An Offprint from

DOWN THE RIVER TO THE SEA

Proceedings of the Eighth International Symposium on Boat and Ship Archaeology, Gdańsk 1997

Edited by Jerzy Litwin

Published in the Polish Maritime Museum's 40th anniversary year

Polish Maritime Museum, Gdańsk 2000

RECONSTRUCTION OF THE HJORTSPRING BOAT - PHILOSOPHY, EXECUTION AND INITIAL RESULTS

Knud V. Valbjørn, Hans P. Rasmussen, Jørn A. Jørgensen

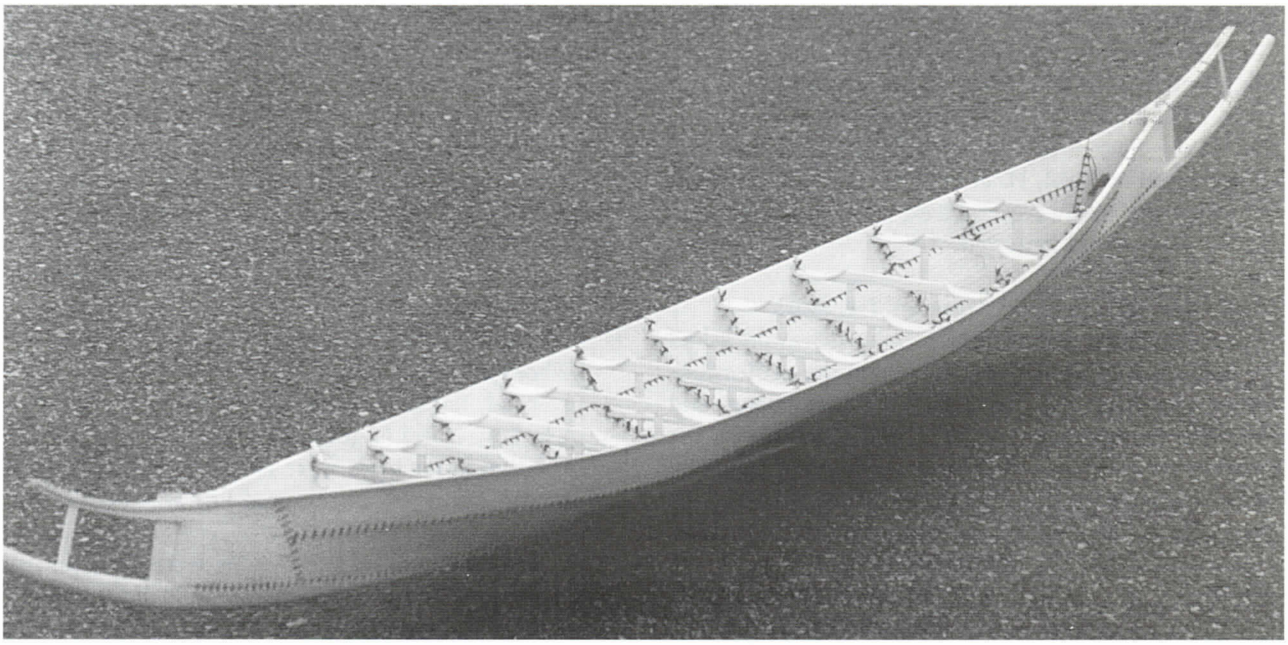
INTRODUCTION

In 1991 a group of people on the island of Als in Denmark, the island where the Hjortspring boat was excavated by the National Museum in 1921/22, decided to investigate the possibility of building a full scale replica of the boat. After consulting various people connected with the Danish National Museum in Copenhagen and Roskilde, the group realised what an immense job it would be, in particular if one wanted accurately to duplicate materials, working methods and design. Subsequently a legal organisation was founded: Hjortspringbådens Laug (The Guild of the Hjortspring Boat) in order to establish a platform from where the work could be governed and coordinated, funds could be raised and long range connections and co-operation with universities and museums could be established and maintained. Within two years the number of members reached 100 and it has been stable since then. The guild attracts persons with a wide variety of backgrounds such as teachers, farmers, housewives, engineers, computer specialists, bricklayers, chauffeurs and doctors. We have no shipwrights, carpenters or cabinetmakers among our members. However we attracted people with a keen sense of quality, that has helped to realise the philosophy stated below. The motivation for joining the guild varies from interest in local history, in ships, in wood working, in video, in smithy work to just enjoying the social life of a club. The average age of the members is 55.

