) 27-28, 67, 113; Unger (supra n. 2) 147; and (supra n. 35) 75 and 122 for the communal use of jacks.

190. Unger (supra n. 2) 23, 148; Unger (supra n. 35) 75-76.

191. Olechnowitz (supra n. 18) 79, 94.

192. Olechnowitz (supra n. 18) 92-93.

193. Olechnowitz (supra n. 18) 82; Unger (supra n. 35) 76-77.
194. Luns (supra n. 13) 61-62; about Dordrecht: Alberts (supra n. 26) 203.

195. Olechnowitz (supra n. 18) 86, 118; van Yk (supra n. 28) 34-35.

196. Alberts (supra n. 26) 64-65, 202-203; W. Ehbrecht, "Von friesischen zu hansischen Seehandelsplätzen im südlichen Nordseeküstengebiet (12./13. Jahrhundert)," in Seehandelszentren des nördlichen Europa (supra n. 32) 99-105; Unger (supra n. 2) 168.


198. Luns (supra n. 13) 50, 61-62, 70.

199. Luns (supra n. 13) 67, 70.

200. Olechnowitz (supra n. 18) 115.

201. Vogel (supra n. 5) 435.


203. van Yk (supra n. 28) 21.

204. Hulst (supra n. 14) 42, but on 91 n. 7 rightly remarks that still some precision was required to make the hooping ends of the strakes lie flush when they-enter the posts; see also supra p. 102-104.

205. Olechnowitz (supra n. 18) 103.

206. Crumlin-Pedersen (supra n. 7) 30; Lahn (supra n. 6) 52.

207. Unger (supra n. 2) 27.

208. Luns (supra n. 13) 46.

209. Luns (supra n. 13) 62.

210. Vogel (supra n. 5) 432.

211. Unger (supra n. 2) 149; Vogel (supra n. 5) 432.

212. Alberts (supra n. 26) 274-79.

213. Olechnowitz (supra n. 18) 18.

214. van Yk (supra n. 28) 319-20.
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APPENDIX A

TECHNICAL CALCULATIONS

1. Form coefficients

Midship section coefficient

\[ C_m = \frac{\text{area of immersed midship section}}{\text{beam} \times \text{draft}} \]

\[ = \frac{312.98}{41.34 \times 9.6} \]

\[ = 0.79 \]

Block coefficient

\[ C_b = \frac{\text{volume capacity}}{1. \text{between perpendiculurs} \times \text{beam} \times \text{draft}} \]

\[ = \frac{17,789}{39,686} \]

\[ = 0.45 \]

Waterplane coefficient

\[ C_{wp} = \frac{\text{area of waterplane}}{1. \text{between perp.} \times \text{beam} \text{dimensions}} \]

\[ = \frac{2,723}{100 \times 40.70} \]

\[ = 0.67 \]
2. Displacement up to waterline 1

<table>
<thead>
<tr>
<th>Body sections</th>
<th>+ Area enclosed</th>
<th>+ Plank area</th>
<th>Total area</th>
<th>Simpson's rule 1</th>
<th>f(V1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>0.14</td>
<td>0.82</td>
<td>0.96</td>
<td>1/2</td>
<td>0.48</td>
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<td>Ch</td>
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<td>1.682</td>
<td>1.17</td>
<td>2.852</td>
<td>1</td>
<td>2.852</td>
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<td>Bh</td>
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<td>4.815</td>
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</tr>
<tr>
<td>B</td>
<td>4.517</td>
<td>2.485</td>
<td>7.002</td>
<td>3/2</td>
<td>10.503</td>
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<tr>
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<td>0.93</td>
<td>1.131</td>
<td>1/2</td>
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\[ \Sigma = 255.725 \]

\[ V_1 = \frac{f(V1) \times S}{3} = \frac{255.725 \times 10}{3} = 852.417 \]

\[ V_2 = \frac{A_d \times h_2}{2} = \frac{0.96 \times 4.2}{2} = 2.016 \]

\[ V_3 = \frac{A_4 \times h_3}{2} = \frac{1.131 \times 4.63}{2} = 2.618 \]

Volume \( V = 2 \times (V_1 + V_2 + V_3) = 2 \times (852.417 + 2.016 + 2.618) \]

\[ = 1.714 \text{ dm}^3 = 1.7 \text{ tonf} \]
3. Displacement up to waterline 2

<table>
<thead>
<tr>
<th>Body sections</th>
<th>Area enclosed + Plank = Total</th>
<th>Simpson’s = f(V1) rule 1</th>
</tr>
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<td>2.09 + 1.55 = 3.64</td>
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<td>5.078 + 2.365 = 7.443</td>
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<td>20.479 + 3.982 = 24.461</td>
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<td>31.524 + 4.785 = 36.309</td>
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<td>49.966 + 5.63 = 56.126</td>
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<td>54.71 + 6.12 = 60.83</td>
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<td>48.704 + 5.94 = 54.644</td>
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<td>3</td>
<td>13.074 + 2.66 = 15.734</td>
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<td>7.206 + 2.20 = 9.406</td>
<td>2 = 18.812</td>
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<td>4</td>
<td>3.562 + 1.74 = 5.302</td>
<td>1/2 = 2.651</td>
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\[ \mathbf{E} = 846.667 \]

\[ V_1 = f(V1) \times \frac{S}{3} = \frac{846.667 \times 10}{3} = 2,822.223 \]

\[ V_2 = \frac{1}{2} \left[ \frac{(Ad + Adh) S}{2} + \frac{(Adh \times h2)}{2} \right] = \left( \frac{3.64 + 1.853}{2} \right) \frac{10}{2} + \left( \frac{1.853 \times 1}{2} \right) = 14.658 \]

\[ V_3 = \frac{1}{2} \left[ \frac{(A4 + A4h) S}{2} + \frac{(A4h \times h3)}{2} \right] = \left( \frac{5.302 + 1.923}{2} \right) \frac{10}{2} + \left( \frac{1.923 \times 2.63}{2} \right) = 20.591 \]

\[ \text{Vol. } V = 2 \left( 2,822.223 + 14.658 + 20.591 \right) = 5,715 \text{ dm}^3 = 5.7 \text{ tonf} \]
4. Displacement up to waterline 3

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<th>Body sections</th>
<th>Area enclosed</th>
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<th>Total area</th>
<th>Simpson's rule</th>
<th>( f(V1) )</th>
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</tbody>
</table>

\[ \sum = 1,649.036 \]

\[ V1 = f(V1) \times \frac{S}{3} = \frac{1,649.036 \times 10}{3} = 5,496.787 \]

\[ V2 = \frac{1}{2} \left[ \frac{(Ad + Adh) \times S}{2} \right] + \left[ \frac{(Adh \times h2)}{2} \right] \]

\[ = \left( \frac{8.57 + 2.736}{2} \right) \frac{10}{2} + \left( \frac{2.736 \times 2.2}{2} \right) = 31.275 \]

\[ V3 = \frac{1}{2} \left[ \frac{(A4 + A4h) \times S}{2} \right] + \left[ \frac{(A4h \times h3)}{2} \right] \]

\[ = \left( \frac{13.642 + 5.712}{2} \right) \frac{10}{2} + \left( \frac{5.712 \times 4.3}{2} \right) = 60.666 \]

Vol. \( V = 2 \left( 5,496.787 + 31.275 + 60.666 \right) = 11,177 \text{ dm}^3 \]

\[ = 11 \text{ tonf} \]
5. Displacement up to waterline 4

<table>
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<th>+ Plank area</th>
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\[ \Sigma = 2,642.613 \]

\[ \text{V1} = f(V1) \times \frac{S}{3} = \frac{2,642.613 \times 10}{3} = 8,808.71 \]

\[ \text{V2} = \frac{1}{2} \left[ (A_d + A_{dh}) \frac{S}{2} + (A_{dh} \times h2) \right] \]

\[ = \left( \frac{19.537 + 7.85}{2} \right) \frac{10}{2} + \left( \frac{7.85 \times 4.3}{2} \right) = 85.346 \]

\[ \text{V3} = \frac{A5 \times h3}{2} = \frac{0.71 \times 0.75}{2} = 0.266 \]

\[ \text{Vol. } V = 2 \times (8,808.71 + 85.346 + 0.266) = 17,788 \text{ dm}^3 \]

\[ = 17.8 \text{ tonf} \]
6. Reserve buoyancy

<table>
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<th>f(Aa)</th>
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<tr>
<td>5</td>
<td>1.05</td>
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\[ \Sigma = 445.525 \]

\[ Aa = f(Aa) \times \frac{S}{3} = 1485.083 \]

\[ Ab = \frac{E \times h^2}{2} = 0.2 \times 0.6 = 0.12 \]

\[ Ac = \frac{5 \times h^3}{2} = 0.525 \times 1.75 = 0.459 \]

Area sheer: \[ As = 2 (Aa + Ab + Ac) = 2971.205 \]

