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Aspects of Viking-Age Shipbuilding

in the Light of the Construction and Trials of the Skuldelev Ship-Replicas *Saga Siglar* and *Roar Ege*

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The study of archaeological remains of ships from the past has considerable potential. Ships are built to serve specific purposes, such as the conduct of trade or war, the procurement of food or general transport; and the structure of these activities is reflected in their design. Shipbuilding is normally based on the best technology locally available at the time. Ships provide indication of fluctuations in the availability of know-how and materials, and they cast light on local building traditions as well as on impulses from outside. Thus, shipfinds are valuable not only for the study of technology but also for that of many aspects of the social structures and economies related to maritime activities.

Ships are moveable objects and they need not have close relations to the findspot. However, detailed study of materials and techniques, the context and associated objects of a particular shipfind may serve to identify the region where construction took place and to cast some light on the history and activities of the ship during its lifetime (Cederlund 1984, Crumlin-Pedersen 1985A).

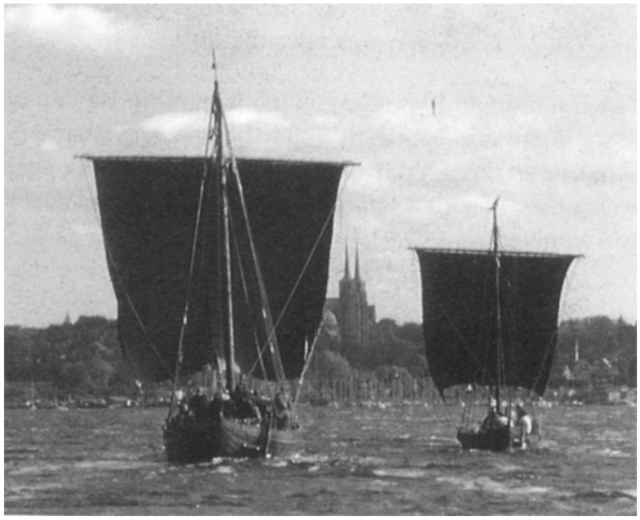

Fig. 1. Rendezvous of the Skuldelev ship-replicas SAGA SIGLAR and ROAR EGE in Roskilde Fjord in June 1986.

For well-preserved shipfinds it is possible to prepare reconstruction drawings which are based much more firmly on recorded facts than are, for example, most replicas of prehistoric farmhouses. On the basis of these plans the carrying capacity and likely performance of the ships can be established, even if these calculations may need verification, in the case of shiptypes unfamiliar to modern experience, by model-experiments and trials with fullscale replicas. Such studies and trials lead to a wellfounded knowledge of the characteristics and data of a number of ships which actually sailed in our waters in the past. We may discuss the representativity of these ships, as well as details of function and ownership. But we cannot deny that these particular ships were actually built and used, even if some of them may be in conflict with our preconceived ideas of, for example, maritime trade in the period in question.

The five ships excavated in 1962 near Skuldelev on the Roskilde Fjord and now exhibited in the Viking Ship Museum in Roskilde offer good opportunities for such detailed studies. They represent five shiptypes of the 10th–11th centuries with varying functions and places of origin (Olsen & Crumlin-Pedersen 1958, 1968 and 1978). These ships are well known today in Danish waters, as the Skuldelev ship Nos. 1, 3 and 5 have served as basis for several replicas built in Denmark and one built in Norway (Crumlin-Pedersen 1984A, Vadstrup 1986, Thorseth 1986). Only one of these, the Skuldelev 3-replica ROAR EGE, has been built primarily as an archaeological experiment, the ROAR-Project in Roskilde. The Skuldelev 1-replica SAGA SIG-

LAR from Norway, however, is also of archaeological interest. For this ship the design of hull, rig and sail and the trials programme were worked out by the Roskilde Viking Ship Museum. Although the scope of the two projects differs, they both contribute to our understanding of Viking shipbuilding and seamanship. At the same time these two replicas may serve as good examples of some of the methodological problems inherent in such projects, – and of some of the results which may be gained through archaeological experiments of this kind.

PLANNING AN ARCHAEOLOGICAL EXPERIMENT

The building and handling of a Viking-ship replica or of a similar ship based on a specific boatfind is a complex undertaking, confronting the experimenting ship archaeologist with a series of problems to be discussed and resolved:

A. Questions related to the documentation of the archaeological sources:

1. Is the documentation of the original shipfind sufficiently precise and detailed to record all important features and to serve as a basis for the analysis of construction principles, shape, extent of repairs and alterations, wear marks, propulsion and steering etc.?
2. Have the materials involved (wood, iron, caulking, tar etc.) been properly identified and studied as to quality and processing (e.g. radial or tangential splitting of planks)?
3. Have original toolmarks been recorded and identified on the ship's timbers, and can these marks be related to known types of contemporary or younger tools?

B. Questions related to the processing of archaeological data and the preparation of a reconstruction plan of the ship:

1. Does the shipfind in itself allow a complete reconstruction of the hull, defined within narrow margins on the basis of possible near-symmetry port/starboard, fore/aft or from the run of the lines over missing parts?
2. If this is not the case, can a hypothetical reconstruction be drawn up within a narrow margin of error on principal dimensions, or would it be preferable for two or more alternative hypothetical reconstructions to be investigated along parallel lines?
3. Should the reconstruction plan represent the ship as built or should it take account of repairs and alterations as found?
4. Is there a basis for a reconstruction of the arrangements for steering and propulsion in the shipfind itself, or can this be based on other relevant evidence?

C. Questions related to the construction of the replica:

1. Should the replica be constructed from the same kind of materials as the original ship and should these be treated in similar ways as in the original construction, or should other techniques and materials be permitted, e.g. the use of sawn timber or laminated elements?
2. Should the replica duplicate the original ship in all details, involving a copying process requiring the use of moulds and other non-authentic measuring techniques, – or should the building process aim at following authentic procedures, as far as these can be established, even if this may lead to slight deviations from (or corrections to) the shape drawn up in the reconstruction plan?
3. The building period will generally be longer for the replica-project than for the original ship. How will this time-factor influence the experiment, and how can it be counteracted?
4. To what degree should present-day techniques and conditions in general be allowed to play a rôle in the project?

D. Questions related to the sailing trials:

1. Even if an overall plan of the rigging can be drawn up on the basis of traces in the original ship, many questions will usually remain to be solved concerning the properties and details of the sail and rig. The same applies to the rowing and steering arrangements, ballasting etc. How are these problems to be dealt with in the experiment?
2. Handling a sailing ship calls for an intimate familiarity with the type of rig and hull to be sailed. Experience can be built up over a period of years but it is

unlikely that brief periods of holiday cruising in a ship replica will lead to a familiarity with the ship comparable to that of the sailor of the past, working professionally under sail in all weather conditions for a whole lifetime. How can the replica-skipper prepare himself best for a realistic trials-programme?

3. How are the results of the trials to be recorded and presented?

These questions should all be discussed and resolved before a proper archaeological ship-replica project of this complex nature is launched. Other replicas may be built to suit purposes such as recreation, filming or PR-activities. In that case it is not customary to go into such questions at any length, although some of the other Danish replica-projects have been strongly motivated for archaeological experiment. These vessels may be able to give a first indication of the performance of such ships and they may serve as training ground for builders and sailors of proper experimental replicas. Up to now these other vessels have yielded few reliable data, as there has been no tradition for a precise recording of trials. Recently, however, the various groups of people who are sailing replicas for recreational purposes in Denmark are finding inspiration in the conscious experimental activities around the ROAR EGE. It is to be hoped that in the future the potentials of the other Danish replicas may be brought out to a higher degree than has so far been the case.

It is not only from the trial's programme that the results of the experimental activities with a ship are to be derived. In fact, naval architectural calculation is a much cheaper and faster way of obtaining several of the data of the ship than is a trial's programme with all its inherent problems (McGrail 1986, Vinner 1986). The principal gain from the experiment consists in the widening of the field of experience of the ship-archaeologist and the revelation of several aspects of shipbuilding and seamanship of the past which would probably have remained unnoticed and unexplored if the replica had not been built and tested.

THE *SAGA SIGLAR*-PROJECT

In 1982 the Norwegian journalist and adventurer Ragnar Thorseth commissioned a replica to be built of the Skuldelev 1-ship, a 16,5 m long deep-sea cargo-carrier, possibly the type known as *knörr* in the sagas. It was Ragnar Thorseth's plan to navigate along the old Norse route across the North Atlantic in the ship, as he had done earlier in more modern boat-types. He was thus following a good old Norwegian tradition of investigating ancient seafaring around the world in replicas of ancient vessels (Christensen 1986, Heyerdahl 1986). He even aimed to take the ship around the world in continuation of the trip to Greenland and Newfoundland.