THE PHILOSOPHY OF THE RECONSTRUCTION

The objective is to build, test and display a full scale replica of the boat. As such a big task will only take place every 25 years, if that often, the replica should represent the latest in understanding as to materials, design and manufacture of the boat. Furthermore as

Fig. 1. Model of the Hjortspringboat. Scale 1:10.



much information as possible should be produced and documented. All documentation should be made available to archaeological scientists from museums and universities. Lastly, all the practical and theoretical observations and analyses should be arranged in a way that they could form elements of the testing plan for the finished boat. Without using these words, McGrail (1987, p. 193) stresses the importance of such measures in order to justify the outlay of funds and effort to build a full scale replica. Rosenberg and Johannessen (1937) and Rieck (1988) describe the Hjortspring boat as being very refined in design and finish. Our own initial studies convinced us that we could never build the boat at the same speed as our predecessors as they must have had the experience of building a long line of still more refined boats, surely in a ship yard. Thus we should build a true copy, true in shape, surface smoothness, elasticity and weight, while time was our free parameter. So we did not produce any knowledge regarding Iron Age shipyard productivity. Neither did we prove which tools were used, although we feel that we have suggested likely designs.

THE WORKING METHODS

The Basis

The main source for understanding the boat is the original, as it is displayed in the National Museum in Copenhagen. This display reflects the boat, as it was understood by the scientists from the museum in 1987. Of equal importance is the book "Hjortspring-fundet" (Rosenberg, 1937). The latter has many elaborate descriptions, photographs and sketches. Of major importance in the book is the drawing of the boat by F. Johannessen in 1931. The guild succeeded in locating the original drawing in the archives of "Det kongelige Nordiske Oldskriftselskab". The drawing is to the scale 1:10. From the "Institut for Archaeology, Kunsthistorie og Numismatikk" at the university in Oslo, Norway, we obtained the sketches which F. Johannessen used when making the drawing.

In 1971 a copy of the Hjortspring boat was built at the Viking Ship Museum in Roskilde. This work is documented by Kahl, H. et al (1971). From this book we learnt the many experiences, good and bad, that the building group gathered.

Input from the National Museum, Denmark

As a consequence of our philosophy the guild asked for and received good assistance from the professionals of the National Museum in Copenhagen and Roskilde. In that way the guild has been able to get answers to questions that arose during the practical work, while the National Museum got their wishes incorporated in the replica, thereby increasing the value of the work. Our log shows a total of 25 letters and probably as many telephone conversations. Professionals have visited our shipyard 10 times, and we have visited the National Museum 7 times in order to study and photograph details from the display and from the stores. Our test models (see later) have been on display at the Viking Ship Museum in Roskilde for three months. In total 10 professionals from different museums and universities are acting as our "scientific network". Four lectures have been given to members of the guild.

The Design

Based on the above sources the design group has procured detail drawings and work specifications. The group has held 19 meetings, especially in the initial phases. All reports from the meetings have been sent to The National Museum.

The drawings of Johannessen have been used as data in a computer program, this as well as being able to print out shapes of the boat used by the building group, also acted as a basis for calculations of the hydrostatic and hydrodynamic characteristics of the boat. The results from this analysis as well as a stress analysis are documented by Fenger (1997).

The Cutting Tools

The foundation upon which the tool group worked was as follows:

Only tools whose design suggests that they probably existed in the Iron Age or were expected to give the same results as tools from the Iron Age, should be used.

The working method of the group was to study finds of tools from the Iron Age (few as they are), and to start producing samples of these tools in a forge, to which we had access. At first the tool group ground and stocked the tools as well, while the building group tested the tools and suggested changes. The changes concerned especially the shape, the edge angle, the handle and the weight. It was later found natural to let the builders develop the handles and the edge angles as these parameters could easily be changed by them.