Area waterplane 4: \[ A4 = 2722.759 \text{ (cf. infra)} \]

Reserve Vol. \[ V = \left( \frac{(A4 + As)}{2} \right) \times 2 = 2722.7 + 2971.2 = 5694 \text{ dm}^3 = 5.7 \text{ ton} \]
7. Area of waterplane

<table>
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<tr>
<th>Body section</th>
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<th>f(Aa)</th>
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\[ \mathcal{S} = 165.06 \]

\[ Aa = f(Aa) \times \frac{S}{3} = 165.06 \times \frac{10}{3} = 550.2 \]

\[ Ab = 2 \times \frac{(Yd \times h2)}{2} = 2 \times \frac{(0.4 \times 4.2)}{2} = 0.84 \]

\[ Ac = 2 \times \frac{(Y4 \times h3)}{2} = 2 \times \frac{(0.75 \times 4.63)}{2} = 1.736 \]

Area = 2 (Aa + Ab + Ac) = 1105.552 dm²
8. Area of waterplane 2

<table>
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\[ \Sigma = 271.855 \]

\[ Aa = f(Aa) \times S = 271.855 \times 10 = 906.184 \]

\[ Ab = \left( \frac{Yd + Ydh \times S}{2} \right) + \left( \frac{Ydh \times h2}{2} \right) \]

\[ = \left( \frac{(1.12 + 0.4) \times 5}{2} \right) + \left( \frac{0.4 \times 1}{2} \right) = 4 \]

\[ Ac = \left( \frac{Y4 + Y4h \times S}{2} \right) + \left( \frac{Y4h \times h3}{2} \right) \]

\[ = \left( \frac{(1.85 + 0.74) \times 5}{2} \right) + \left( \frac{0.74 \times 2.63}{2} \right) = 7.448 \]

Area = 2 (Aa + Ab + Ac) = 1835.263 dm²
9. Area of waterplane 3

<table>
<thead>
<tr>
<th>Body section</th>
<th>Yi</th>
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<th>f(Aa)</th>
</tr>
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<td>15.83</td>
<td>3/2</td>
<td>23.745</td>
</tr>
<tr>
<td>2h</td>
<td>13.65</td>
<td>2</td>
<td>27.30</td>
</tr>
<tr>
<td>3</td>
<td>10.95</td>
<td>1</td>
<td>10.95</td>
</tr>
<tr>
<td>3h</td>
<td>7.06</td>
<td>2</td>
<td>14.12</td>
</tr>
<tr>
<td>4</td>
<td>3.9</td>
<td>1/2</td>
<td>1.95</td>
</tr>
</tbody>
</table>

\[ \Sigma = 339.73 \]

Aa = \( f(Aa) \times \frac{S}{3} = 339.73 \times \frac{10}{3} = 1132.434 \)

Ab = \( \left( \frac{Yd}{2} + \frac{Ydh \times S}{2} \right) + \left( \frac{Ydh \times h^2}{2} \right) \)
  \[ = \left[ \frac{(2.2 + 0.75) \times 5}{2} \right] + \left[ \frac{0.75 \times 2.2}{2} \right] = 8.2 \]

Ac = \( \left( \frac{Y4}{2} + \frac{Y4h \times S}{2} \right) + \left( \frac{Y4h \times h^3}{2} \right) \)
  \[ = \left[ \frac{(3.9 + 1.83) \times 5}{2} \right] + \left[ \frac{1.83 \times 4.3}{2} \right] = 18.259 \]

Area = 2 (Aa + Ab + Ac) = 2317.785 dm²
### 10. Area of waterplane 4

<table>
<thead>
<tr>
<th>Body section</th>
<th>$Y_1$</th>
<th>$\times$ Simpson's rule 1</th>
<th>$f(Aa)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>5.18</td>
<td>1/2</td>
<td>2.59</td>
</tr>
<tr>
<td>Ch</td>
<td>10.9</td>
<td>2</td>
<td>21.8</td>
</tr>
<tr>
<td>C</td>
<td>14.05</td>
<td>1</td>
<td>14.05</td>
</tr>
<tr>
<td>Bh</td>
<td>16.38</td>
<td>2</td>
<td>32.76</td>
</tr>
<tr>
<td>B</td>
<td>18.34</td>
<td>3/2</td>
<td>27.51</td>
</tr>
<tr>
<td>A</td>
<td>18.98</td>
<td>4</td>
<td>79.92</td>
</tr>
<tr>
<td>$\Phi$</td>
<td>20.35</td>
<td>2</td>
<td>40.70</td>
</tr>
<tr>
<td>I</td>
<td>19.4</td>
<td>4</td>
<td>77.6</td>
</tr>
<tr>
<td>2</td>
<td>17.65</td>
<td>3/2</td>
<td>26.475</td>
</tr>
<tr>
<td>2h</td>
<td>16.05</td>
<td>2</td>
<td>32.1</td>
</tr>
<tr>
<td>3</td>
<td>13.33</td>
<td>1</td>
<td>13.33</td>
</tr>
<tr>
<td>3h</td>
<td>10.05</td>
<td>2</td>
<td>20.1</td>
</tr>
<tr>
<td>4</td>
<td>6.4</td>
<td>1</td>
<td>6.4</td>
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<td>4h</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>1/2</td>
<td>0.25</td>
</tr>
</tbody>
</table>

$\Sigma = 401.58$

$$Aa = f(Aa) \times \frac{\Sigma}{3} = 401.58 \times \frac{10}{3} = 1338.612$$

$$Ab = \left[\frac{(5.18 + 2.07) \times 5}{2}\right] + \left[\frac{2.07 \times 4.3}{2}\right] = 22.575$$

$$Ac = \frac{0.5 \times 0.75}{2} = 0.376$$

Area = 2 ($Aa + Ab + Ac$)

= 2722.759 dm²
11. Vertical center of buoyancy up to waterplane 4

<table>
<thead>
<tr>
<th>Waterplanes</th>
<th>$A_i$</th>
<th>Simpson's rule 1</th>
<th>Moment-arm in dm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$A_1$</td>
<td>1105.552</td>
<td>4</td>
<td>4422.208</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11055.52</td>
</tr>
<tr>
<td>$A_2$</td>
<td>1835.263</td>
<td>2</td>
<td>3670.526</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18352.63</td>
</tr>
<tr>
<td>$A_3$</td>
<td>2317.785</td>
<td>4</td>
<td>9271.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>69533.55</td>
</tr>
<tr>
<td>$A_4$</td>
<td>2722.759</td>
<td>1</td>
<td>2722.759</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27227.59</td>
</tr>
</tbody>
</table>

$\bar{X} = 20086.633$  $\bar{X} = 126169.29$

$\text{VCB} = \frac{f(M)}{f(V)} = \frac{126,169.29}{20,086.633} = 6.3 \text{ dm above baseline}$
12. Longitudinal center of buoyancy at waterplane 1

<table>
<thead>
<tr>
<th>Body section</th>
<th>( f(V1) \times \text{Moment-arm in dm} )</th>
<th>( f(M) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>0.48 \times 40</td>
<td>19.2</td>
</tr>
<tr>
<td>Ch</td>
<td>3.322 \times 35</td>
<td>116.27</td>
</tr>
<tr>
<td>C</td>
<td>2.852 \times 30</td>
<td>85.56</td>
</tr>
<tr>
<td>Bh</td>
<td>9.63 \times 25</td>
<td>240.75</td>
</tr>
<tr>
<td>B</td>
<td>10.503 \times 20</td>
<td>210.06</td>
</tr>
<tr>
<td>A</td>
<td>75.996 \times 10</td>
<td>759.96</td>
</tr>
<tr>
<td>h0</td>
<td>44.04 \times 0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>73.688 \times 10</td>
<td>736.88</td>
</tr>
<tr>
<td>2</td>
<td>14.931 \times 20</td>
<td>298.62</td>
</tr>
<tr>
<td>2h</td>
<td>12.28 \times 25</td>
<td>307</td>
</tr>
<tr>
<td>3</td>
<td>3.331 \times 30</td>
<td>99.93</td>
</tr>
<tr>
<td>3h</td>
<td>4.106 \times 35</td>
<td>143.71</td>
</tr>
<tr>
<td>4</td>
<td>0.566 \times 40</td>
<td>22.64</td>
</tr>
</tbody>
</table>

\[ \Sigma = 255.725 \quad \Sigma = 176.98 \]

**LCB1** for \( V1 = f(M) = \frac{176.98}{255.725} = 0.692 \)

**LCB2** for \( V2 = -\left( \frac{h3}{3} + 4S \right) = -\left( \frac{4.2}{3} + 40 \right) = -41.4 \)

**LCB3** for \( V3 = \frac{h3}{3} + 4S = 4.63 + 40 = 41.543 \)

**LCB** = \( \frac{V1 \times (LCB1) + V2 \times (LCB2) + V3 \times (LCB3) \times 2}{V \text{ up to waterplane 1}} \)

\[ = \frac{(852.417 \times 0.692) - (2.016 \times 41.4) + (2.618 \times 41.543) \times 2}{1,741} \]

\[ = 0.72 \text{ dm aft of amidships} \]
13. Longitudinal center of buoyancy at waterplane 2