As Ragnar Thorseth was approaching the subject on the basis of careful preparations, he soon came to an agreement with the present author as to mutual cooperation in the project. The replica was constructed on the basis of detailed studies of the hull and rig of the original ship, carried out in Roskilde by Erik Andersen and Ole Crumlin-Pedersen as part of the preparations for the definitive publication of the Skuldelev-ships. The hull was built by the very competent boatbuilder Sigurd Bjørkedal, working in his old workshop in the Bjørkedal valley near Ålesund in Western Norway. Rigging and sailtraining were supervised by Jon Godal on the basis of his studies of the living tradition in Western Norway of techniques of handling the local square-rigged boats around 1900 (Godal 1986).

The voyage across the North Atlantic took place in the summer of 1984, after initial trials and trips to harbours around the North Sea and the Baltic, including Roskilde, in 1983. The SAGA SIGLAR was met with heavy drift ice near Greenland and ran into a hurricane with wind speeds up to 65 knots on the passage to Labrador. The hull, rig and steering arrangement, however, functioned perfectly and ensured a safe passage. The ship carried modern navigation and safety equipment, and a 22HP dieselengine was fitted for propulsion in harbours and canals.

After a period of six months in North American waters, the voyage continued through the Panama Canal and across the Pacific to Australia and Singapore. Then SAGA SIGLAR sailed across the Indian Ocean and through the Red Sea, the Suez Canal, the Mediterranean and the rivers and canals of France back to North European waters, with a visit to Roskilde in June 1986, before returning to Norway for future exhibition as part of the Sunnmøre Museum at Ålesund.

Thus the SAGA SIGLAR fulfilled the aims of Ragnar Thorseth by setting two different maritime records, being the oldest boat-type ever to circumnavigate the

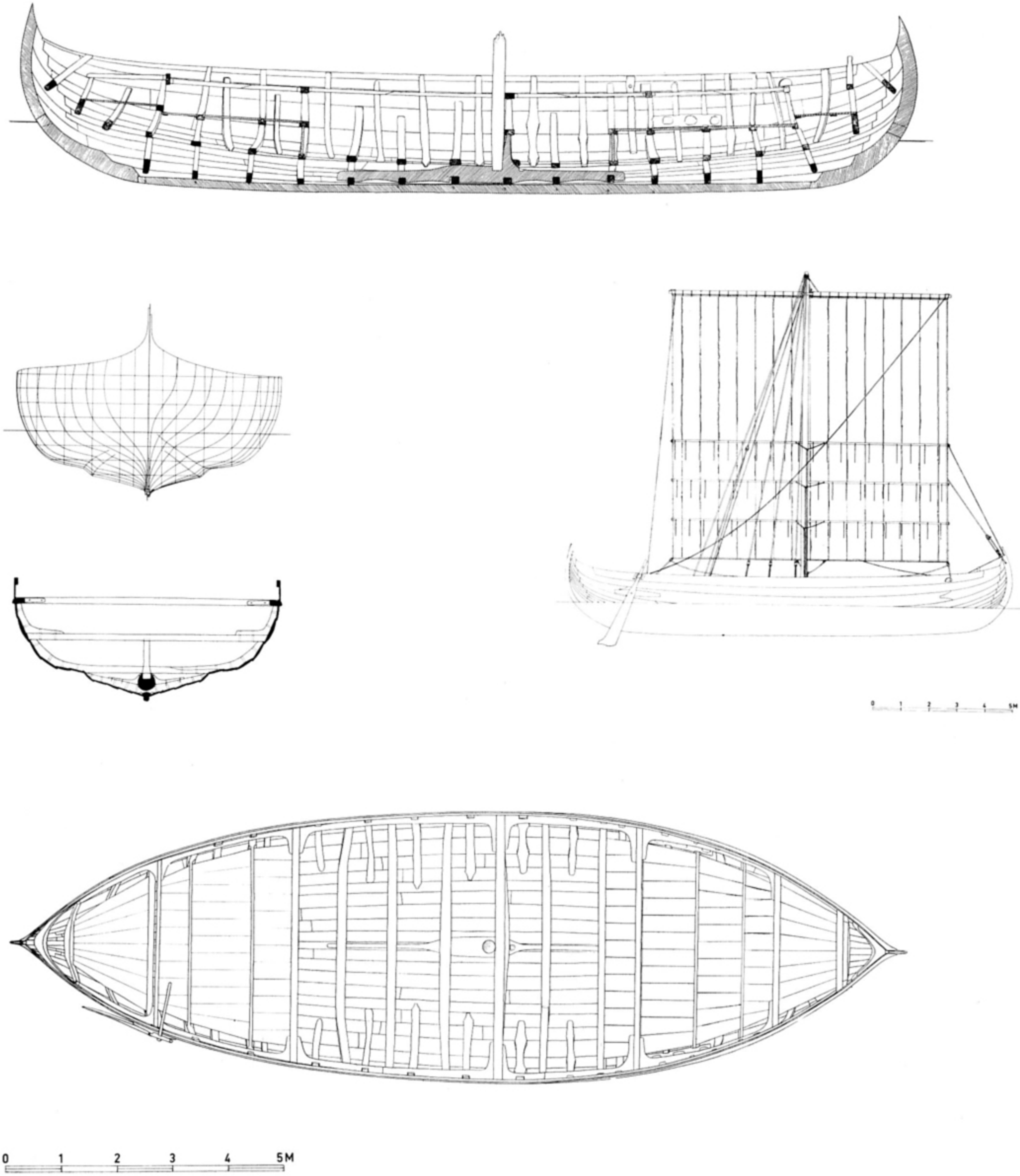

Fig. 2. Preliminary reconstruction plans of the Skuldelev No. 1 ship. These plans formed the basis for the construction of the replica SAGA SIGLAR.

globe, and the first open, undecked vessel to do so. The voyage, however, also provided practical proof of the workability of the reconstruction and of the great seaworthiness of the shiptype. In the hurricane south of Greenland SAGA SIGLAR logged a speed of 8.5 knots over 2–3 hours, sailing on the rig alone! The total mileage of the voyage was c. 35.000 nautical miles, and the ship covered 3.200 miles from Galapagos to Marquesas in French Polynesia in 22 days, giving a mean speed of 6 knots over this entire period.

The ship's tacking ability depends on windspeed and wave-height, giving an efficient angle of 60° to the wind under normal conditions. A detailed report of these observations and the results of systematic trials to be held after the return to Norway will be prepared and published by the Viking Ship Museum, Roskilde, in cooperation with Ragnar Thorseth and Jon Godal.

THE *ROAR*-PROJECT

The idea of building and sailing a replica of the Skuldelev 3-ship, a 14 m long coastal carrier of elegant and slender design, was born soon after the excavation of the ship in 1962. It has been materialized within the framework of the ROAR-Project, with a first phase comprising the construction and first trials of the ship in 1982–84 (Crumlin-Pedersen 1986A). The second phase, covering the years 1985–87, will explore details of Viking rig and sail, and also seek information about properties of hull, rudder and rig through model tank and wind-tunnel tests.

The aims of the ROAR-Project, as these were laid down in 1981–82 at the preparatory stage, are

1) to promote research on Viking shipbuilding and seamanship as an integral part of the study of aspects of the Skuldelev ships,
2) to provide a floating full-scale reconstruction of the best preserved of the Skuldelev ships to present vis-a-vis the original ship in the museum,
3) to provide an opportunity for training in the skills related to Viking shipbuilding and seamanship, and
4) to provide possibilities for a visual recording of scenes illustrating aspects of Viking crafts for presentation to the public.

The main principles of the experiment were also fixed before work was started:

Fig. 3. SAGA SIGLAR beating against the wind in Roskilde Fjord in June 1986.

The project was to be under the direction of a steering group chaired by the present author and comprising experts actively engaged in the study of various important aspects of the experiment, such as the building process, rig and trials (Søren Vadstrup, Erik Andersen and Max Vinner respectively).

The construction work was to be carried out by a group of young people with previous experience from other replica projects in Denmark, working at the Boat Yard of the Viking Ship Museum in Roskilde.

In principle, the same kind of materials, tools and techniques were to be used in the construction of the replica as in the original ship. Special studies were to be undertaken during the process to cast light on matters that could not be resolved on the basis of the evidence of the original find alone.

The ship was to be built to match the original ship at the time this was new, excluding later repairs.