With this cut-and-try method, we developed very highly productive tools, that *might* have been used when building the original boat.

Where appropriate tools could not be found from the Celtic Iron Age, the tool group analysed finds from later periods, in order to identify useful tools. (For unimportant cutting like shortening the trunks or drilling holes for sewing, electric tools were used.)
The following tools became the most popular ones:

Modern axe.
The Mæstermyr wide adze.
A heavy, hollow adze.
A broad, flat slice or chisel.
A hollow chisel (a gouge).

The two latter tools were developed from socketed tools, normally interpreted as adzes (Nielsen, (1984) and Lund (1978).

As a matter of fact these tools were of little use when stocked as adzes because of their light weight, but stocked as chisels they performed excellently both for removing big quantities of wood and for smoothing surfaces. (These tools became so popular that they were named "The Hjortspring Irons"). McGrail (1987, p. 156) suggests the same interpretation on similar socketed tools from the early medieval period. Flat axes were not used very much.

Fig. 2. Typical Hand Tools.

Training in Wood Work and Assembly

None of the members of the building group had any formal education in wood working, but two had earlier participated in building Viking ship replicas. A training period was organised in order to develop and master the tools that are described above. Initial objects made were shields and paddles from the Hjortspring find. Then a few thwarts from the boat were hewn out. The next step was to make a middle section of the boat to scale 1:1 with a length of 1.4 meter, thus containing two frame assembles. The third step was to build the stem from the peak to just after the first frame, a total length of 5 meters.

When making these test pieces we touched on most of the elements of the boat. Many problems appeared and were solved. A major one was whether to mount the side and the gunwale planks inside on the stem block (as Rosenberg/Johannessen suggest) or outside as is normal in later ship designs (Nydam, Viking ships). The National Museum (Rieck, 1994) suggests the latter solution. The boat building training period lasted two years, and 1650 man hours were logged.

EXPERIENCES AND RESULTS FROM THE RECONSTRUCTION

Materials

All materials of the boat are organic, no metal is used. All major parts including the planks are made from lime wood, some parts of the frame assembly are ash, while the frame itself is hazel. The locking elements in stem and stern are oak. The bast for the strings is from lime tree bark, and the stopping material chosen was sheep wool saturated in a paste of ox tallow and linseed oil. For surface treatment wood tar and linseed oil was used. While all the other materials could be acquired locally, lime trunks of the dimensions needed for the planks do not exist in Denmark. We looked in various countries in Western Europe without success. We were advised to search for the trees in Poland and in the forest district of Kisielewo in Kwitajny,10 km from Pasłęk, we located a small forest of lime trees (*tilia parvifolia*).These were 170 years old, with a diameter at the root of 60-80 cm and a height of 18-20 meters before the first branches appeared. It was later recognised that larger diameters were necessary.

Trunk splitting

Each trunk was split into two down the middle. The most promising crack at the root end was chosen, and the trunk was turned, till the crack was vertical. 3-5 wedges were hammered axially into the crack to widen it. Eventually wedges were hammered into the trunk along the axial crack that appeared on top of the lying trunk. Initially steel wedges were used, but with a still widening crack, wooden wedges were employed. They were made of beech wood with a width of 10-15 cm, a length of 5 m and an angle of 5-7 degrees. These wedges did not harm the soft lime wood as much as the steel wedges. Lime wood does not split as cleanly as oak or ash. The fibres often slant across the crack connecting the two halves. Consequently those slanting fibres must be cut continuously. The splitting was done, while the trunks were still full of sap. Until splitting the trunks were kept under water in a fjord nearby. Unfortunately the trunks had a loose core with a diameter of 10-15 cm. The consequences of this are discussed below.

Plank Production

Each of the planks (the keel plank, the two side planks and the two gunwale planks) required half a trunk in order to produce the wide planks. The orientation of the planks in the trunks was discussed, but the loose core forced us to choose the solution as shown below.