<table>
<thead>
<tr>
<th>Body section</th>
<th>f(V1) x Moment-arm in dm</th>
<th>f(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>1.82 - 40</td>
<td>72.8</td>
</tr>
<tr>
<td>Ch</td>
<td>14.886 - 35</td>
<td>521.01</td>
</tr>
<tr>
<td>C</td>
<td>14.518 - 30</td>
<td>435.54</td>
</tr>
<tr>
<td>Bh</td>
<td>48.922 - 25</td>
<td>1223.05</td>
</tr>
<tr>
<td>B</td>
<td>54.464 - 20</td>
<td>1089.28</td>
</tr>
<tr>
<td>A</td>
<td>224.504 - 10</td>
<td>2245.04</td>
</tr>
<tr>
<td>0</td>
<td>121.66 0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>218.576 10</td>
<td>2185.76</td>
</tr>
<tr>
<td>2</td>
<td>56.860 20</td>
<td>1137.2</td>
</tr>
<tr>
<td>2h</td>
<td>53.26 25</td>
<td>1331.5</td>
</tr>
<tr>
<td>3</td>
<td>15.734 30</td>
<td>472.02</td>
</tr>
<tr>
<td>3h</td>
<td>18.812 35</td>
<td>658.42</td>
</tr>
<tr>
<td>4</td>
<td>2.651 40</td>
<td>106.04</td>
</tr>
</tbody>
</table>

\[ \Sigma = 845.357 \quad \Sigma = 304.22 \]

LCB1 for \( V1 = \frac{f(M)}{f(V1)} = \frac{304.22}{845.357} = 0.36 \)

LCB2a for \( V2a = -\left[ \frac{1}{2} \times \frac{S}{2} + 4S \right] = -\left( \frac{1.667 + 40}{2} \right) = -41.667 \)

LCB2b for \( V2b = -\left( \frac{h^2}{3} + 4.5S \right) = -\left( \frac{0.333 + 45}{3} \right) = -45.333 \)

LCB3a for \( V3a = \left( \frac{1}{2} \times \frac{S}{2} \right) + 4S = 41.667 \)

LCB3b for \( V3b = \frac{h^3}{3} + 4.5S = 45.877 \)

\[ \text{LCB} = V1(LCB1) + V2a(LCB2a) + V2b(LCB2b) + V3a(LCB3a) + V3b(LCB3b) \]

\[ = 0.44 \text{ dm aft of amidships} \]
14. Longitudinal center of buoyancy at waterplane 3

<table>
<thead>
<tr>
<th>Body section</th>
<th>( f(V_1) \times \text{Moment-arm in dm} )</th>
<th>( f(M) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>4.285 (-40)</td>
<td>171.4</td>
</tr>
<tr>
<td>Ch</td>
<td>39.792 (-35)</td>
<td>1392.72</td>
</tr>
<tr>
<td>C</td>
<td>39.15 (-30)</td>
<td>1174.5</td>
</tr>
<tr>
<td>Bh</td>
<td>114.818 (-25)</td>
<td>2870.45</td>
</tr>
<tr>
<td>B</td>
<td>113.626 (-20)</td>
<td>2272.52</td>
</tr>
<tr>
<td>A</td>
<td>404.712 (-10)</td>
<td>4047.12</td>
</tr>
<tr>
<td>B0</td>
<td>213.402 (0)</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>395.004 (10)</td>
<td>3950.04</td>
</tr>
<tr>
<td>2</td>
<td>113.476 (20)</td>
<td>2269.52</td>
</tr>
<tr>
<td>2h</td>
<td>116.294 (25)</td>
<td>2907.35</td>
</tr>
<tr>
<td>3</td>
<td>39.85 (30)</td>
<td>1195.5</td>
</tr>
<tr>
<td>3h</td>
<td>47.806 (35)</td>
<td>1673.21</td>
</tr>
<tr>
<td>4</td>
<td>6.821 (40)</td>
<td>272.84</td>
</tr>
</tbody>
</table>

\[ \Xi = 1,694.036 \quad \Xi = 339.75 \]

\(\text{LCB1 for } V_1 = \frac{f(M)}{f(V_1)} = 0.206\)

\(\text{LCB2a for } V_2a = -41.667\)
\(\text{LCB2b for } V_2b = -45.733\)
\(\text{LCB3a for } V_3a = 41.667\)
\(\text{LCB3b for } V_3b = 46.433\)

\[ \text{LCB} = \frac{V_1(\text{LCB1}) + V_2a(\text{LCB2a}) + V_2b(\text{LCB2b}) + V_3a(\text{LCB3a}) + V_3b(\text{LCB3b})}{V \text{ up to waterplane 3}} \]

\[ = 0.43 \text{ dm aft of amidships} \]
15. Longitudinal center of buoyancy at waterplane 4

<table>
<thead>
<tr>
<th>Body section</th>
<th>f(VI)</th>
<th>Moment-arm in dm</th>
<th>f(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>9.768</td>
<td>-40</td>
<td>-390.72</td>
</tr>
<tr>
<td>Ch</td>
<td>92.283</td>
<td>-35</td>
<td>-3229.905</td>
</tr>
<tr>
<td>C</td>
<td>72.746</td>
<td>-30</td>
<td>-2182.38</td>
</tr>
<tr>
<td>Bh</td>
<td>194.145</td>
<td>-25</td>
<td>-4533.625</td>
</tr>
<tr>
<td>B</td>
<td>182.1</td>
<td>-20</td>
<td>-3642</td>
</tr>
<tr>
<td>A</td>
<td>601.16</td>
<td>-10</td>
<td>-6011.6</td>
</tr>
<tr>
<td>B</td>
<td>312.98</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>587.792</td>
<td>10</td>
<td>5877.92</td>
</tr>
<tr>
<td>2</td>
<td>178.084</td>
<td>20</td>
<td>3561.68</td>
</tr>
<tr>
<td>2h</td>
<td>192.778</td>
<td>25</td>
<td>4819.45</td>
</tr>
<tr>
<td>3</td>
<td>71.339</td>
<td>30</td>
<td>2140.17</td>
</tr>
<tr>
<td>3h</td>
<td>93.546</td>
<td>35</td>
<td>3274.11</td>
</tr>
<tr>
<td>4</td>
<td>27.895</td>
<td>40</td>
<td>1115.8</td>
</tr>
<tr>
<td>4h</td>
<td>25.642</td>
<td>45</td>
<td>1153.89</td>
</tr>
<tr>
<td>5</td>
<td>0.355</td>
<td>50</td>
<td>17.75</td>
</tr>
</tbody>
</table>

∑ = 2642.613

LCB1 for VI = \( \frac{f(M)}{f(VI)} = \frac{1970.54}{2642.613} = 0.746 \)

LCB2a for V2a = -41.667
LCB2b for V2b = -46.433
LCB3 for V3 = 50.25

LCB = \( \frac{V1(LCB1)+V2a(LCB2a)+V2b(LCB2b)+V3a(LCB3a)+V3b(LCB3b)}{V} \) up to waterplane 4

= 0.33 dm aft of amidships
16. Vertical center of gravity of total vessel

<table>
<thead>
<tr>
<th>Body section</th>
<th>Half girth</th>
<th>Simpson’s = ( f(A1))</th>
<th>VCG estimate = ( f(M1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>28.8</td>
<td>1/2</td>
<td>14.4</td>
</tr>
<tr>
<td>Dh</td>
<td>42.2</td>
<td>2</td>
<td>84.4</td>
</tr>
<tr>
<td>D</td>
<td>45.2</td>
<td>1</td>
<td>45.2</td>
</tr>
<tr>
<td>Ch</td>
<td>46.8</td>
<td>2</td>
<td>93.6</td>
</tr>
<tr>
<td>C</td>
<td>47.4</td>
<td>1</td>
<td>47.4</td>
</tr>
<tr>
<td>Bh</td>
<td>50.2</td>
<td>2</td>
<td>100.4</td>
</tr>
<tr>
<td>B</td>
<td>52.6</td>
<td>3/2</td>
<td>78.9</td>
</tr>
<tr>
<td>A</td>
<td>55.2</td>
<td>4</td>
<td>220.8</td>
</tr>
<tr>
<td>B</td>
<td>55.6</td>
<td>2</td>
<td>111.2</td>
</tr>
<tr>
<td>l</td>
<td>53.6</td>
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<td>213.6</td>
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<tr>
<td>2</td>
<td>49.6</td>
<td>3/2</td>
<td>74.4</td>
</tr>
<tr>
<td>2h</td>
<td>46.6</td>
<td>2</td>
<td>93.2</td>
</tr>
<tr>
<td>3</td>
<td>42.2</td>
<td>1</td>
<td>42.2</td>
</tr>
<tr>
<td>3h</td>
<td>41</td>
<td>2</td>
<td>82</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td>4h</td>
<td>34.4</td>
<td>2</td>
<td>68.8</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>1/2</td>
<td>11.5</td>
</tr>
</tbody>
</table>

\[ \Sigma = 1418 \quad \Sigma = 10517.49 \]

\[ A_2 = 105 \quad M_2 = 2 \times \left[ \frac{(10 \times 10.5)}{2} \times 19 \right] = 1995 \]

\[ A_3 = 74.75 \quad M_3 = 2 \times \left[ \frac{(6.5 \times 11.5)}{2} \times 15 \right] = 1121.25 \]

\[ \text{VCG shell} = f(M1) + M_2 + M_3 = 10,517.49 + 1995 + 1121.25 \]

\[ \text{area} = \frac{f(A1) + A_2 + A_3}{1,418 + 105} \]

\[ = 8.53 \text{ cm} \]
Area planking = \( \left( \sum f[A1] \times 2S \right) \div 3 + A2 + A3 \)
\[ = \left( 1418 \times 20 \right) \div 3 + 105 + 74.75 = 9633 \text{ dm}^2 \]