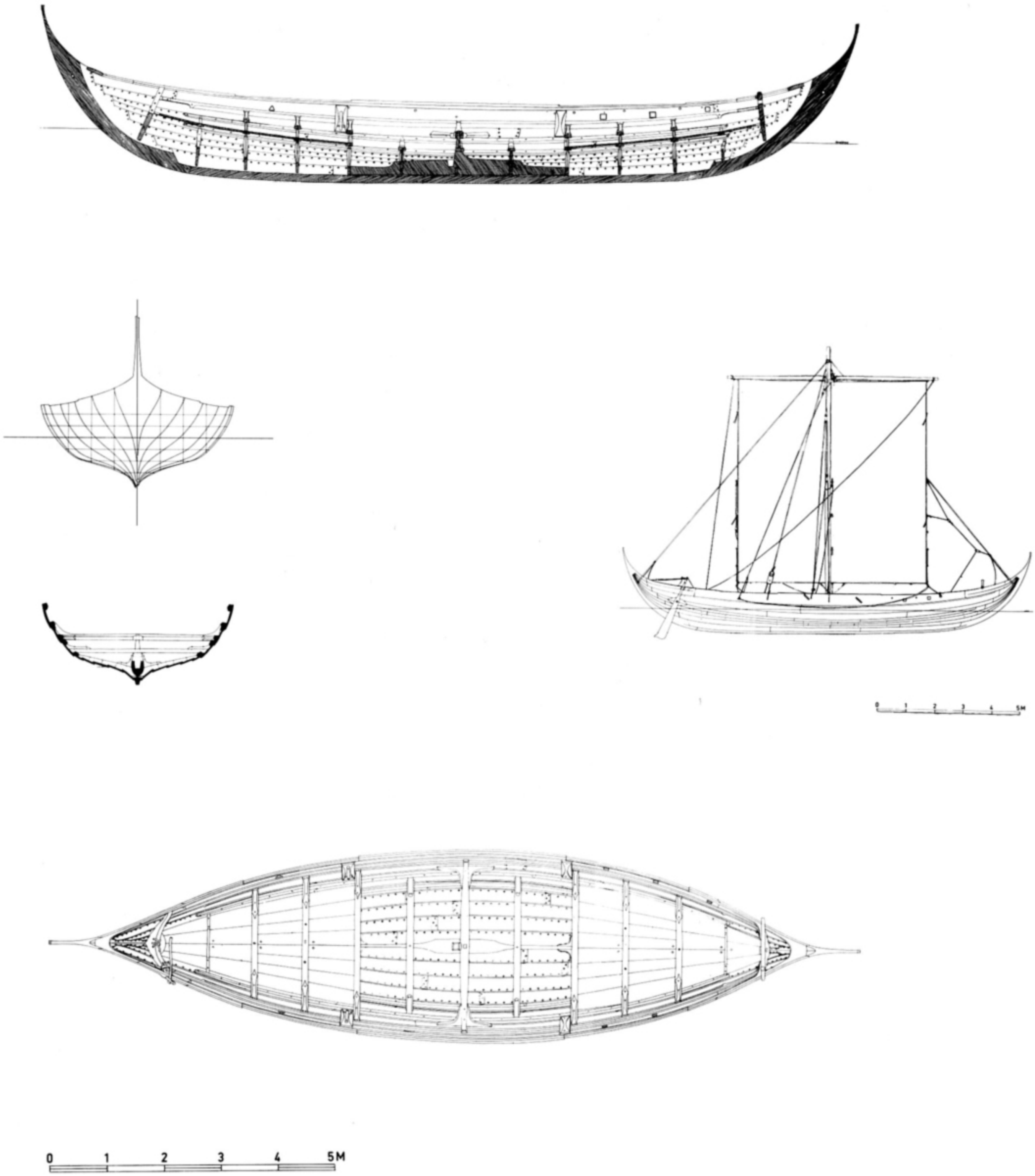

Fig. 4. Plans of the ROAR EGE based on the reconstruction of the Skuldelev 3-ship as built (prior to repairs).

Fig. 5. ROAR EGE under construction in Roskilde in October 1983. The bottom planks have been fitted and are held in position by sticks from below and stones from above.

Extensive systematic trials were to be undertaken after launching, based on the sailing technique practised over several years in the Nordland-boat RANA, belonging to the museum (Crumlin-Pedersen & Andersen 1980, Andersen & Gøthche 1981), and logged via a suitable data-recording system.

All phases of the work were to be recorded in writing, photos and film/video, to provide for the publication of a definitive report on the project as well as for exhibits, popular articles etc., and a film for the general public.

On the basis of a project-description outlining these aims and principles, the museum received a grant of 1.0 mill. D.kr. from the Velux Foundation. Work was started by October 1982 with the selection of the first trees to be felled for the keel and stemposts, and the manufacturing of tools for the job. By May 1983 the keel had been laid and stem and stern mounted. Bottom planking was ready by February 1984 and launching took place on August 25th 1984.

During the building period, members of the steering group prepared preliminary reports on studies in special subjects of importance for the project. These reports were typed and distributed as "ROAR Notes" to everybody participating in the project. Between November 1982 and June 1984 a total of 19 reports were issued, covering topics such as:

Documentation
Tools for shipbuilding
Selection and cleaving of oak
Reconstructing the shape of the hull
Keel, stem and stern
Tools and techniques for controlling hullshape
Iron-nails
Plank cutting and shaping
Building sequence
Rudder system
Mast and yard
Principles for trials

Trials were undertaken in 1984 and 1985 with a pilot rig of hemp for cordage and canvas of flax. In the course of these two years the ship has been under sail for c. 120 days, including seven weeks of intense trials. Rather

Fig. 6. Fitting topstrakes and beams in ROAR EGE in Roskilde in July 1984.

late in the season of 1985, the first trials with a wool sail were started, to be continued in 1986 and 1987. During this period the hemp-materials of the rigging will gradually be replaced by the materials most likely to have been used in the original ship, including walrus-hide, bast rope and withies.

In the course of 1985 and 1986 further "ROAR Notes" have been issued, reporting on work on various aspects of the project, and a good description of the practical work in the boatyard was published 1985 by Henrik Juel, a member of the building group (Juel 1985). The official detailed report on the first phase of the experiment 1982–85, the construction of the ship and the trials with the pilot rig, is being prepared for publication in 1987.

PRINCIPLES COMPARED

The SAGA SIGLAR and ROAR EGE have a common base in the fact that both ships have been built under the guidance of the shiparchaeologist responsible for the excavation, restoration and publication of the original ships. The studies undertaken in relation to the two ship-replicas should be seen as a stage in the preparations for the final publication of these two Skuldelev-ships. Thus the practical experiments with the replicas have been integrated in the archaeological analytical process, and a wider range of relevant evidence has been at hand for these projects than would have been the case if the replicas had been built in another context. It has been possible to include parallel material, such as finds from the Hedeby harbour and the Fribrødre shipyard site, which are at present under analysis prior to publication, as background evidence for tools and rigging.

For both ships, a complete set of tracings in scale 1:1 has been prepared from all surviving parts (Crumlin-Pedersen 1977). 1:10 versions of these drawings have served as the basis for work-models to determine the shape of the hull. Two models were built for Skuldelev 1 and three models for No. 3 in the process of establishing the original shape of the ships and eliminating repairs. In both cases sufficiently large portions of the

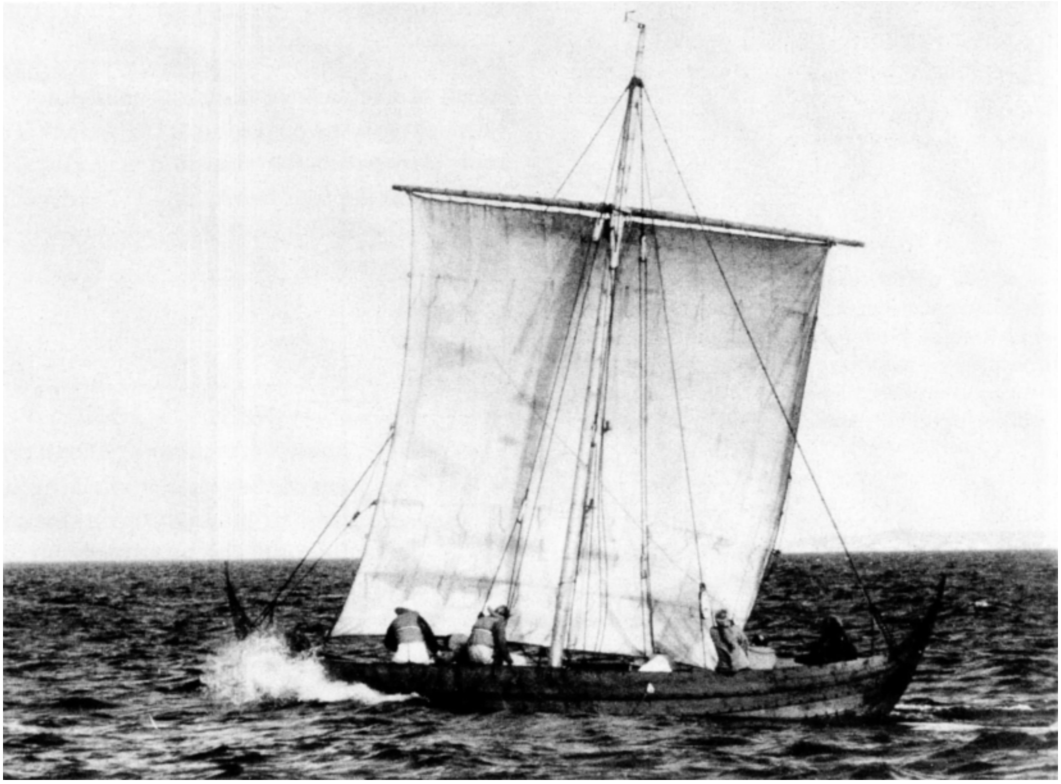

Fig. 7. ROAR EGE on sea-trials with a wool-sail in Isefjord, September 1985.

original ships have been preserved to make it possible to define all the basic elements in the ships as well as the overall dimensions within a margin of c. 0.2 m.