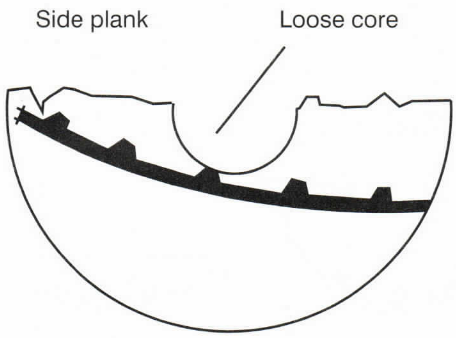


Fig. 4. Side Plank.

The loose core particularly caused problems with the keel plank as this, in the middle section, is very wide. We decided to hew it hollow and afterwards open it to its real shape. While hewing it we, at the

Fig. 3. Trunk Splitting.

same time, made two test pieces with the same dimension but with a length of 1 m. The test pieces were then heated in boiling water for 1 hour and then opened. Both pieces cracked. As we could not use fire to heat the keel plank (which was probably done, Crumlin-Pedersen) we had to hew the keel plank down to the nearly flat shape (over the middle 6 meters) and then increase the width by means of gluing pieces of planks onto the keel plank. Figure 5 shows the procedure. The glue was an Epoxy- West System that has been used for ship purposes in USA over 30 years. The process was performed by Arne Wahl, Svendborg, Denmark. After the hardening was completed, the plank was hewed to its final shape. With a humidity of the wood of 16%, and with a glue notch of less than 0.7 mm, the assembly was shown to be as strong as the wood itself and had the same elasticity. Further details of the process are documented in our files.

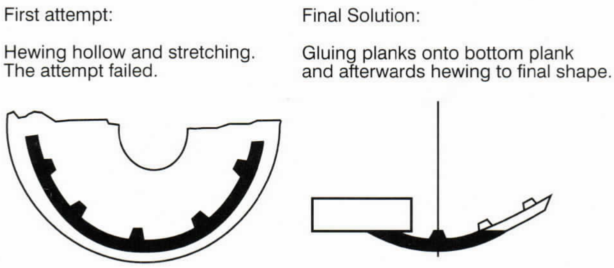


Fig. 5. Keel Plank Production.

We had to increase the width of the gunwale plank as well by gluing, as the trunks did not have a sufficient width to contain the curved shape of the gunwale.

The thickness of the planks was, after consultation with The National Museum (Rieck), chosen as shown below.

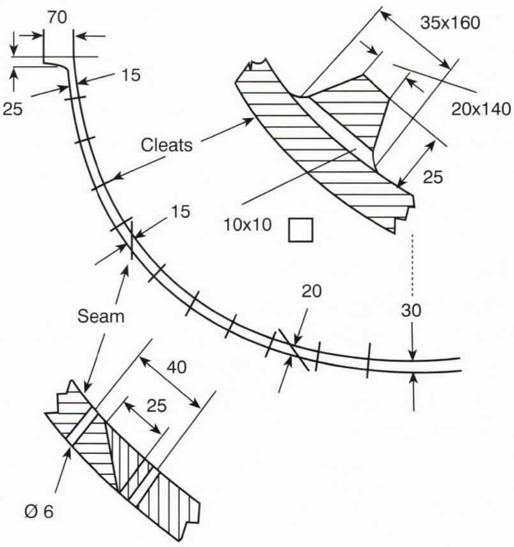


Fig. 6. Plank Thickness and Detail Dimensions.

String Material, Production and Sewing

The string for sewing the planks together and for lashing the frames to the planks was chosen to be bast made from lime wood bark, although new research (Rieck) indicates that roots from birch or fir might have been used. The procedure for making the bast, the cords and the strings is the one described by La Boube and Magnus (1987). In accordance with Rosenberg (1937), we used two chords in the strings used for sewing the planks but three cords for lashing the frames to the planks. The sewing strings had a mass density of 8-11 grams pr meter. Tensile strength was 250-350 Newton and the elasticity coefficient was 0.05% per Newton. The stitch used for sewing was a self locking double stitch, while the lashing arrangement was chosen to be the same as shown in the Nydam boat exhibition in Slesvig, Germany. The tightening of the stitches was performed using the odd shaped tool that is part of the Hjortspring find. This tool resembles the T-shaped tools used by shipwrights in Finland/ NW Russia as described by Westerdahl (1993).