Volume planking = area \times \text{average thickness}
\[ = 9633 \times 0.31 = 2986 \text{ dm}^3 \]

Volume frames = 9633 \times 0.5 (estimated average molded dimension over area planking)
\[ = 4816.5 \text{ dm}^3 \]

Volume shell = volume planking + frames
\[ = 2986 + 4816.5 = 7802.5 \text{ dm}^3 \]

Weight shell = volume \times \gamma (\gamma \text{ wet oak} = 0.90 \text{ kgf/dm}^3)
\[ \text{(Metz p.10)} \]
\[ = 7802.5 \times 0.90 = 7022 \text{ kgf} \]

*Bipod mast area cross section = (1.2)^2 \times 3.14 = 4.52 \text{ dm}^2

height = 60 \text{ dm}

volume = 60 \times 4.52 = 271.32 \text{ dm}^3

Two masts volume = 542.64 \text{ dm}^3 (\gamma \text{ dry oak} = 0.85 \text{ kgf/dm}^3)

weight = 542.64 \times 0.85 = 461 \text{ kgf}

*Sail hemp canvas area = 25 \text{ m}^2 \ (\text{cf. Landstrom p. 75})

weight = 25 \text{ kgf} \ (\text{cf. Harland p. 29})

*Mast, sail, yard, ropes, and tackle weight = 520 \text{ kgf}

If cargo consists of bricks, weight = 4 \text{ kgf}

volume = 2.8 \times 1.3 \times 0.65 \text{ dm}^3
\[ \text{(volume bricks M107)} \]

then 9,200 tonf = 2300 bricks = 5441.8 \text{ dm}^3 \text{ volume}

area ceiling floor = 690 \text{ dm}^2

height = 7.9 \text{ dm}

VCG = 4 \text{ dm above baseline}
<table>
<thead>
<tr>
<th>Item</th>
<th>Weight in kgf</th>
<th>VCG estimate</th>
<th>Moment in kgf dm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>7.022</td>
<td>8.53</td>
<td>59.898</td>
</tr>
<tr>
<td>Protruding keel: shoe: hor. hooks</td>
<td>17</td>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td>Protr. stem: vert. bow hook: outer post</td>
<td>28</td>
<td>11</td>
<td>298</td>
</tr>
<tr>
<td>*Sternpost: vert. stern hook</td>
<td>46</td>
<td>11</td>
<td>506</td>
</tr>
<tr>
<td>*Rudder and tiller</td>
<td>40</td>
<td>13</td>
<td>620</td>
</tr>
<tr>
<td>*Ceiling area</td>
<td>40</td>
<td>3.5</td>
<td>140</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>23</td>
<td>3</td>
<td>69</td>
</tr>
<tr>
<td>Two &quot;mast blocks&quot;</td>
<td>110</td>
<td>5</td>
<td>550</td>
</tr>
<tr>
<td>*Bipod mast: yard: sail: ropes: tackle:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lifting devices</td>
<td>520</td>
<td>40</td>
<td>20.800</td>
</tr>
<tr>
<td>*Four deck beams</td>
<td>164</td>
<td>15</td>
<td>2.460</td>
</tr>
<tr>
<td>*Two half decks</td>
<td>120</td>
<td>10</td>
<td>1.200</td>
</tr>
<tr>
<td>*Three crew: supplies</td>
<td>270</td>
<td>5</td>
<td>1.350</td>
</tr>
<tr>
<td>Cargo in ceiling area</td>
<td>9.200</td>
<td>4</td>
<td>36.800</td>
</tr>
<tr>
<td>Two iron anchors: chains</td>
<td>200</td>
<td>6</td>
<td>1.200</td>
</tr>
</tbody>
</table>

$$\Sigma = 17.800 \quad \Sigma = 125.896$$

VCG loaded vessel = $$\frac{M}{W} = \frac{125.896}{17.800} = 7$$ dm above baseline
17. Longitudinal center of gravity at midship sheer height

<table>
<thead>
<tr>
<th>Body section</th>
<th>f(A1)</th>
<th>x</th>
<th>Moment-arm</th>
<th>= f(M1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>14.4</td>
<td>-50</td>
<td>720</td>
<td></td>
</tr>
<tr>
<td>Dh</td>
<td>84.4</td>
<td>-45</td>
<td>3798</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>45.2</td>
<td>-40</td>
<td>1808</td>
<td></td>
</tr>
<tr>
<td>Ch</td>
<td>93.6</td>
<td>-35</td>
<td>3276</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>47.4</td>
<td>-30</td>
<td>1422</td>
<td></td>
</tr>
<tr>
<td>Bb</td>
<td>100.4</td>
<td>-25</td>
<td>2510</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>78.9</td>
<td>-20</td>
<td>1578</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>220.8</td>
<td>-10</td>
<td>2208</td>
<td></td>
</tr>
<tr>
<td>@</td>
<td>111.2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>213.6</td>
<td>10</td>
<td>2136</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>74.4</td>
<td>20</td>
<td>1488</td>
<td></td>
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<tr>
<td>2h</td>
<td>93.2</td>
<td>25</td>
<td>2330</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>42.2</td>
<td>30</td>
<td>1266</td>
<td></td>
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<tr>
<td>3h</td>
<td>82</td>
<td>35</td>
<td>2870</td>
<td></td>
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<tr>
<td>4</td>
<td>36</td>
<td>40</td>
<td>1440</td>
<td></td>
</tr>
<tr>
<td>4h</td>
<td>68.8</td>
<td>45</td>
<td>3096</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>11.5</td>
<td>50</td>
<td>575</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Sigma = 1418 \quad \Sigma = -2119 \]

\[ M_2 = \frac{(10 \times 28.8) \times (-53)}{2} = -7632 \]

\[ M_3 = \frac{(6.5 \times 23) \times 51.5}{2} = 3849.625 \]

\[ LCG \ shell = \frac{f(M1) + M2 + M3}{area} = \frac{-2119 - 7632 + 3849.625}{1418 + 105 + 74.75} = 3.7 \text{ dm fore of 0} \]
<table>
<thead>
<tr>
<th>Item</th>
<th>Weight in kgf</th>
<th>LCG estimate</th>
<th>Moment in kgf dm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>7.022</td>
<td>-3.7</td>
<td>-25.981</td>
</tr>
<tr>
<td>Protruding keel: shoe: hor. hooks</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Protr. stem: vert. bow hook: outer post</td>
<td>28</td>
<td>-51.5</td>
<td>-1.442</td>
</tr>
<tr>
<td>*Stern post: vert. stern hook</td>
<td>46</td>
<td>50</td>
<td>2.300</td>
</tr>
<tr>
<td>*Rudder and tiller</td>
<td>40</td>
<td>53.5</td>
<td>2.140</td>
</tr>
<tr>
<td>*Ceiling area</td>
<td>40</td>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>23</td>
<td>-4</td>
<td>-92</td>
</tr>
<tr>
<td>Two &quot;mast blocks&quot;</td>
<td>110</td>
<td>-5</td>
<td>-550</td>
</tr>
<tr>
<td>*Bipod mast: yard: sail: ropes: tackle:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lifting devices</td>
<td>520</td>
<td>-5</td>
<td>2.600</td>
</tr>
<tr>
<td>*Four deck beams</td>
<td>164</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>*Two half decks</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>*Three crew: supplies</td>
<td>270</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cargo in ceiling area</td>
<td>9.200</td>
<td>4</td>
<td>36.800</td>
</tr>
<tr>
<td>Two iron anchors: chains</td>
<td>200</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[
\Sigma = 17.800 \quad \quad \quad \Sigma = 15.935
\]