The steering arrangement was based on evidence from other finds, mainly Vorså (Crumlin-Pedersen 1960, 1966) and Fribrødre (Skamby Madsen 1984 A, B), and the concept of the balance between hull and sail, ballast and rudder followed that known from the square-rigged boats of Western Norway (Andersen 1986). Similarly, the sail and rig were reconstructed on the basis of extensive studies in relevant archaeological and ethnological material, including significant traces in the original ships of the way the rigging and sail were worked (Andersen i.p.).

The building materials were selected with the aid of the same criteria for both ships, – that they should represent the same qualities of wood as those employed in the original ship. Sigurd Bjørkedal found the trees for hullplanks, including some extraordinarily long and wide lengths of planking, as well as the grown timbers for knees etc. in the pine stands on his own land. The long lengths of oak for keel, stem and stern were imported from Denmark. In Skuldelev 1 some of the knees and beams are made of lime-tree. They were cut from pine for the replica, as no large stands of lime with such naturally grown shapes were available. In ROAR EGE the materials, oak for everything in the hull except treenails of willow and cleats of beech, were found after intense searching in the forests of Southern Denmark. Here the large straight-grained trunks needed for the radially split planks were very difficult to find because of the present forestry policy of growing oak in monocultures over a maximum of c. 200 years.

Thus far the basis for both replicas was very similar. But the building processes differed considerably. For ROAR EGE the planks were split and cut to shape with an axe. In this case the manual labour was unavoidable, as the radially split oak planks could only be made this way. The SAGA SIGLAR was built from sawn timber and the chain saw took over most of the work which the boatbuilder used to do by the axe until a few years ago. In this ship, whose original was built from tangentially split pine planks, this technique was acceptable, as the sawn planks had the same orientation in the trunk as

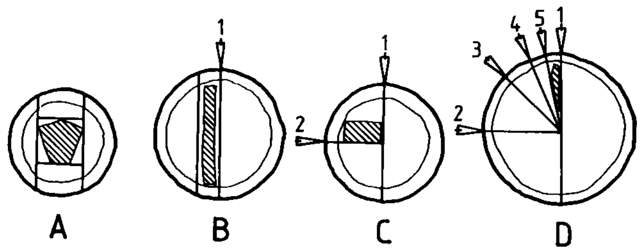

Fig. 8. Schematic representation of the four pricipal ways of working the elements for shipbuilding from a log in the Viking age. *A*: cut directly from the log or branch (for keel, stems, frames). *B*: log split in two, each half worked down to one element (for long, wide planks and stringers). *C*: log split in four, each quarter worked down to one element (for beams and stringers). *D*: radial splitting into "cloveboards" by repeated halving (for planks).

the original planks. Sigurd Bjørkedal and his two sons managed to build the hull of SAGA SIGLAR within a period of 6 months, whereas the building process for ROAR EGE took 22 months. This caused severe problems for the building team of ROAR EGE during the summer months, as the stemposts tended to warp and crack and the unfinished plank elements to dry out and harden unless they were stored in water.

The fact that SAGA SIGLAR has an engine with a propeller shaft through the sternpost makes navigation in narrow waters much easier than it was a thousand years ago, and it has been a precondition for the PR-activities of the ship in various harbours. On the other hand, the propeller gives a slight reduction in speed when going under sail. In this ship, modern anti-fouling bottom-paint was employed, whereas no such modern material has been used in ROAR EGE. This fact tends to influence the results of the trials, as the speed of ROAR EGE varies over the sailing season as a result of the varying effect of algae-growth on the bottom of the ship. This prompts considerations as to remedies for anti-fouling in the Viking Age and these should be searched for and studied in future shipfinds.

SOME OBSERVATIONS RELATED TO THE BUILDING PROCESS

Here a few examples will be given of some of the special studies which were undertaken during the initial stages of the ROAR Project (Crumlin-Pedersen 1986B, Wagner 1986).

Provision of timber

It was necessary to know the orientation in the tree-trunk of the various building elements of the ship in order to plan the provision of the timber. To begin with each element in the ship-find was classified as to its position in the tree-trunk. The 117 individual elements found in the Skuldelev 3-ship represented the following conditions (see fig. 8):

A: 24%
B: 8%
C: 16%
D: 52%

This reflects, however, the damaged and repaired shipwreck. The plans of the original planking as found (fig. 9), therefore, had to be analyzed to locate the repair planks and to identify the most probable positions for the original scarves for the plank-lengths in the ship as built. Thus a reconstruction of the original pattern of the planks, the strake diagram, including the missing stern part outlined on the basis of the models, could be drawn up (fig. 10).

When the maximum length/width of each of these planks is plotted in a graph, it is possible to identify groups of planks of similar length and width. In fig. 11 three groups of such planks are marked A–C, comprising all radially cloven planks in the hull of the replica. These groups may serve as a guideline for determining the number of logs needed for the hull planking.

Experience has shown that the radial cleaving of a log must follow the pattern shown in fig. 8D, where each section of the log is split in halves, leading in principle to a division in 4, 8, 16 or 32 parts of the same size and wedge-shaped cross-section. In practice we have experienced that splitting into 8 parts is relatively simple but that further splitting is critical for long lengths of planks. Instead of splitting purely radially into 1/16s a slightly different technique may be used which produces one broad and one slightly narrower plank out of each of the 8 basic elements. Thus we should expect to get a maximum of 16 planks out of each log.

Now we may investigate if the boxes A, B and C in fig. 11 are likely to represent the three oak-logs needed for providing the cloveboards for the planking:

Group A represents 4 planks c. 0.4 m wide, and 8 planks c. 0.3 m wide, with a length of 4.6–5.8 m.

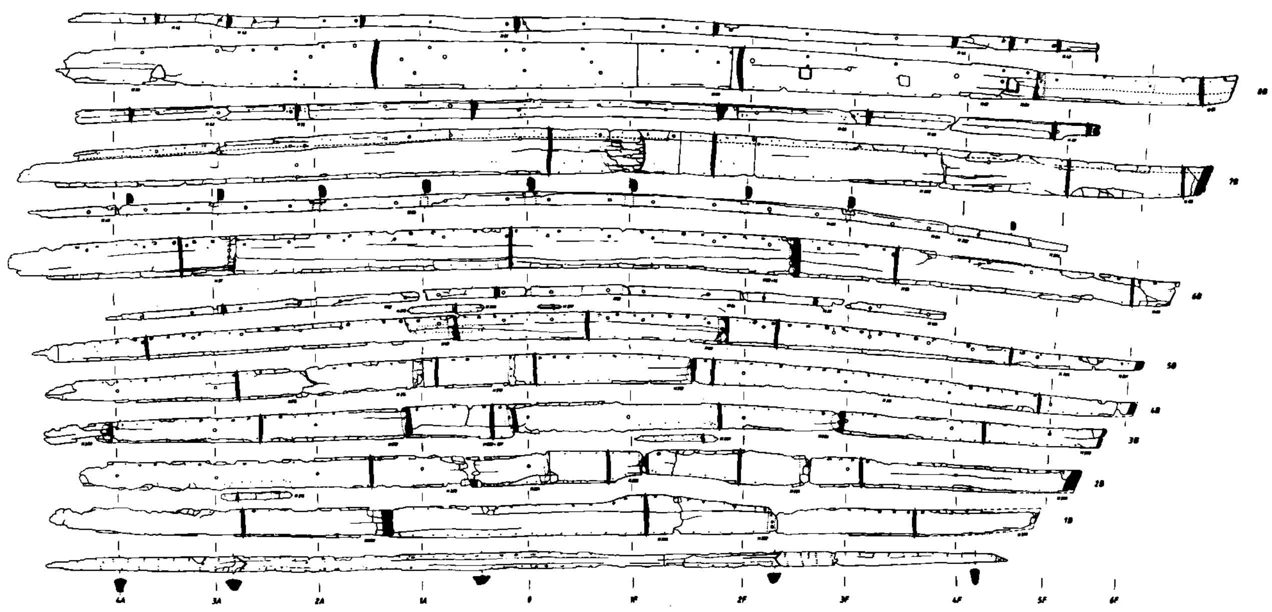

Fig. 9. Port-side planking of Skuldelev-3 as found, showing repairs and missing stern end.