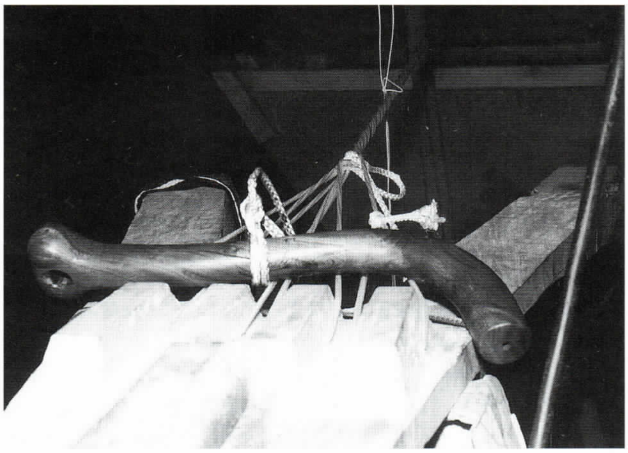


Fig. 7. Tightening Tool.

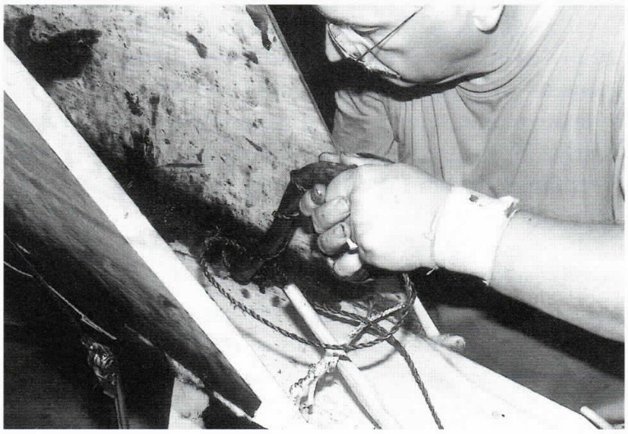
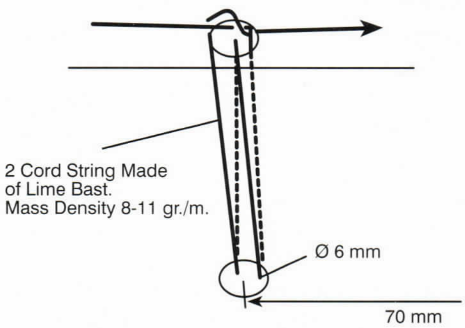


Fig. 8. Tightening a Stitch.

Fig. 9. Self Locking Knot or Stitch Seen from the Inside.



The Stopping

Rosenberg (1937) describes the stopping material as being resin. New research (Rieck, 1994) indicates that the stopping material contains animal fat with traces of linseed oil. We used sheep wool rolls dipped in a lukewarm paste of 80% ox tallow and 20% linseed oil. The mass density of the wool was 7 grams pr meter and saturated with the paste 20 grams pr meter. The stitching holes were filled with the above described paste in the relation 90/10.

It is a critical choice to choose a slippery stopping material such as tallow and linseed oil instead of the quasi-adhesive resin. Even if traces of animal fat and linseed oil are detected, it is possible that resin was being used as well between the plank landings.

The Stem and Horns

Situated in both ends of the boat is a stem block carved out of a lime trunk with a diameter not smaller than 90 cm. We used local lime trees (tilia grandefolia), and we had to work on four before we got two with satisfactory quality (the problem was rotten heartwood, that appeared late in the process).

The carving of the stem blocks was an immense work, because large amounts of wood had to be removed and because the stem consists of oblique planes 2 cm thick, fitting accurately where it meets the keel plank, the upper edge acting as a continuation of the gunwale. Lastly, the upper, foremost end of the stem blocks continues in the gunwale horn.

While the keel horn is connected to the keel plank in a well understood manner, there is no evidence from the boat as to the gunwale horn connection.

It is established, however, that the part found of the gunwale horn contains heartwood, suggesting that the gunwale horn was carved out from a branch, starting out from the stem trunk. We had to abandon this solution, as we could not identify sound lime trunks with such a branch. We decided therefore to fabricate loose gunwale horns and connect them to the stem in a similar way as the keel horns are connected to the keel plank.

