THE ROLE OF THREE-DIMENSIONAL RESEARCH IN THE KYRENAIA SHIP RECONSTRUCTION

Through the medium of nautical archaeology, well-preserved shipwrecks often clarify what could only be surmised before. For instance, scholars long believed holkas to be broad, tubby, and comparatively small merchant vessels as illustrated by vase paintings and models. The discovery of the Kyrenia ship confirmed this, but additionally provided details such as principal dimensions, tonnage, the types of timber used for construction, and the graceful lines of the hull. It clarified vague construction details, too. Homer hinted at the methods of mortise-and-tenon joinery, but only a discovery like Kyrenia could be expected to provide so many precise details—joint spacing and size, the direction of tapered pegs, the wood types employed, tools used to cut mortises, etc. Without a doubt, the introduction of underwater archaeology has added an important dimension to the study of ships and seafaring.

But archaeology cannot supply all the answers either. Some materials are so fragile that they are destroyed by the most careful removal of overburden, some do not survive recording and conservation, and recording techniques still lack perfection. The greatest obstacle lies in the fact that no shipwreck is completely preserved—there are gaps where nothing survived, topsides and ends usually disappear completely, and distortion belies original hull shapes.

Another dimension can be added to the study of ship construction and handling that overrides some of these shortcomings of archaeology and archival studies. In my laboratory it is called three-dimensional research, a form of experimental archaeology utilizing models, mock-ups, replicas of individual hull components, fragment assemblies, or other physical devices designed to solve problems. Eighteen such devices were used to enhance research on the remains of the Kyrenia ship. They ranged in size from a working model of the mast step to a two-meter-long replica of the hull's midship section; some were as simple as a single planking scarf, while others duplicated every joint, nail, and curvature in the original hull. The replica launched last June is the latest and most elaborate of these testing vehicles.

The use of models and replicas

Three-dimensional research can be a powerful tool when used to interpret the remains of sunken ships. Most of the devices used in Kyrenia research provided some new information, while a few others merely confirmed what was suspected before. One model was not worth the effort of building, but this too is part of research. The program as a whole was extremely successful, contributing new information which could not have been determined from any other source. Indeed, we could not have built the present sailing replica with such confidence and accuracy had it not been for the experimental models.

Three-dimensional research vehicles —let's call them models for the rest of this
presentation—have the potential of probing subject areas that graphic and archival research cannot satisfy. The nature of their construction is such that one is forced to duplicate the original builder's movements, thereby revealing techniques and processes. Their shape permits volume interpretation where only areas could be interpreted graphically. Their bulk and strength are increments of the prototype, permitting a better understanding of these characteristics. Their comparative strength sets limits for error, and their resistance to unnatural curvatures refutes blatantly false assumptions. Most importantly, these models must answer the laws of physics and geometry, and thereby their conclusions can be proved.

Like all other forms of investigation, however, the resultant value of research models is directly related to the faithfulness of reproduction and the extent of applied information. One could not expect to obtain reliable information from the Kyrenia replica had it been built from different materials or by different techniques than its prototype. But by using oak tenons and pegs, making at least some of the mortises by ancient procedures of drilling and chiseling, installing them with similar dimensions and spacings, and occasionally testing hull strength, it became obvious that these fastenings were much more than connectors for plank edges. Essentially they were little internal frames whose size and spacing were carefully regulated to add considerable strength and stiffness to the hull.

One cannot replicate an ancient ship, or even draw its hull lines, by directly reproducing what is seen on a shipwreck. That vessel has been distorted and flattened into the seabed, some of its members being bent or cracked to shapes and sizes which now contradict their original and true characteristics. First it is necessary to understand what to build, how to build it, and how to obtain the most information from it. That is a long and involved process which is now being prepared for publication; this paper discusses the more important processes briefly, and describes a few of the models used to implement them.

Interpretation of the Kyrenia ship began with the start of excavation. Cargo distribution and seabed hull dispersion are important in the study of hull construction. After a site plan of the vessel was produced, hull parameters could be determined and structural components identified. As soon as timbers were excavated and stored in fresh water, they were photographed individually and full size drawings were made of each of the fragments. Descriptive catalogs also were compiled. So far all the reconstruction work could be handled by graphic methods, but already details appeared which were not recorded previously, and construction techniques surfaced which we did not understand. The answers to many of these new mysteries could not be solved by literary or graphic investigation. It was at this early stage of the project that models were first employed as aids in the study of the hull. They were simple, crude models, but nevertheless they provided the answers we needed to proceed with our work.