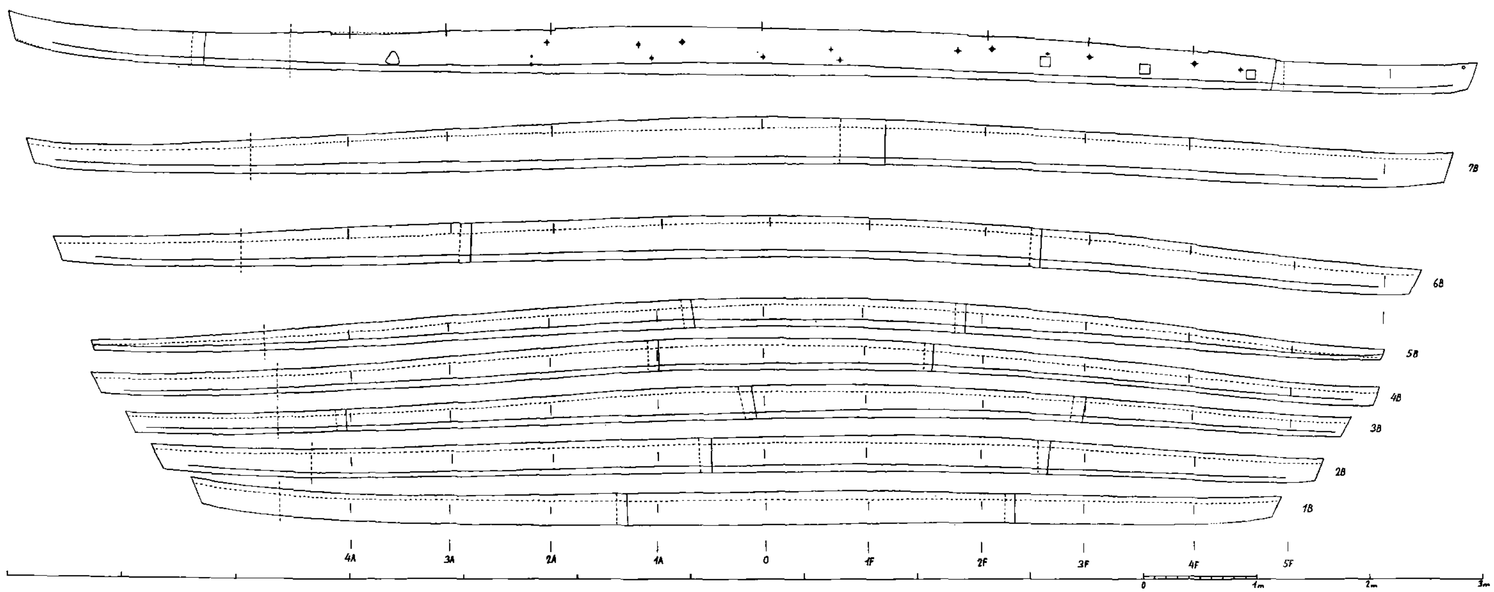

Fig. 10. Strake diagramme prepared for port-side planking of ROAR EGE, after analysis of scarf pattern, lines of afterbody etc. in Skuldelev-3 as built (cf. fig. 9).

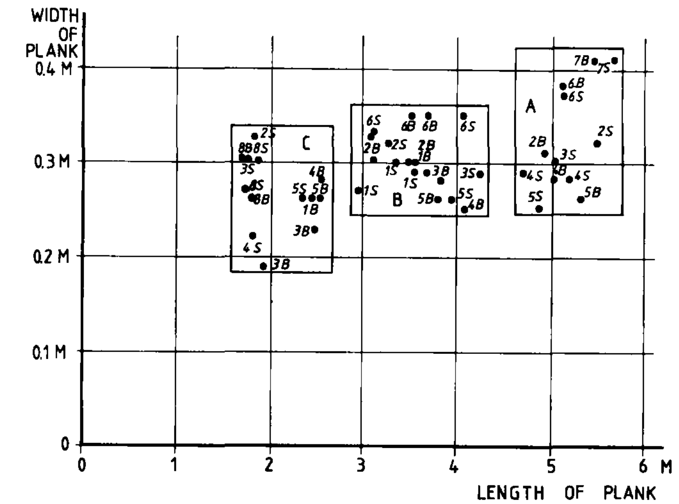

Fig. 11. Graph showing all radially split planks in the planking of Skuldelev-3 as built (cf. fig. 10), plotted according to length and width of planks.

Group B represents 4 planks c. 0.35 m wide, and 14 planks c. 0.3 m wide, with a length of 2.9–4.3 m.

Group C represents 13 planks c. 0.2–0.3 m wide, with a length of 1.7–2.6 m.

It makes good sense to look upon each of the groups as representing one log, except that the four planks in group B should be transferred to group A.

Thus the largest log would need to have a minimum length of c. 6 m and a diameter of 1.1–1.2 m to provide 8 wide planks (34–41 cm) up to 5.8 m in length and 8 planks of normal width (25–33 cm) of a length of 4.7–5.5 m. The remaining 14+13 planks should then be obtained by splitting two further logs, 4.5 and 2.6 m long and 0.9–1.0 m in diameter, into 18 parts each.

We searched for oak-stands with straight and knot-free trees of these dimensions. As a result of an initial lack of experience in selecting logs without spiral growth or internal defects, however, we had to fell more than three trees for the clove-boards of the ship. Quite evidently it is extremely difficult to find logs of the dimensions and quality needed for even such a small ship in the present-day Danish forests.

This gives rise to some questions about the provision of materials for the intense shipbuilding activities of the Viking Age. There are in fact indications of the recycling of shipbuilding materials in the 11th century (Crumlin-Pedersen 1968, 143f, 1986B, 50, Skamby Madsen 1984A, B) and of a later decrease in the average length and width of the planks if those of the Skuldelev 3-ship are compared with the planks of the mid-12th century Lynæs ship (Crumlin-Pedersen 1986B, fig. 8). On the other hand, certain ships show their high prestige value not only in their exquisite workmanship but also by the fact that extraordinarily high quality materials have been used in them, such as the up to 10 m long lengths of radially split planks in the 11th-century warship Hedeby 1 (Crumlin-Pedersen 1969, Schietzel & Crumlin-Pedersen 1980).

Shaping the stempost

The elegant shape of the stempost of Skuldelev 3 showed up clearly during excavation and later (fig. 12). Now it was necessary to take a closer look at this element in order to approach the question of how the Viking-Age shipbuilder determined the shape of this important part of the ship. Various loose stemposts found in bogs, especially in Norway, indicate that the Viking boatbuilder cut such elements to shape and stored these in water prior to construction. One of these stemposts, found on the island of Eigg in Scotland (Shetelig 1940, 179–80), is a very close though smaller parallel to Skuldelev 3 (fig. 13). This stem had been cut to final shape, including the curved lines along the sides and the steps for the planking, before being laid down in the water. It is evident that the stem had not been taken out of an old boat, as the scarves for the keel and plank-ends had not been cut, and no holes for fastenings were present.

Thus we had to accept the idea that the stemposts, even those of Skuldelev 3, were cut to their final shape as one of the very first jobs undertaken by the boatbuilder when constructing the vessel. But how could he design this complicated element, which is the key to the overall lines, the height of the ship's sides etc., in advance without having drawings at hand? And there are certainly no indications that construction drawings were used in Viking or Medieval shipbuilding in Scandinavia.