The locking planks, made of oak, connect the horns, the keel plank and the stem to each other, secured by rectangular keys. We fastened these keys by splitting them and hammered a slim oak wedge into the key.

The Frame Assembly

The frame system consist of a hazel branch that follows the planks from one gunwale to the other, a beam near the plane of the gunwales acting as a double thwart, made of lime wood, two columns (only one column for frame one and ten) and a lower beam made of ash.

The parts of the frame system were assembled before being inserted in the boat hull. There is no fixed connection between the parts such as keys. The hazel branch is severely bent when mounting it. We used branches just harvested and barked.

All parts have the characteristic of being strong for their weight.

It is significant that the lower beam and the columns are made of ash (see later).

REFLECTIONS ON THE HJORTSPRING BOAT DESIGN

General Reflections

The boat weights 550 kg, and has a typical load of 2000 kg.

During the design, the study of the details and the production of the replica, it became very clear that the most important parameters when designing the boat must have been: **high velocity and low weight.**

Arguments for the first parameter are:

- A very long water line length giving a low wave forming resistance.
- Extremely smooth surface giving a low friction coefficient.
- Very light and slim paddles, signifying high velocity.
- Very light weight of boat (little wetted surface).
- The cross section of the boat (close to a circle segment) gives minimum wetted surface for a given displacement.

Arguments for the second parameter:

- The use of lime wood (low mass density vs. bending strength, compared with oak).
- Refined frame assemblies as to strength vs. weight.
- Extremely thin boards with varying thickness according to load.

Generally speaking, the boat is a war canoe, intended for transporting men and not goods, and not very suitable for rough seas (Fenger 1997). It is a river and coastal vessel, suitable for being carried from one arm of a river to the next or for being carried onto the beach instead of landing on the beach. Eighteen seamen or warriors could carry it, each one with an arm crooked under his end of the thwart, plus by two men at each end, gripping the keel horn at its root (25 kg per man).

HYPOTHESES, DERIVED DURING THE WORK

Many questions arose during the building of the boat. Some of them were answered through consultations with the National Museum, some we had to answer ourselves based on common sense and analogies with other parts of the boat. Finally some major questions and interpretation possibilities appeared that could not be confirmed right away, thus they must be treated as hypotheses. **These hypotheses are part of the plan for the tests afloat.**

The Stem Cleats

In each end of the boat, carved out on top of the stem blocks are four cleats, 2 cms from each other and oriented in the direction of the boat. The function of these cleats has not been discussed much in literature. A hypothesis of the guild is that these cleats acted as a tackle-block for tightening a rope truss, used to counteract hogging (Hjortspringbådens Laug, The Membership Ledger, Chapter 2). A similar suggestion is found at Åkerlund, H. (1963). Simple mathematical models have verified the effect but not the hypothesis. More exact models are being considered and tests during trials are planned in order to clarify the subject. As a matter of fact, the boat builders used such a trussing rope in order to stabilise the boat form while sewing the lower seams.

Another possible use of the cleats is as fixture for lashing a transversal beam that carries pins for controlling a longitudinal steering oar, as is seen in the Chinese Dragon boats. Practical tests will clarify this the proposal.

There is no archaeological evidence to support this hypothesis.

The Function of the Horns

The horns have been the subject of interpretation by many scientists and authors. Nancke-Krogh (1982) challenges Rosenberg's interpretation that the Hjortspringboat had horns. Marstrander (1972) claims to have experienced in his test with a skin boat with horns a lifting effect from the keel horn when paddled (at three knots!).

Randsborg (1995) suggests that the keel horn was intended for ramming enemy boats and that the whole horn assembly was used when the first man jumped ashore at beaching. Hale (1980) uses ethnographic arguments to render probable that the keel horn has a hydrodynamic effect when sailing in short waves. Lastly, Brøndsted (1960), Landstrøm (1961) and Crumlin-Pedersen (1970) suggest that the horns come from skin boat designs.