LCG loaded vessel = \[ M = \frac{15.935}{17.800} = 0.9 \text{ dm aft of amidships} \]
9.2 tonf cargo \[ W = 17.800 \]

LCG unloaded vessel = \[ -\frac{20.865}{8.600} = 2.4 \text{ dm fore of amidships} \]
0 tonf cargo \[ 8.600 \]
18. Longitudinal center of flotation of waterplane 4

<table>
<thead>
<tr>
<th>Body section</th>
<th>f(A1)</th>
<th>x Moment-arm</th>
<th>= f(M1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.59</td>
<td>-40</td>
<td>-103.6</td>
</tr>
<tr>
<td>Ch</td>
<td>21.8</td>
<td>-35</td>
<td>-763</td>
</tr>
<tr>
<td>C</td>
<td>14.05</td>
<td>-30</td>
<td>-421.5</td>
</tr>
<tr>
<td>Bk</td>
<td>32.76</td>
<td>-25</td>
<td>-819</td>
</tr>
<tr>
<td>B</td>
<td>27.51</td>
<td>-20</td>
<td>-550.2</td>
</tr>
<tr>
<td>A</td>
<td>79.92</td>
<td>-10</td>
<td>-799.2</td>
</tr>
<tr>
<td>B</td>
<td>40.70</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>77.6</td>
<td>10</td>
<td>776</td>
</tr>
<tr>
<td>2</td>
<td>26.475</td>
<td>20</td>
<td>529.5</td>
</tr>
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<td>2h</td>
<td>32.1</td>
<td>25</td>
<td>802.5</td>
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<td>30</td>
<td>399.9</td>
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<td>20.1</td>
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<td>703.5</td>
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<td>4h</td>
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<td>270</td>
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<tr>
<td>5</td>
<td>0.25</td>
<td>50</td>
<td>12.5</td>
</tr>
</tbody>
</table>

\[ \sum = 401.58 \quad \sum = 293.4 \]

LCF(1) for A1 = \( \frac{\sum f(M1)}{\sum f(A1)} = 0.731 \)

LCF(2) for A2a = -41.667

LCF(2b) for A2b = -46.433

LCF(3) for A3 = 50.25

\[ LCF = A1(LCF[1]) + A2a(LCF[2a]) + A2b(LCF[2b]) + A3(LCF[3]) \]

\[ = \frac{(1338.6 \times 0.73) - (18.12 \times 41.67) - (4.45 \times 46.43) + (0.19 \times 50.25)}{1361.38} \]

\[ = \frac{26.135}{1361.38} = 0.02 \text{ dm aft of amidships} \]
19. Transverse moment of inertia of waterplane 4

<table>
<thead>
<tr>
<th>Body section</th>
<th>Y1</th>
<th>Y1^3</th>
<th>x</th>
<th>Simpson’s rule</th>
<th>f(11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>5.18</td>
<td>138.992</td>
<td>1/2</td>
<td></td>
<td>69.496</td>
</tr>
<tr>
<td>Ch</td>
<td>10.9</td>
<td>1295.029</td>
<td>2</td>
<td></td>
<td>2590.058</td>
</tr>
<tr>
<td>C</td>
<td>14.05</td>
<td>2773.505</td>
<td>1</td>
<td></td>
<td>2773.505</td>
</tr>
<tr>
<td>Bh</td>
<td>16.38</td>
<td>4394.826</td>
<td>2</td>
<td></td>
<td>8789.652</td>
</tr>
<tr>
<td>B</td>
<td>18.34</td>
<td>6168.762</td>
<td>3/2</td>
<td></td>
<td>9253.142</td>
</tr>
<tr>
<td>A</td>
<td>19.98</td>
<td>7976.024</td>
<td>4</td>
<td></td>
<td>31904.095</td>
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<tr>
<td>H</td>
<td>20.35</td>
<td>8427.393</td>
<td>2</td>
<td></td>
<td>16854.785</td>
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<tr>
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<td>7301.384</td>
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<td>29205.536</td>
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<tr>
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<td>5498.372</td>
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<td>8247.558</td>
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<tr>
<td>2h</td>
<td>16.05</td>
<td>4134.52</td>
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<tr>
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<td>13.33</td>
<td>2368.593</td>
<td>1</td>
<td></td>
<td>2368.593</td>
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<tr>
<td>3h</td>
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<td>4</td>
<td>6.4</td>
<td>262.144</td>
<td>1</td>
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<td>262.144</td>
</tr>
<tr>
<td>4h</td>
<td>3</td>
<td>27</td>
<td>2</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>0.125</td>
<td>1/2</td>
<td></td>
<td>0.062</td>
</tr>
</tbody>
</table>

Σ = 122671.79

\[ I = 2 \times 11 + 2 \times 12a + 2 \times 12b + 2 \times 13 \]

2 11 = \frac{2}{3} \left[ \frac{5}{3} \sum f(11) \right] = \frac{25}{9} \times 122,671.79 = 272,604

2 12a = 2 \left[ \left( \frac{Yd + Ydh}{2} \right)^3 \times dx \right] = 2 \left[ \left( \frac{5.18 + 2.07}{2} \right)^3 \times 5 \right] = 476.44

2 12b = 2(Ydh^2 \times dA) = 2(2.07^2 \times 4.45) = 38.136

2 13 = 2(Y_5^2 \times dA) = 2(0.5^2 \times 0.188) = 0.094

I = 272,604 + 476.44 + 38.14 + 0.09 = 273,119 dm^4 = 27.3 m^4
20. Metacentric height

\[ \bar{GM} = \bar{K}\bar{M} - \bar{K}\bar{G} = \bar{K}\bar{B} + \bar{B}\bar{M} - \bar{K}\bar{G} = \frac{VCB + \frac{I}{V} - VCG}{V} \]

\[ = 6.3 + \frac{273.119}{17,800} - 7 \]

\[ = 14.6 \text{ cm} \]

\[ = 1.46 \text{ m} \]

\[ \bar{K}M = \bar{K}G + \bar{G}M = 7 + 14.6 = 21.6 \text{ cm} = 2.16 \text{ m} \]
21. Transverse stability

Heeling moment = righting moment = $\Delta \overline{GZ}$

\[
\overline{GZ} = \overline{GM} \sin \phi
\]

\[
\max. \sin \phi = \frac{h}{b/2} = \frac{2}{21} = 0.0095
\]

\[
\phi \approx 0.0095 \text{ radians} = 5.4^\circ
\]

\[
\max. \overline{GZ} \approx 14.6 \times 0.095
\]

\[
\approx 1.39 \text{ dm} = 0.14 \text{ m}
\]

\[
\max. \Delta \overline{GZ} = 17.8 \times 0.14 \text{ tonf m}
\]

\[
= 2.5 \text{ tonf m}
\]

\[
= 24,518 \text{ N m}
\]

Maximum heeling moment = maximum wind force $F_w$

\[
\Delta \overline{GZ} = dF_w \quad \text{whereby } d = \text{vertical distance from } 1/2 \text{ height of hull to } 1/2 \text{ height of sail}
\]

\[
\max. F_w = \frac{\Delta \overline{GZ}}{d}
\]

\[
= \frac{24,518 \text{ N m}}{3 \text{ m}} = 8,173 \text{ N} = 1,837 \text{ lbf}
\]

Maximum wind velocity $V_w$ the vessel can take laterally
if $c$. 1/2 of sail area is exposed to wind force:

\[
F_w = V_w^2 \times A_p \times \frac{\rho_a}{2} \times \frac{1}{2} \times C_l
\]

whereby $A_p = \text{projected sail area in ft}^2$

\[
\rho_a = \text{air density}
\]

\[
C_l = \text{part of total wind force acting on the vessel's hull}
\]

(values: cf. Comstock ed. p. 316)

\[
F_w = V_w^2 \times 125 \times 0.002377 \times 0.4
\]

\[
1,837 = V_w^2 \times 0.1
\]

\[
V_w = 1,837 = 18,370 \text{ (ft/sec)}^2
\]

\[
0.1
\]

\[
V_w = 135.5 \text{ ft/sec} = 80 \text{ knots}
\]
### 22. Longitudinal moment of inertia \( I_l \) around midship frame of waterplane 4