The most reasonable answer to this question seemed to be to assume that the boatbuilder had worked from a set of rules-of-thumb as known from recent boatbuilding practice. Here the concept of the boat is usually firmly based on traditions of shape and lines, and the scantlings of the actual vessel to be built are

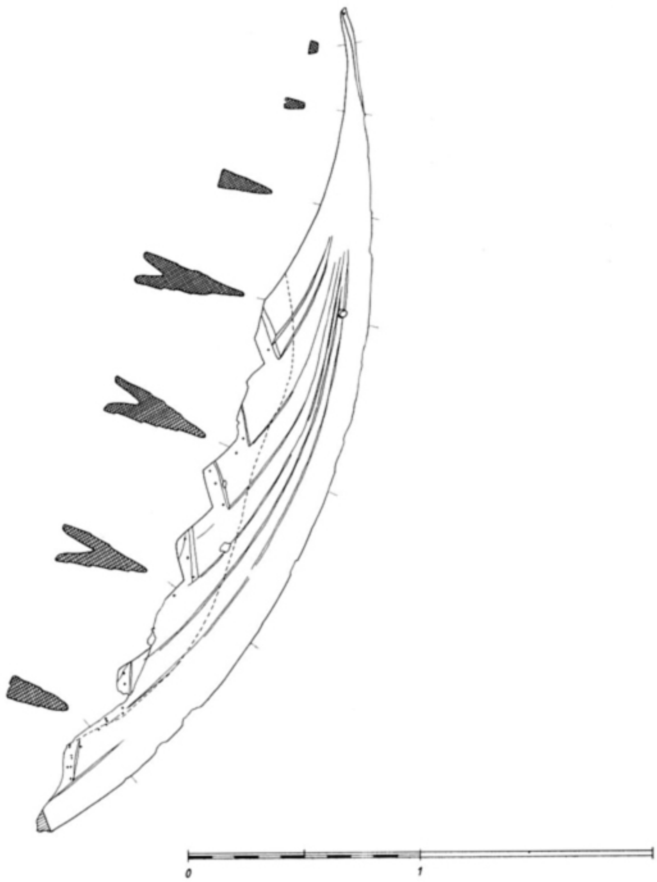

Fig. 12. The stempost of Skuldelev-3 as found.

Fig. 13. Stem piece, 1,93 m in length, found in a bog on the island of Eigg in Scotland. Photo National Museum of Antiquities of Scotland.

based on proportions determined from, for example, the dimensions of the keel.

The shape of the stem was therefore analyzed to see if it was possible to describe it in simple geometrical figures to be drawn up with the aid of a string and a piece of chalk, i.e. straight lines and circles. The result of this investigation was most interesting (fig. 14). It showed that the curved lines on the stem were segments of circles, and that those following the edges of the stem were interrelated in length of radius og position of centre, with a small excentricity at the tip of the stem.

The radii of these circles are 6.0 m and 3.0 m. The upper curvature has a radius of 1.55 m, and the divergence of the tip has been achieved by shifting the centre of the upper curve 5 cm away from the midpoint of the line connecting the intersection of the 3 m and 6 m curves with the 3 m centre. Only after having observed this interrelationship did we notice that the keellength of the ship is 9.0 m.

These observations of the sequence 9–6–3–1.5 m strongly support the assumption that the boatbuilder did in fact work from a set of rules-of-thumb when constructing this ship in the late Viking age. We have probably only traced a very few of his rules, and we do not even know his units of measurement with certainty. The sequence points to units of 25, 30 or 50 cm in length, indicating a hypothenthical foot of 25 or 30 cm or an "alen" of 50 cm.

In the boatyard it was easy to trace out the stem according to these principles. Here the difficulties once again lay in the provision of tree-trunks of the right shape, size and quality. In addition, the stem dried out, cracked and warped in the sun to such a degree that it

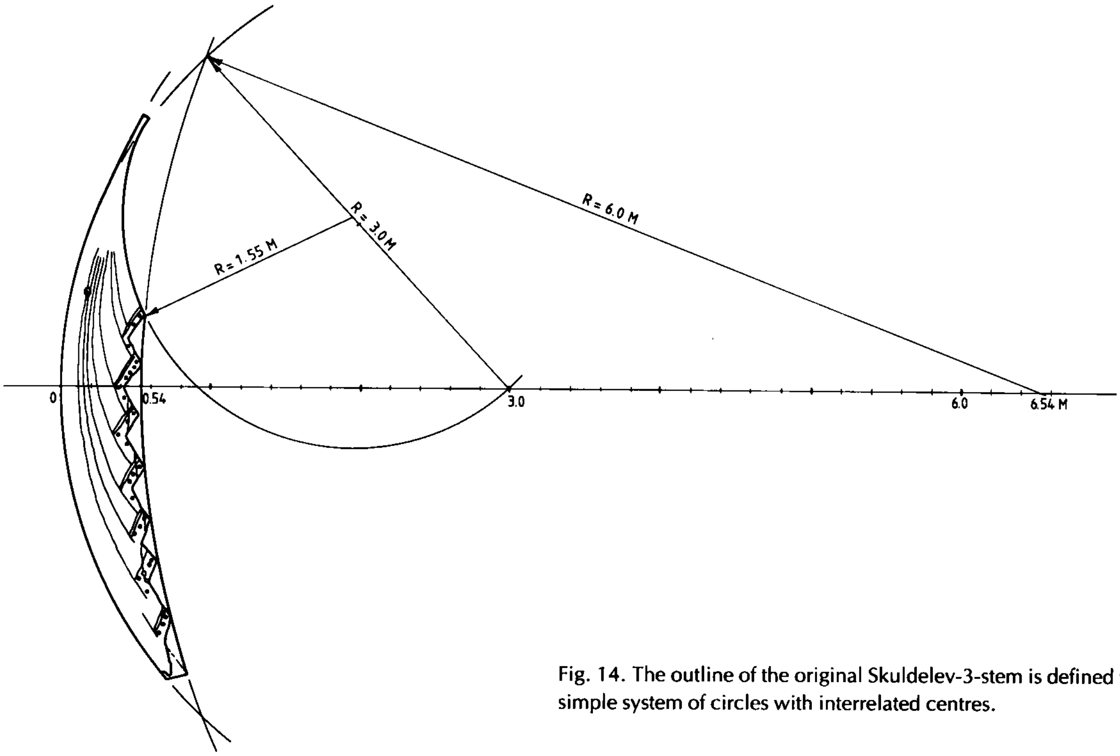

Fig. 14. The outline of the original Skuldelev-3-stem is defined within a simple system of circles with interrelated centres.

caused severe problems. This indicates to us that the stems found in the bog were probably stored there in order to stabilize the wood rather than for other purposes. A prolonged water bath, preferably in a stream, is still used in Japan to wash out some of the sap of oak-wood to stabilize it against changes in humidity (Suenson 1922, 92).

This analysis of the stempost would probably not have been undertaken if it had not been needed for the construction of the replica. A similar analysis may be carried out of other well preserved shipfinds, and they will probably show different proportions between keel-length and radii for the stem-circles, as these relations are bound to vary in ships built for different purposes.

This example illustrates that with Skuldelev 3 we can come into close contact with some of the underlying design principles. The raison d'être for such principles is to guide the boatbuilder in the construction of several ships of roughly the same type and size, and it is therefore permissible to look upon this ship as a representative of an established shipttype rather than as a unique, individual vessel. Further steps along these lines can be taken by studying other elements in this ship and by comparing it with the other ships in the Skuldelev find, taking repairs etc. into consideration.

Axe-work

The tools and techniques used in the past for a specific construction process may be studied with the aid of archaeological finds of

the tools
the finished products,
the semi-manufactured products, or
the debris of the manufacturing process.

The study may even include an analysis of

contemporary written sources,
contemporary iconographic evidence,
possible ethnological/ethnographical parallels
and the evidence from archaeological experiments.

In the ROAR Project all these potential sources of information were kept in mind, even if they were not all analyzed in detail in each case. The most important non-archaeological source for us was the Bayeux Tapestry, which depicts the shipbuilding scene on the shores of Normandy prior to William's conquest of

England in 1066. The archaeological evidence was primarily drawn from the Skuldelev-, Hedeby- and Fribrødre-finds.

We shall here consider one aspect of the shipbuilding process, the transformation of the radially split plank elements, the cloveboards, into ship's planks of individual size and cross-section.

For this task the building team of previous Danish ship replicas had used copies of the broad adze from the Mästermyr find from Gotland (Arvidsson & Berg 1983). This was in good accordance with the recent tradition for using the adze as a shipbuilder's tool for trimming the shape of frames, planks etc. in carvel built ships. But the planks cut with this tool differed in character from the original planks. These are neither plane nor parallel-sided, as they would have been if they had been sawn. They are generally slightly thicker in the middle than along the edges and their cross-section has been shaped to fit hullshape – with an inner face which is convex for the lower planks and concave for the upper planks, and vice versa for the outside.

Because of the nature of the stroke of the adze from a position at right angles to the plank it is relatively easy to cut the hollow sides of the planks with this tool but difficult to avoid making the convex or plane side of the plank hollow too. Thus the planks of the other replicas tend to be thinner along the middle instead of thicker, when cut with the adze.

In addition, the tool-marks to be seen on the planks of e.g. Skuldelev 3 (fig. 15) had a different character from those left by the adze. Evidently some type of axe with the cutting edge parallel, or almost so, to the handle would be a more appropriate tool to use in order to imitate the original work process.