We support the interpretation that the horns were a carry-over tradition as we have not been able to identify any practical use of the horn assembly. Simple calculations reject a hydrodynamic effect of the keel horn and the fragility of the boat and the horn assembly rejects beaching use.

We will certainly study these aspects during the trial test. No ramming tests are planned!

The Function of the Frames

When mounting the frames the question of how the thwart beam should end at the gunwale plank arose. An immediate solution was that the beam should rest on the uppermost rectangular cleat. This solution was, however, challenged for two reasons: firstly, the string that lashes the hazel branch to this cleat would be worn out very quickly, and secondly the thwart would be statically undetermined, being supported vertically by two columns (or pillars) and two cleats, and furthermore in an oblique way by the hazel branches, piercing through the seats.

The two pillars were made out of ash wood, no doubt in order to be able to transmit a heavy load.

The pillars could either transmit the load of the crew directly through the columns down to the bottom of the boat through compression, where it is transformed to hydraulic pressure, or their function could be to keep the thwarts from twisting. In that case the thwarts should rest on the cleats, and thus transmit the load down through the planks, thereby compressing the stopping. The latter solution was chosen. In order to counteract a non symmetrical load (one crewman sitting alone on a thwart), one needs a member for keeping the other end of the thwart from rising.
Stays were therefore introduced, running from an existing hole in the thwarts under the seat and down to the frame.

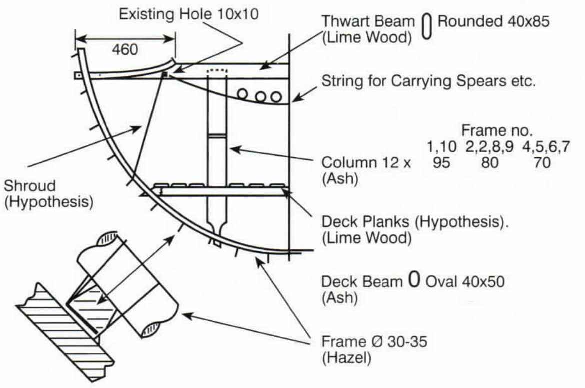


Fig. 10. The Frame System. Dimensions in mm.

The mounting of the frames and trials afloat will determine the validity of this solution.

The introduction of these ropes makes it possible that the boat could be carried by lifting under the end of the thwart, as suggested above.

The Deck Planks
Rosenberg (1937, p.85) noted that the find contains at least 85 boards, 105-118 cm in length.
28 have a width of 10 cm and a thickness of 1 cm.
56 have a width of 6 cm and a thickness of 1.5 cm.

Materials are lime and ash wood. All boards are tapered at the ends over 10-20 cm. As the distance between the frames is 100 cm, it is evident that these boards must have had a function covering some parts of the boat between the frames and somehow be fastened to the frames.

Rosenberg suggests that the boards would have been stuck in under the hazel branch frames with the object of protecting the seams, and perhaps as coverings following the bottom from one side to the other.

As bilge-water must have been unavoidable, it would be necessary to keep the feet of the crew out of the water to keep them healthy. It is our hypothesis that the boards are used as deck planks in the following way: the narrow ones, 56 in total, fit exactly on top of the lower beam between the side of the boat and the pillars, thus forming a ring deck, which will support the outer leg of the paddlers. The boards must have been lashed to the beam.

The number of the wide boards corresponds roughly to the space between the columns, so they could act as deck planks here, also on top of the lower beam. In that way, the whole boat from frame 1 to frame 10 had a deck. See figure 10.

Another solution could be that the broad boards were used as coverings for the seams, as Rosenberg suggested, while the narrow ones remains as ringdeck planks.

A third solution is to use the wide boards to cover the middle of the boat in order to carry a ballast of stones.
It is planned to produce 100 boards in total in a ratio of 1:2 and let testing decide.

CONCLUSIONS

The Quality of the Hjortspringboat
Using the best of available technology, the builder of the original Hjortspringboat certainly produced a high quality vessel, as to smoothness, refined details and design, no doubt fulfilling the specification of the buyer: **"Build me a war canoe for river and coastal use, capable of transporting 22 warriors at a speed of 8 knots, and suitable for being carried over land by the crew".**

The details of the boat indicate that the boat is a number in a line of still more refined boats, built in a professional shipyard.