<table>
<thead>
<tr>
<th>Body sections</th>
<th>( Y_l \times ) Simpson's rule 1</th>
<th>( f(Y_l) \times )Moment-arm(^2)</th>
<th>( F(I_l) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>5.18 ( \times ) 1/2</td>
<td>2.59 ( \times ) 1600</td>
<td>4144</td>
</tr>
<tr>
<td>Ch</td>
<td>10.9 ( \times ) 2</td>
<td>21.8 ( \times ) 1225</td>
<td>26705</td>
</tr>
<tr>
<td>C</td>
<td>14.05 ( \times ) 1</td>
<td>14.05 ( \times ) 900</td>
<td>12645</td>
</tr>
<tr>
<td>Bh</td>
<td>16.38 ( \times ) 2</td>
<td>32.76 ( \times ) 625</td>
<td>20475</td>
</tr>
<tr>
<td>B</td>
<td>18.34 ( \times ) 3/2</td>
<td>27.51 ( \times ) 400</td>
<td>11004</td>
</tr>
<tr>
<td>A</td>
<td>19.98 ( \times ) 4</td>
<td>79.92 ( \times ) 100</td>
<td>7992</td>
</tr>
<tr>
<td>B</td>
<td>20.35 ( \times ) 2</td>
<td>40.70 ( \times ) 0</td>
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<td>77.6 ( \times ) 100</td>
<td>7760</td>
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<td>26.475 ( \times ) 400</td>
<td>10590</td>
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<td>16.05 ( \times ) 2</td>
<td>32.10 ( \times ) 625</td>
<td>20062.5</td>
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<td>13.33 ( \times ) 1</td>
<td>13.33 ( \times ) 900</td>
<td>11997</td>
</tr>
<tr>
<td>3h</td>
<td>10.05 ( \times ) 2</td>
<td>20.10 ( \times ) 1225</td>
<td>24622.5</td>
</tr>
<tr>
<td>4</td>
<td>6.4 ( \times ) 1</td>
<td>6.4 ( \times ) 1600</td>
<td>10240</td>
</tr>
<tr>
<td>4h</td>
<td>3 ( \times ) 2</td>
<td>6 ( \times ) 2025</td>
<td>12150</td>
</tr>
<tr>
<td>5</td>
<td>0.5 ( \times ) 1/2</td>
<td>0.25 ( \times ) 2500</td>
<td>625</td>
</tr>
</tbody>
</table>

\[ \Sigma = 181012 \]

\[
2 I_{ll} = 2 \sum f(I_l) \times \frac{1}{3} S = 181,012 \times \frac{20}{3} = 1,206,746.6
\]

\[
2 I_{12a} = 2 \left[ \frac{(Y_d + Y_{dh}) \times S}{2} \right] \times (-40)^2 = 2 \left[ \frac{(5.18 + 2.07) \times 5}{2} \right] \times 1600 = 58,000
\]

\[
2 I_{12b} = 2 \left( x^2 dA \right) = 2 \left( 2025 \times 4.450 \right) = 18,022.5
\]

\[
2 I_{13} = 2 \left( x^2 dA \right) = 2 \left( 2500 \times 0.188 \right) = 940
\]

\[ I_l = 2 I_{ll} + 2 I_{12a} + 2 I_{12b} + 2 I_{13} \]

\[ = 1,283,709 \text{ dm}^4 = 128.371 \text{ m}^4 \]
23. Longitudinal stability

Moment to change trim = MCT

\[ MCT = \Delta GZ1 = \Delta x \]
\[ x = LCG - LCB \]
\[ = 0.6 - 0.33 \text{ dm} \]
\[ = 0.57 \text{ dm} \]
\[ = 17.800 \times 0.57 \]
\[ = 10.146 \text{ kgf dm} \]
\[ = 1.0146 \text{ tonf m} \]
\[ = 9.950 \text{ N m} \]

One-meter-trim moment = MCT\text{l}m

\[ MCT\text{l}m = \frac{\Delta BM}{LPP} = \frac{\Delta GM}{LPP} = \frac{\Delta l}{LPP} \text{ whereby } l = 128.371 \text{ m}^4 \]
\[ \text{LPP} \quad \text{LPP} \quad \text{LPP} \quad \text{LDD} = 10 \quad \text{m} \]
\[ = \frac{128.371}{10} \]
\[ = 12.837 \text{ tonf m} \]
\[ = 125.892 \text{ N m} \]

Initial trim aft and fore if 9.2 ton cargo in ceiling area

\[ x = \frac{\Delta GM}{\text{sin } \phi} \]
\[ \text{sin } \phi = \frac{x}{\frac{\Delta GM}{l}} = \frac{x}{128.371} = 0.057 = 0.0079 \]
\[ \frac{V}{17.8} \]
\[ = 0.0079 \text{ radians } = 0.45^\circ \]

Additional trim aft \( a = \text{sin } \phi \times C \)
\[ a = 0.0079 \times 50.9 = 0.4 \text{ dm} \]

Less trim fore \( f = 0.0079 \times 48.5 = 0.38 \text{ dm} \)
Maximum trim moments if initial trim aft = 0.4 dm

\[ MCT = \Delta GZ = \Delta GM \sin \phi = \frac{\Delta I_{11}}{V} \sin \phi = I_{11} \sin \phi \]

max. angle aft: \( \sin \phi_{\text{aft}} = \frac{6.4}{54.3} = 0.117 \)

max. angle fore: \( \sin \phi_{\text{f}} = \frac{8.7}{55.7} = 0.156 \)

max. trim moment aft: \( 128.371 \times 0.117 = 15 \) tonf m

max. trim moment fore: \( 128.371 \times 0.156 = 20 \) tonf m

Maximum trim moment = maximum wind force \( F_w \)

\[ \Delta GZ = dF_w \]

aft: \( F_w = \frac{\Delta GZ}{d} = \frac{20}{3} = 6.67 \) tonf = 65,413 N = 14,705 lbf

fore: \( F_w = \frac{15}{3} = 5 \) tonf = 49,035 N = 11,023 lbf

Maximum wind velocity \( V_w \) the vessel can take aft and fore if 250 sq.ft. of sail area is exposed to wind force:

\[ F_w = (V_w - V_s)^2 \times A_p \times \sigma_a \times \frac{1}{2} C_l \]

whereby \( V_s \) = ship speed

\[ (V_w - V_s)^2 = \frac{F_w}{250 \times 0.002377 \times 0.4} = \frac{F_w}{0.238} \]

aft: \( (V_w - V_s)^2 = \frac{14,705}{0.238} = 61,785 (\text{ft/sec})^2 \)

\( V_w - V_s = 248 \) ft/sec

\( = 147 \) knots

fore: \( (V_w - V_s)^2 = \frac{11,023}{0.238} = 46,315 (\text{ft/sec})^2 \)

\( V_w - V_s = 215 \) ft/sec

\( = 127 \) knots
24. Roll and pitch motions

Calculated as free motions in calm water without damping

**Roll motion:**

Frequency $\omega_R = \sqrt{\frac{AGM}{l}} = \sqrt{\frac{AGM}{m(b^2)}} = \sqrt{\frac{AGM}{b^4}}$

$$= \sqrt{\frac{9.807 \times 1.46}{(4.13)^2}} = \sqrt{13.38} = 3.66 \text{ radians/sec}$$

Period $T_R = \frac{2\pi}{\omega_R} = \frac{6.28}{3.66} = 1.72 \text{ seconds}$

**Pitch motion:**

Frequency $\omega_P = \sqrt{\frac{AGM}{(L/4)^2}}$ whereby $\frac{GMl}{V} = \frac{11}{17.8} = 0.617$

$$= \sqrt{\frac{9.807 \times 7.212}{(10/4)^2}} = \sqrt{11.316} = 3.36 \text{ radians/sec}$$

Period $T_P = \frac{2\pi}{\omega_P} = \frac{6.28}{3.36} = 1.87 \text{ seconds}$
### 25. Wetted surface area up to waterline 4

<table>
<thead>
<tr>
<th>Body station</th>
<th>Arc length in dm</th>
<th>× Simpson’s rule 1</th>
<th>= f(A1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>2.4</td>
<td>1/2</td>
<td>1.2</td>
</tr>
<tr>
<td>Dh</td>
<td>27.5</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td>D</td>
<td>31</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>Ch</td>
<td>34.5</td>
<td>2</td>
<td>69</td>
</tr>
<tr>
<td>C</td>
<td>38</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>Bh</td>
<td>41.5</td>
<td>2</td>
<td>83</td>
</tr>
<tr>
<td>B</td>
<td>45</td>
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<td>67.5</td>
</tr>
<tr>
<td>A</td>
<td>50</td>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>@</td>
<td>53.6</td>
<td>2</td>
<td>107.2</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>4</td>
<td>200</td>
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<td>2</td>
<td>44.6</td>
<td>3/2</td>
<td>66.9</td>
</tr>
<tr>
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<td>81.3</td>
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<td>36.7</td>
</tr>
<tr>
<td>3h</td>
<td>31.2</td>
<td>2</td>
<td>62.4</td>
</tr>
<tr>
<td>4</td>
<td>25.7</td>
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<td>20</td>
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<td>40</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>1/2</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ \sum = 1166.9 \]

\[ A1 = \frac{f(A1) \times S}{3} = \frac{1166.9 \times 10}{3} = 3889.667 \]

\[ A2 = 2 \left( \frac{0.6 \times 0.8}{2} \right) + (1.1 \times 0.4) = 0.92 \]

\[ A3 = 2 \left( \frac{0.7 \times 1.3}{2} \right) + (1.6 \times 1.0) = 2.51 \]

\[ A_w = A1 + A2 + A3 = 3893.097 \text{ dm}^2 = 419 \text{ sq.ft.} \]
26. Total resistance \( R_t \) at ship speed \( V_s = 1 \) to 10 knots