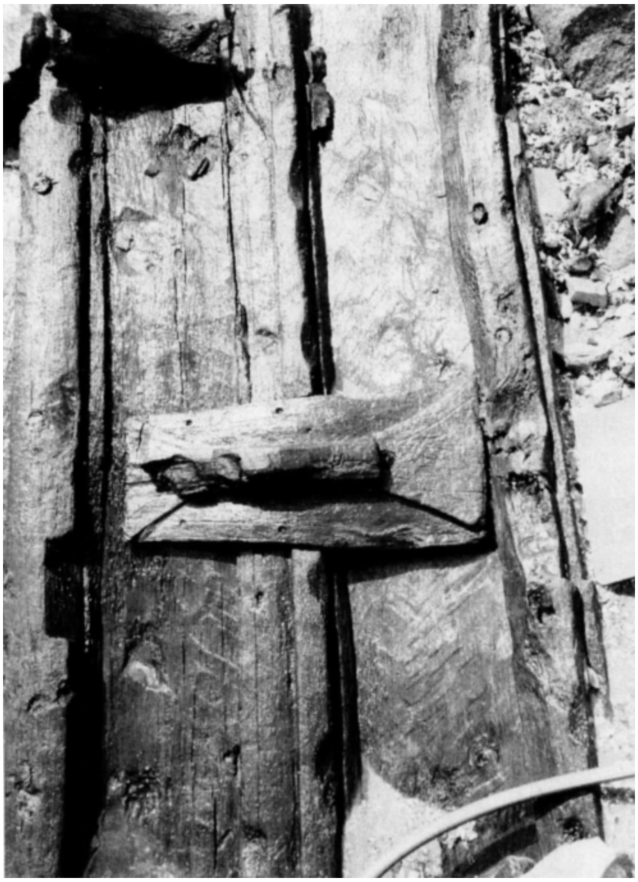

Fig. 15: Axe-marks on the inside of the planking of Skuldelev-3. Photo taken during excavation 1962.

On the Bayeux Tapestry two axe types are shown in use for the felling of trees and the cutting of planks for William's invasion fleet. The ordinary axe with a long handle is shown in three cases in use for felling the trees and possibly for the first stages of splitting and cutting the planks (fig. 16). A very different axe, with a short handle and a broad curved cutting edge, is also shown three times (fig. 17). This is evidently the shipbuilder's tool par excellence for it is shown in the hand of the master-shipbuilder, who is seen receiving orders from Duke William to build the ships for the invasion fleet. Then a man straddles a cloveboard and dresses the side of it to fit one of the ships with the aid of this broadaxe. Finally in one of the ships a man with a broadaxe in his hand is communicating with another person standing outside the ship who is fairing the lines by eye.

These scenes indicate a light broadaxe with an offset or curved handle as the tool we were looking for. A broken broadaxe of this nature has been found in an 11th-century pit in London (Schofield & Dyson 1980, 40). In this case the straight handle could be shifted from one side to the other by moving an iron wedge in the shaft-hole. Nevertheless, neither this find nor the illustrations on the Bayeux Tapestry proves the existence of such an axe in late Viking-age Scandinavia; it might have been used only in Western Europe.

The Scandinavian axe-finds have not been studied in detail by us, as with axes found without a handle it is not usually possible on the basis of publications to distinguish between battle-axes and work-axes.

During the harbour excavations in Hedeby 1979-80,

Fig. 16: Long-handled axes used for the felling of trees for William's invasion fleet in 1066. From the Bayeux Tapestry.

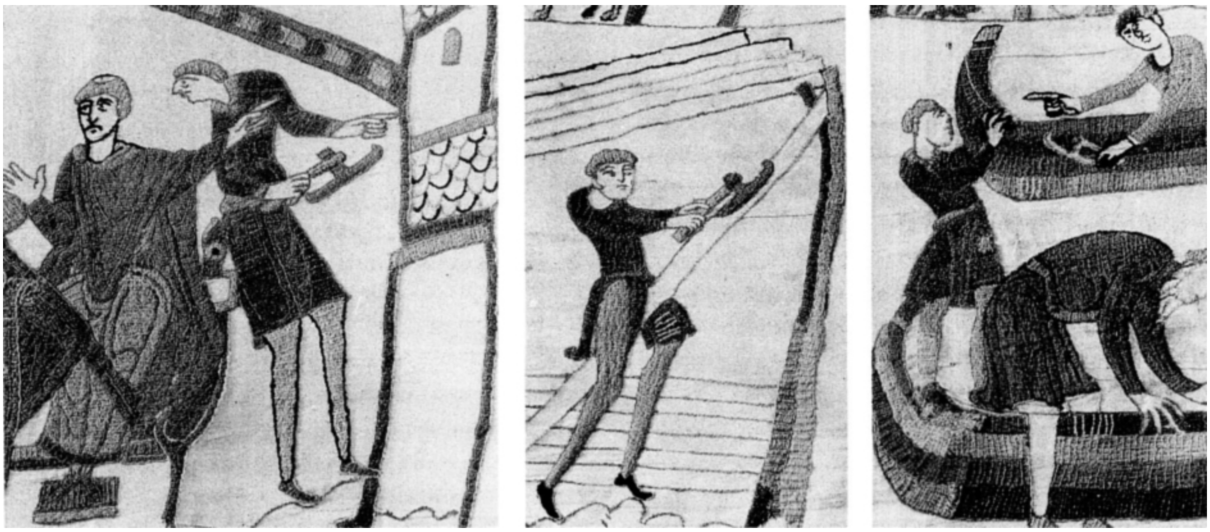

Fig. 17. The short-handled broadaxe is shown in the Bayeux Tapestry in the hands of shipbuilders: 1) receiving orders for the construction of the fleet, 2) dressing the sides of the cloveboards for planking and 3) adjusting the sheerline of one of the ships.

however, Kurt Schietzel spotted a very special axe-head among the tools and weapons found in the harbour. He provided us with a cast, which showed clearly that this axe had only been sharpened from one side and that the shaft-hole was pointing slightly to the same side (fig. 18). Here was definite evidence in a clear Viking context of a specialized woodworker's tool of the kind shown in the Bayeux Tapestry.

A blacksmith provided us with a number of working copies of this light broadaxe, which has proved its value as a handy and efficient tool for dressing the sides of the planks to achieve the correct cross-sections as well as toolmarks of the same nature as those observed on the original planks.

In this case the experimental work guided us on to a search for a specialized tool which was eventually found. The particular features of the Hedeby broadaxe, demonstrating its nature as a woodworking tool, are

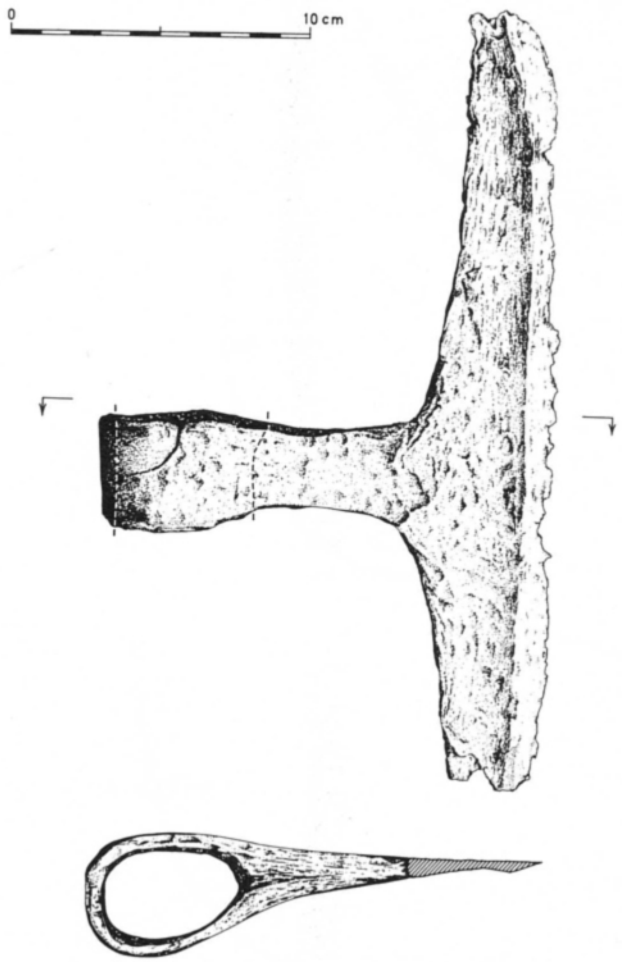

Fig. 18. The broadaxe found in the harbour at Hedeby in 1979. Drawn by W. Karrasch.

clearly to be seen on both the original axe and the cast. But on a standard two-dimensional photo or drawing these features may well remain hidden. Therefore studies of this kind must be based on firsthand evidence. It should also be noted that the wooden chips and shavings left over on the construction site of a woodworking craftsman may, after systematic analysis, offer a good clue to the nature of his activities.

PRELIMINARY ASSESSMENT OF THE RESULTS

The construction of SAGA SIGLAR at Sigurd Bjørkedal's yard gave rise to few questions. He handled the building of the ship with a splendid combination of old traditions and modern tools, and he solved the problems arising during the process before we even realized that there was a problem. Thus the ship itself, and not much more, was the result of this work.