An analysis of the design shows, that modern knowledge could hardly improve the predicted performance, taken the manufacturing technology in the Celtic Iron Age into consideration.

The only possible improvement is to get rid of the horns but one must acknowledge the tradition of carrying over aesthetic values from past ships into new designs.

The Royal Motor Yacht of Denmark, "Dannebrog", has a bow sprit!

Aspects of Contribution by Amateurs
The members of the Hjortspring Guild are amateurs in both an archaeological and ship building context. We had to keep this in mind and at the same time organise the work to make use of the many professions and qualities of the members, in order to reach a credible result.

As we could not start a total study of archaeology and ship building, we decided to establish a narrow platform of archaeology and ship technology knowledge. We let different groups study and document "all" aspects of the find, the boat and the Celtic Iron Age (as to landscape, living conditions, religion etc). We hardly produced any new knowledge that way, but it gave us a firm, but narrow platform, upon which we could build new knowledge in accordance with the heuristic model. The validity is ensured by our policy of documenting everything.

The probability of creating new knowledge is increased by the existence of many relevant skills and professions, such as wood carving, hydrodynamics, sailing, computerised geometry, stress analysis and metallurgy. Secondly it is increased by the lengthy work, month after month, year after year, consisting of doing, testing and discussing all details, in an atmosphere of mature enthusiasm and professionalism.

REFERENCES

Åkerlund, H. (1963), Nydamskeppen, Sjøfartsmuseet, Gøteborg.

Brøndsted, J. (1960), Danmarks Oldtid, Gyldendals forlag, p. 38.

Crumlin-Pedersen, O. (1970), Skind eller træ, Vikingeskibshallen, Roskilde, p.237.

Fenger, N. P. (1997), The Reconstruction of the Hjortspring Boat, Theoretical Performance and Initial Test Results. ISBSA 8, Gdańsk 2000.

Hale J. R. (1980), Plank built in the Bronze Age, Antiquity, LIV, p.124.

Hjortspringbådens Laug, Medlemsmappen (The Membership Ledger).

Kahl, H. et al (1971), Roar Linde, Vikingeskibshallen, Roskilde

La Boube, H. og Magnus, O. (1987), Lindebast til tovværk. Historisk-Arkæologisk Forsøgscenter, Lejre. HAF j. nr. 24/87.

Lund, Jørgen (1978), I en Kælder. Skalk Nr. 1 1978. p. 9.

(Marstrander, S. and) Johnstone, P. (1972), Bronze Age Sea Trial, Antiquity, XLVI, p. 273.

McGrail, Sean (1987), Ancient Boats in N. W. Europe. Longman Group UK. ISBN 0-582-49267-X.

Nancke-Krogh, S. (1982), Søfolk og Kentauer, Nyt Nordisk Forlag, København.

Nielsen, Svend (1984), Søtoftegård, Det Kongelige Nordiske Oldskriftselskab.

Randsborg, Klaus (1995), Hjortspring. Århus University Press, ISBN 87 7288 545 9, p. 23.

Rieck, Fl. og Crumlin-Pedersen, O. (1988), Både fra Danmarks Oldtid, Vikingeskibshallen, Roskilde.

Rieck, Fl., (1994), The Iron Age Boats from Hjortspring and Nydam, Proceedings of ISBSA 6, p. 48.

Rosenberg, G (1937), Hjortspringfundet Det kongelige Nordiske Oldtidsskriftselskab, Gyldendal.

Westerdahl, C. (1993), Links between Sea and Land. A Spirit of Enquiry/Essays for Ted Wright. ISSN 1350-2832.

DOWN THE RIVER TO THE SEA

Proceedings of the Eighth International Symposium on Boat and Ship Archaeology, Gdańsk 1997

Edited by Jerzy Litwin

Contens include:

A4, 274 pages with numerous figures and photos. Polish Maritime Museum 2000, ISBN 83-909987-5-0
Available from Centralne Muzeum Morskie • ul. Ołowianka 9–13 • 80-751 Gdańsk • tel.: (48-58) 320-33-58, fax: (48-58) 301-84-53