<table>
<thead>
<tr>
<th>( V_s ) kts ft/sec</th>
<th>( R = \frac{V_L}{V} )</th>
<th>( C_F \times 1 \frac{\rho}{2} \times \frac{1}{(\text{ft/sec})^2} \times V^2 \times A_W = R_F ) lbf</th>
<th>( R_t = 2R_F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1.689 4.008x10^6</td>
<td>0.0038 0.97 2.853 419 4.4 8.8</td>
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<td></td>
</tr>
<tr>
<td>2 3.378 8.017x10^6</td>
<td>0.0034 11.41 15.8 31.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 5.067 1.202x10^7</td>
<td>0.003 25.67 31.3 62.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 6.756 1.603x10^7</td>
<td>0.0029 45.64 53.8 107.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 8.445 2.004x10^7</td>
<td>0.0029 71.31 84.1 168.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 10.134 2.405x10^7</td>
<td>0.0029 102.69 121.1 242.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 11.823 2.806x10^7</td>
<td>0.0028 139.78 159.1 318.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 13.512 3.207x10^7</td>
<td>0.0028 182.57 207.8 415.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 15.201 3.608x10^7</td>
<td>0.0028 231.07 263.0 526.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 16.89 4.008x10^7</td>
<td>0.0027 285.27 313.1 626.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reynolds number \( \Re \): speed \( V \) in ft/sec
\( \ell_{pp} = 33.226 \text{ ft} \)
\( \nu = \text{kinematic viscosity of fresh water at } 10^\circ C \text{ or } 50^\circ F \): \( 1.4 \times 10^{-5} \)
(Comstock ed. p. 337, table 13)

\( C_F = \text{friction coefficient, experimentally determined on the basis of Reynolds number} \) (Comstock ed. p. 298, fig. 4: A.T.T.C. line + 0.0004 for surface roughness)

\( \rho = \text{mass density of fresh water at } 10^\circ C \text{ or } 50^\circ F \): \( 1.94 \)
(Comstock ed. p. 337, table 12)
## 27. Ship speed vs. wind speed

<table>
<thead>
<tr>
<th>Vs (kts)</th>
<th>Rt (ft/sec)</th>
<th>VxRt</th>
<th>EHP</th>
<th>Vw-Vs (ft/sec)</th>
<th>(Vw-Vs)^2</th>
<th>Ap x Qa</th>
<th>( \frac{1}{2}C_l ) = Fw 1bf</th>
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<tbody>
<tr>
<td>1</td>
<td>1,689</td>
<td>8.8</td>
<td>0.03</td>
<td>1</td>
<td>2.853</td>
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<td>0.00238 0.4 0.7</td>
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<td>2</td>
<td>3.378</td>
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<td>1509.089</td>
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</tr>
</tbody>
</table>
(cont.)

\[
\begin{array}{ccc}
V_w-V_s & (V_w-V_s)^2 & \Phi_a \\ 
kts & (\text{ft/sec})^2 & \frac{1}{2} \frac{C_l}{\text{lbf}} \\
24 & 1643.167 & 391.1 \\
25 & 1782.951 & 424.3 \\
26 & 1928.439 & 459.0 \\
27 & 2079.634 & 494.9 \\
28 & 2236.533 & 532.3 \\
29 & 2399.138 & 571.0 \\
30 & 2567.449 & 611.0 \\
31 & 2741.465 & 652.5 \\
\end{array}
\]

\[C_l = \text{part of total wind force acting on the vessel’s hull}\]

(cf. Comstock ed. p. 316)

\[R_t = \frac{F_w}{V_w} : \quad \frac{V_s}{V_w} \begin{array}{c} 1 \quad 3.6 \\
2 \quad 6.8 \\
3 \quad 9.6 \\
4 \quad 12.6 \\
5 \quad 15.7 \\
6 \quad 18.9 \\
7 \quad 21.6 \\
\ldots \quad \ldots \\
10 \quad 30.4 \end{array} \]

Hull efficiency: \[\eta_H = \frac{R_t \times V_s}{V_w \times V_w} = \frac{V_s}{V_w} = \frac{1}{3}\]
APPENDIX B

GLOSSARY OF SHIP TERMS

Aft : At or near the stern of the vessel.

Apron : In post-medieval vessels: timber rigidly attached to the inside of the stem for the sake of reinforcement. In cog research: raised part of a hook just before its upward turn.

Backstay : Rope running from the mast head to the stern, in order to support the mast against the forward thrust of the sail; part of the standing rigging.

Ballast : Heavy material such as stones, placed in the hold in order to lower the hull's center of gravity and increase stability.

Beam : Transverse timber connecting both sides of the hull, providing strength and eventually supporting a deck; see also s.v. Deck beam. Maximum width of a vessel.

Belaying : Fastening a rope, usually part of the running rigging.

Bilge : Area of the hull forming the transition between bottom and side.

Bilge water : Water collected in the hold through leaks in the planking or as a result of rain or incoming waves.

Block : Wooden device containing one or more sheaves, used as part of tackle to increase the mechanical power applied to ropes.

Bowline : Line running from the sail to the bow, used to hold the forwardmost side of the sail steady so that the vessel can sail as close to the wind as possible; part of the running rigging.

Brace : - In hull construction: wooden device clasping the hull planks and holding them tightly in the required shape (fig. 61 on p. 112).

- In rigging: rope running from the yard arm to the deck, used to adjust the yard in a
horizontal plane; part of the running rigging.

Butterfly clamp: see s.v. Caulking clamp

Carling: Fore-and-aft timbers connecting hull beams for longitudinal reinforcement.

Caulking: Closing the seams between strakes by filling them with suitable material. In cog-like vessels, moss was used as caulking material, often mixed with animal hair and/or pitch; it was covered with a batten (mosslash) and rows of close-set, overlapping caulking clamps.

Caulking clamp: Elliptic iron plate provided with lips at both long sides (Fig. 64 on p. 117); the lips were bent and the clamp was driven into the wood at either side of the plank seam in order to cover the seam's caulking. Known in Central Europe from Roman times through the early 20th century (v. pp. 118-119). Also called "butterfly clamp."

Ceiling: Planks running over the inner faces of the frames. In cogs, ceiling planks run in a fore-and-aft direction.

Center of flotation: Transverse horizontal axis around which the hull pitches; symbol LCF.

Channel rail: short, small timber running fore-and-aft near the sheer at the outer face of the hull planking, provided with slots for belaying shrouds.

Clamp: Thick strake fastened to the inner faces of the frames to provide longitudinal stiffening. In cog-like vessels, clamps run along the inner faces of the outer strakes, through notches in the outer frame faces, but they serve a similar purpose.

Cleat: In Dutch shipbuilding: short wooden battens temporarily holding hull planks together during construction.

Clench nailing: Nailing method in which nails are driven through the wood and their ends bent back and eventually the points driven into the wood again. In cog-like vessels, this method was used to fasten overlapping strakes and plank
scarfs (fig. 64 on p. 117).

Deadrise: Angle between the extremities of the hull bottom and the horizontal plane.

Deadweight: Carrying capacity of a vessel, excluding the weight of the hull itself.

Deck beam: Transverse beam supporting a deck.

Design waterline: Line on the hull indicating the maximum safe draft as calculated or estimated by the designer. For short history: see p. 181. Also called "load line."

Draft: Depth of a hull below the waterline.

Eye-bolt: Bolt with circular opening at one end.

Flat scarf: Type of scarf in which the extremities of both pieces taper in thickness and are fitted onto each other.

Floor (timber): Lowermost central part of a frame, crossing the keel.

Flush planking: Type of planking in which the strakes are placed next to each other so that their corresponding faces are lying in one line, thus presenting a smooth surface.

Fore-and-aft sail: Sail running more or less parallel to the keel.

Forelocked bolt: Bolt provided with a slot near one end, in which a wedge is inserted in order to prevent the bolt from slipping out of its hole.

Forestay: Rope running from the mast head to the bow, in order to support the mast against any backward thrust; part of the standing rigging.

Frame: Single or composite transverse timber running on the inner side of the hull planking, usually reaching up to the sheer line; it provides transverse strength to the hull. A composite frame consists of a floor and futtocks. See also s.v. Half frame.

Freeboard: Vertical distance between the waterline and the deck or sheer line of a hull.
**Futtock**: Upper part(s) of a composite frame.

**Garboard**: First strake of outer hull planking, resting against the keel.

**Gudgeon**: Metal bracket attached to the sternpost, and provided with an eye on which the rudder is hung by means of a pintle. In some cog-like vessels, gudgeons resemble eye-bolts (fig. 40 on p. 70).