With the ROAR EGE conditions were very different. The prolonged building period was needed to deal with the many problems arising out of the process. Here a few of these aspects have been presented and discussed, and the value of such an approach to the archaeological evidence has, I hope, been demonstrated.

The complex problems of sail and rigging have not been described here. Even though there has not been as much evidence to build upon for the rigging as for the construction of the hull, we feel that we are on relatively safe ground, even with such complex arrangements as the tack in Skuldelev 1. This subject is still under investigation, however, and the results will be reported at a later date.

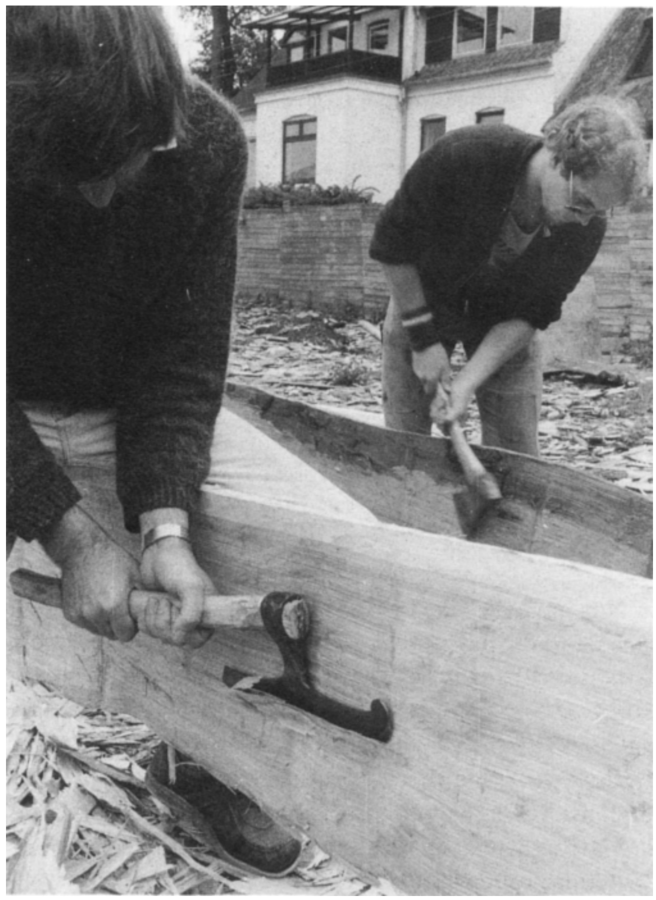

Fig. 19. A replica of the Hedeby broadaxe in use in the ROAR Project.

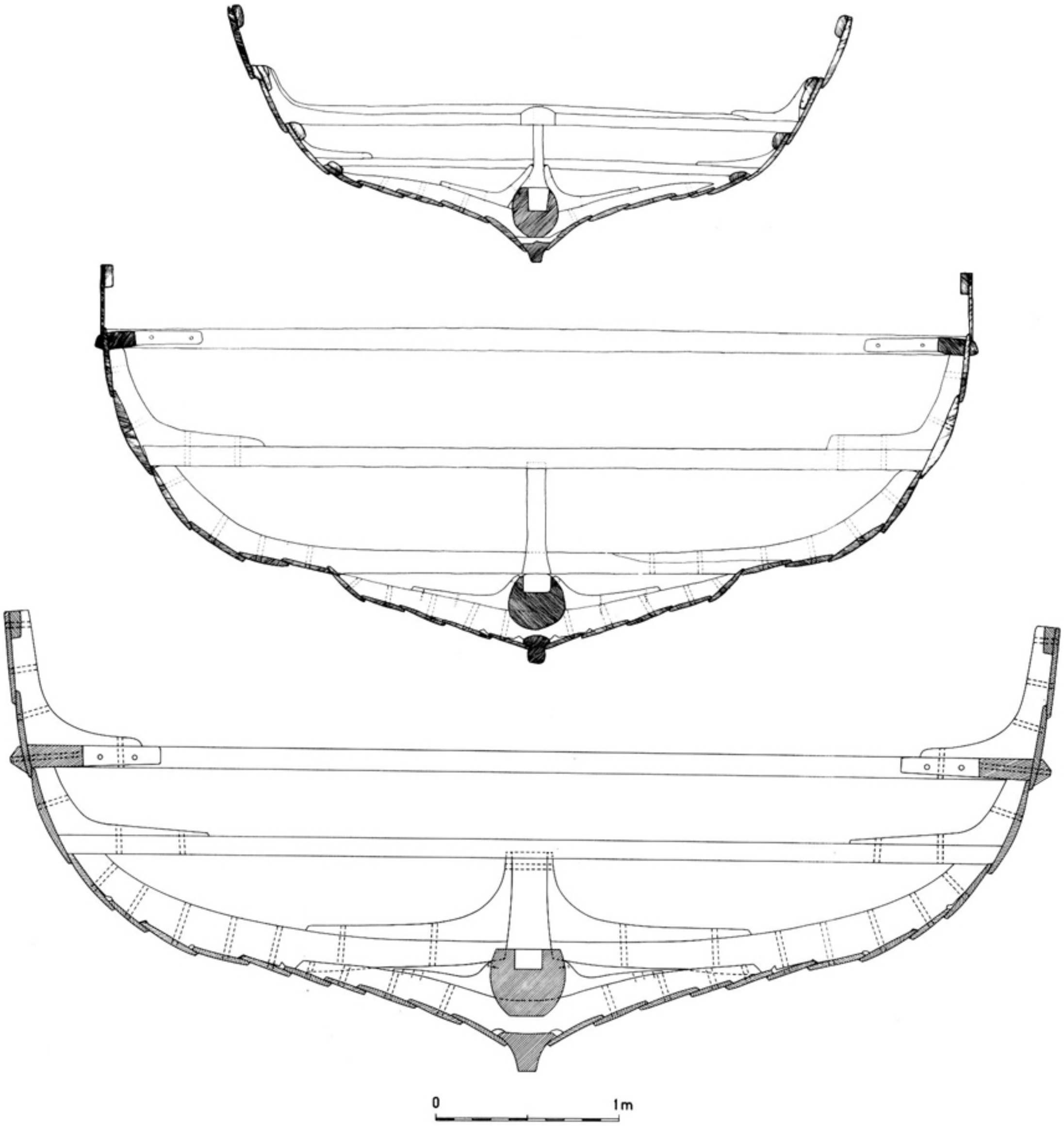

Fig. 20. Cross-section amidships of the late-Viking-age cargoships Skuldelev-3, Skuldelev-1 and Hedeby-3.

Nor have the trials of the two ships yet been brought to an end. Both ships, however, sail very well under all conditions in comparison with the standards of other ships of the age of sail. They do not match modern yachts in their extreme ability to tack against the wind but, on the other hand, few if any of these yachts can match a Viking ship in beaching on an open coast.

Starting from the "load-line regulation" given in the 13th-century Icelandic *Grágás*-text, the cargo capacities of Skuldelev 1 and 3 have been calculated at c. 24 tons and c. 5 tons respectively, corresponding to a payload of 4 tons and 1 ton per crew-member in the two ships (Crumlin-Pedersen 1985B, 84–85). These figures are related to a free-board of 2/5 of the total height of the ship amidships. Trials with the two ship-replicas indicate that this *Grágás*-rulse may relate to a rather unsafe loading tradition by today's standards, but one well known from the 19th-century Norwegian coastal jekts. A safe loading condition for the Skuldelev 1 and 3 ships in the open sea at wind-speeds above 10 m/sec.

is rather to be found with cargoes of 16 tons and 4.5 tons respectively. Even with these figures the capacity of Skuldelev 1 indicates a pattern of trade in the late Viking age involving commodities of large bulk and relatively low value.

Further support for this idea is supplied by the recent find in the harbour at Hedeby of a wreck similar to Skuldelev 1 but much larger. Only parts of the ship have been recovered but sufficient to establish the cross-section amidships (fig. 20), and measurements made by the divers indicate an overall-lenght of c. 25 m. A conservative estimate would suggest that this ship carried c. 38 tons of cargo at a *Grágás*-freeboard (Crumlin-Pedersen 1985B, 87). The ship has been dated by its context to the late Viking age.

Thus we have very solid evidence of late-Viking-age ships carrying shiploads of c. 16,–20,000 kg and c. 35,–40,000 kg respectively per voyage. I shall leave it to other archaeologists to consider the nature of the goods in these shiploads but on the basis of the experiments with SAGA SIGLAR and ROAR EGE I can confirm that these vessels were well suited for their purposes, being well built and seaworthy to standards which have hardly ever been surpassed by other undecked vessels in the entire age of sail.

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