One example of these early models was the one used to solve the riddle of the patch tenons. "Patch tenon" was the name we gave to those curious fastening devices which had one end exposed on the inner or outer surface of planking,
appearing as rectangular “patches” (fig. 1). In all cases these tenons were found in association with planking that was not as degraded as most of the hull planking, suggesting that they represented some sort of repair or replacement. But some authorities had assumed that replacing rotten strakes on classical hulls would have been difficult or impossible because of the method of edge-fastening employed in the construction. The only way to answer such a question with certainty was to duplicate what we saw and experiment. In this case a section of the port bow, consisting of a suspected replacement strake with 7 patch tenons and its adjacent strakes and frames, was reproduced exactly as found on the original hull. In relatively short time the purpose and method of installation of patch tenons was understood, as was the way in which ancient ship carpenters replaced rotten strakes.

I do not mean to infer that the basic function of the patch tenon could not have been interpreted graphically. Indeed, I was certain of its function before I built that little assembly of planks and frames. But the three-dimensional aspect of that experiment additionally suggested the reasons for the particular shape of the patch tenon. One has to actually drive these things, experience the resounding snap when they are correctly shaped and driven into place, and feel the rigid attachment they create in order to understand why they were so made. There were additional advantages in making these strakes and performing an actual repair, and herein lies the real benefit of three-dimensional research. Duplicating the work of the ancient shipwright automatically reveals unexpected problems and techniques which ancient builders experienced. Engineers call this phenomenon “spin-off”, the accidental acquisition of knowledge beyond that intended for the project through the familiarity and confidence gained by frequent and concentrated experimentation. Probably no greater benefits have come to mankind than through the spin-offs of space research, but we experienced some interesting ones of our own on the Kyrenia project.

The patch tenon experiments contributed two additional revelations which were important to our understanding of ancient construction. The first came when the strange edge angles and shapes of the replacement strakes were considered; that revealed the nature and sequence of all the repair work done on the Kyrenia hull. This information has been published already and will not be included here. The second matter has been mentioned in previous papers and soon will be published in great detail, but it deserves some consideration at this conference. It became apparent in our models that after the rotten strakes and their adjoining tenons had been cut out of the hull, the replacement of the strake could follow the same procedure used in modern wooden hulls. The frames were already there; it was necessary only to nail the new strake to the frames as is still done in the eastern Mediterranean. But that was not the way it was done. Our ancient shipwright carefully and laboriously cut a series of replacement mortises and tenons at the same spacings as the original construction, shaped the new plank surfaces and edges to fit in all directions, and installed a very strong repair without

251
any frame support. Only after all this work was completed did he add the frame nails, an extra measure of security to be sure but not an actual necessity according to the strength of our model.

The use of these strong patch tenons illustrated the degree of importance our ancient shipwright placed on the mortise-and-tenon joints and how secondary he regarded the role of framework. No graphic or literary study could have made us appreciate this fact sufficiently, because it was the strength and functionality of the model alone which could provide such information. This, more than any other experiment, illustrated the differences between shell-first and frame-first construction.

Another of the more basic model types used in the Kyrenia project was the mould-and-batten model, an early method of determining hull shape. It would not be wise to attempt to reassemble wreck remains without first learning something about the vessel's design and construction. The original function of these models was to supply such information. But even after the hull fragments were reassembled there would still be questions about its design and construction. The Kyrenia shipwreck was exactly that—a wreck. Like so many other shipwrecks in the Mediterranean, it had lost its ends and topsides, had been smashed and flattened to the seabed by the weight of its cargo, was partially distorted by the disorderly release of its joints and fastenings, and had much of its strength and bulk destroyed by rot and teredo. Dimensional change automatically resulted when individual fragments were removed from their seabed environment and treated chemically. While the reassembly of such remains presents a good illustration of the original hull, it cannot possibly supply all the answers. The reassembly in Kyrenia castle provided most of the information used to construct Kyrenia II, but some of the details had to be acquired by the same models or types of models first used to determine hull design and construction techniques.

The final lines drawings of the Kyrenia ship were the result of a combination of information sources, most of which was confirmed by three-dimensional projections. Timber dimensions were taken in the waterlogged state. In the event that original dimensions had been altered on the seabed or during freshwater storage, a distinct and not infrequent possibility with waterlogged wood, additional dimensions were derived from impressions made by the contact of one member against another. Total distances along curved frame and plank members were checked against the sum of the individual fragment measurements which were joined to them. With Allepo pine hulls such as Kyrenia, curvatures tend to be reliable along surfaces where cracks and breaks do not exist but are suspect where cracks are present. Therefore, in addition to recording existing curvatures of frames and planks, curvatures between cracks and breaks were recorded individually and plotted as the geometric sum of a series of arcs. The plotted curvatures then were checked against those of contacting members, nail and joint spacings, and other supporting data. All of this information was combined and compiled directly on hardboard sheets which described the hull shape visually. The
hardboard moulds were marked with all sorts of information: planking seams, nail locations, important tool marks, etc. When enough of these moulds evolved, it was possible to project the hull lines by connecting them with thin wooden battens along their marks for plank seams, level lines, and buttock lines (fig. 2). This presented a far more accurate interpretation of the hull shape than that derived exclusively from existing hull shapes or from the reassembled hull remains. It had the additional advantage of requiring a careful study of every fragment surface, thereby assuring a thorough investigation of all areas of the hull.