**Half frame**: Frame running on one side of the hull only, without crossing the keel.

**Halyard**: Rope used to hoist and lower the sail or yard; part of the running rigging.

**Heel angle**: Inclination angle of a vessel with regard to its vertical axis, seen in a transverse plane; result of rolling.

**Hooding end**: Very extremity of a strake, which is fastened to the stem or sternpost.

**Hook**: Heavy, grown knee-like timber making the transition from the keel to the stem or sternpost.

**Keel plank**: Plank forming the lowest longitudinal member of the hull.

**Knee**: Angled piece of timber, usually connecting a beam with the hull side or a frame.

**Lanyard**: In general, any short piece of line fastened to an object to secure it or to act as a handle. More particularly, short lines securing shrouds, forecastays or backstays.

**Lapstrake**: Method of fastening hull planking in which the strakes partially overlap and the overlapping edges are fastened to each other.

**Load line**: see s.v. Design waterline.

**Mast step**: Slotted timber holding the foot of the mast.

**Midship frame**: Frame situated at widest part of the hull, indicated by the symbol Ø.

**Molded dimension**: For the hull, measurement taken to the
outer frame faces and eventually to the upper face of the deck beam. For a timber:
measurement taken across forward or aft faces of frames or across vertical or fore-and-aft faces of longitudinal timbers; see also "Sided dimension."

**Mosselth** : see s.v. Caulking.

**Pintle** : Metal bracket attached to the stern rudder and provided with a downward-pointing pin by which it is hung in the eye of the gudgeon.

**Pitching** : Rotation of the hull about its center of flotatation.

**Port (side)** : Left-hand side of the vessel, seen from the stern.

**Rebbet** : Groove cut into the keel, stem or sternpost into which the outer planking is seated.

**Rolling** : Rotation of the hull about its longitudinal axis.

**Running rigging** : All ropes used for raising, lowering or adjusting yard and sail.

**Scarf** : Overlapping joint connecting two timbers or planks.

**Shear** : Sweep or longitudinal curvature of the hull as seen from the side.

**Sheer strake** : Uppermost strake of the hull.

**Sheet** : Rope running from the lower corners of the sail (clews) aft, in order to extend the sail or hold it in place; part of the running rigging.

**Shroud** : Rope running from the mast head to the hull sides, bracing the mast athwartships; part of the standing rigging.

**Sided dimension** : Measurement taken across the inside or outside faces of frames or longitudinal timbers.

**Spritsail** : Fore-and-aft sail bent to a short mast and held up by a diagonal spar called a sprit.

**Stanchion** : Upright supporting post.
Standing rigging: Fixed ropes used to support the mast.

Starboard (side): Right-hand side of the vessel, seen from the stern.

Stern rudder: Rudder mounted on the sternpost by means of gudgeons and pintles.

Strake: Continuous line of planks extending from the stem to the sternpost.

Tabernacle: Ensemble consisting of two uprights, one at either side of the hull, which are joined by transverse beam upon which a mast is mounted.

Tabernacle mast: Mast mounted on a tabernacle.

Tiller: Timber fitted onto the rudder and used as a handle to turn pivot the rudder blade on its pintles.

Treenail: Cylindrical or multi-sided wooden pieces driven through timbers and planks to connect them.

Trim angle: Inclination angle of a vessel with regard to its vertical axis, seen in a longitudinal plane; result of pitching.

Watercourse: Hole or notch cut in the outer face of a frame in order to permit free passage of bilge water; usually situated near the keel and often also in the bilges. Watercourses near the keel are called "limber holes."

Yard: Large spar mounted across the mast to carry the sail.

Yard-arm: Extremity of the yard.
APPENDIX C

LETTERS OF PERMISSION

Wolfgang Steusloff
Am Markt 1
DDR 2530 Warnemünde
25th May 1987

Dear Miss,

answering your letter from 5th of May '87 I have the pleasure to give you full permission to use the illustrations noted in your letter (the photographs and the drawing of the 'Ebersdorf model' from my article in "Deutsches Schiffahrtsarchiv" 6/1983).

I hope you will get my reply in good time, and I want to wish you well success to your Master's thesis and your future works.

Yours sincerely,

[Signature]

Wolfgang Steusloff
Dear Miss Van de Moortel,

thank you very much for your letter from May 5, 1987, concerning the reproduction of some pictures of our brochure "The Hanse Cog of 1380". I see no problem to give you the permission to reproduce the seven pictures, you asked about, if you do it with the correct credit line.

Do you see any possibility for us to get a copy of your master thesis? As you perhaps can imagine, we would be very interested in it.

I wish you good luck for your master theses!

Yours sincerely,

[Signature]

(Dr. Uwe Schnall)
Miss Aleydis Van de Moortel
Dept. of Anthropology
Nautical Archaeology
Texas A&M University
College Station TX 77843
U.S.A.

Rostock, den 4.5.1987

Ihr

Sehr geehrte Frau Van de Moortel,

Wir erhielten Ihren Brief vom 5.5.1987 und arbeiten Ihnen die Genehmigung zum Abdruck der gewünschten Abbildungen in Ihrer Dissertation. Wir bitten um einen korrekten Quellschweis und daß das Material nicht veröffentlicht wird.

Mit freundlichem Gruß

[Unterschrift]

Eija Reinecke
Ms. Aleydis Van de Moortel  
Nautical Archaeology Program  
Texas A&M University  
College Station, TX 77843  
U.S.A.

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This is to confirm that you have permission to use in your Master's Thesis the following illustrations:

O. Crumlin-Pedersen, "Danish Cog Finds," in S. McGrail, The Archaeology of Medieval Ships and Harbours in Northern Europe (Greenwich 1979)

+ fig. 2.6: rudder points of the Vigsø wreck
fig. 2.12: sketch of cross sections of cogs from Kollerup, Kolding, and Vejby
fig. 2.13: longitudinal sections of cog finds

"Schiffe und Seehandelsrouten im Ostseeraum 1050-1350," in Seehandelszentren des nördlichen Europa (LSAK 7, Bonn 1983)

fig. 63: four basic northern European hull types A.D. 1050-1350

By

O. Crumlin-Pedersen  
Nationalmuseet  
Skibshistorisk Laboratorium  
Frederiksborgvej 63  
DK-4000 Roskilde  
Denmark

Date 26/6-87

+ may be replaced by Fig. 24 in Ole Crumlin-Pedersen: Skibe på havbunden. Handels- og seafartsmuseet på Kronborg, aarbog 1981, Helsingør.
Ms. Aleydis Van de Moortel  
Nautical Archaeology Program  
Texas A&M University  
College Station, TX 77843  
U.S.A.

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R.A. Hulst

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This is to confirm that you have permission to use in your Master's Thesis the following illustrations:

- Photos and drawings of wreck NZ43
- Photos and drawings of wreck M107
- Illustrations from:
  
  R. Reinders, Cog Finds from the IJsselmeerpolders (Flevobericht nr. 248, Lelystad 1985).

  Shipwrecks of the Zuyderzee (Flevobericht nr. 197, Lelystad 1982).

  R. Reinders et al., Drie schepen uit de late middeleeuwen (R.I.J.P. Opgravingssverslagen 2, 3, 4, Lelystad a.d.).

  Kijk op koggen (Ketelhaven 1983) Exhibition Catalog Ketelhaven Museum for Maritime Archaeology.

- J. de Jong et al., The Conservation of Shipwrecks at the Museum of Maritime Archaeology at Ketelhaven (Flevobericht nr. 199, Lelystad 1982) fig. 1.

IJsselmeerpolders Development Authority
Scientific Division.

By

Date 6/10/87
VITA

Aleydis Maria P.A. Van de Moortel

Date of Birth: November 18, 1958

Permanent Address: Hoogstraat 52, B-2670 Puurs, Belgium

Education:
1982 Summer course on preservation of underwater cultural heritage, in Bodrum, Turkey; INA, under the auspices of the Council of Europe

1981 B.A. (Licentiaat), Katholieke Universiteit Leuven; Major: Classical Philology; Thesis about Greek and Roman ship construction

1978 Kandidaat, Universitaire Faculteiten Sint-Ignatius Antwerpen; Major: Classical Philology

Professional Experience:

1985 Research on amphoras from Yassi Ada
1984 Byzantine wreck in Bodrum Museum, Turkey; INA; project director: F.H. van Doorninck; assistant

1984 Excavation of Late Bronze Age shipwreck at Uluburun, Turkey; INA; project director: G.F. Bass; crew member

1982 Excavation of Roman shipwreck at Anse des Laurons, France; Direction des Recherches Archéologiques Sous-Marines; project director: B. Liou; crew member

Excavation of Roman and Merovingian river harbors at Kerkhove, Belgium; Katholieke Universiteit Leuven; project director: A. van Doorselaer; crew member

1981 Excavation of mesolithic site at Brecht, Belgium; Katholieke Universiteit Leuven, project director: P. Vermeersch; crew member