In all there were five mold-and-batten models used to develop the final Kyrenia lines, and it took several years to arrive at what I considered to be the most accurate set of lines possible. This was because each new process in the reconstruction presented additional information which could be applied to a more complete or accurate set of architectural drawings. The layman might not have detected much difference between the first set of drawings and the final set (fig. 3), but indeed there were important differences to those interested in the finer details of ancient construction. Three of the models were mere assemblies of hardboard moulds and thin wooden battens; two others were rather complex with detailed fragment drawings on milar attached to posterboard skins. These mould-and-batten processes are no longer used in my laboratory reconstructions. The simpler procedures are done with computer graphics; those demanding more precision are accomplished on what is known as a fragment model (fig. 4).

An example of how modern and contemporary models can be combined to solve problems may be seen in the mast support studies. The excavated mast step and what were thought to be two partner beams were modeled in pine (fig. 5) after graphic studies did not supply the information I believed to be attainable. Only after extending these partner beams in the experiments did it become evident that they closely resembled the arrangement found in a Cypriot clay model (fig. 6). In fact, there were excavated parallels for some of the other timbers indicated in the mast support structure on that model. By rearranging our model to resemble the partner and stanchion arrangement in the clay model, all of which satisfied excavated evidence, it was possible to reconstruct the step and partner assembly shown in figure 7. It is exactly the reverse of that found in the clay model, whose mast would have reclined in a forward direction.

It is impractical to describe here the construction and function of all the other models used in reconstructing the Kyrenia hull, but one other deserves brief consideration. Some models have value only because they disprove faulty theories or illustrate what could not have been. Such was the role of the sailing model, a 3-meter-long glass reinforced plastic (GRP) vessel configured to evaluate excavated rigging artifacts, test hull characteristics, and perhaps learn something about ancient sailing techniques (fig. 8). Although not intended to fulfill the functions of a sophisticated tank model, it did reveal a lot of facts about the hydrodynamic properties of the hull; the replica has already confirmed some of these findings.
We also were able to observe some of the basic principles of sailing with brailing gear, the use of quarter rudders (steering oars) with this type of hull, and values for centers of effort and lateral resistance. But most of this information came in a negative way, revealing what should have been on the model rather than what we put there. The sail, which was higher than it was wide, was found to be much less efficient than one of lower aspect and greater breadth would have been. Obviously, those vase paintings showing low, wide sails are not mere stylizations. Its area of 700 square feet seemed about right, however, and early indications are that the replica will confirm this sail area.

The stem, whose vertical portion had disappeared on the wreck, was configured in rounded form. The mold models and the excavated evidence pointed to a short, upright stem but there were a few good arguments for a round stem which could not be ignored. One of the ways to help prove or disprove the stem configuration was to test the sailing and displacement characteristics of each shape. Hence the GRP model was given a round nose. The sailing tests indicated that this gave her poor lateral resistance, and suggested that our earlier drawings of a vertical stem were correct.

On the sailing model, a set of balanced quarter rudders were mounted in the quarter rudder position. They represented paired blades of the type we found on the Kyrenia wreck (fig. 9). But our tests revealed that this was too large a blade, resulting in oversteering or erratic handling. In short, our model (and subsequent tests) was telling us that it would have been better to use oars with single blades of the type we had found. This certainly satisfied the evidence better than double blades, and the resulting replica-type oar was reconstructed (fig. 10). There seems to be a contemporary parallel to such a blade in the black vase painting of a pirate vessel attacking a merchantman which, although the painting is not disciplined enough to use for interpreting details, certainly is suggestive of the way in which the Kyrenia ship may have met her fate.

The Kyrenia blade, which I believe was part of the starboard rudder at the time of sinking, was 7 cm thick at the top and tapered to a 3 cm thickness along its bottom edge; maximum width was 32 cm. Its reconstructed length of 1.7 m is based on the tapering blade thickness which survived, the arrangement of fastenings, and the hull depth and waterline which it had to satisfy. The loom had disappeared completely, although it impressed its dimensions on the blade before doing so. Copper strapping holding the upper end of the blade to the loom had been torn away as well, but the metallic residue remaining in the grooves left little doubt as to the thickness or identity of this material. The nosing, which must have been wood, was thought to be made from the same kind of Turkey oak as the tenons and false keel. The original blade was made of pine.

Loom length, tiller design, and attachment to the hull are completely hypothetical, being based on contemporary evidence and the structural patterns found elsewhere. On the model tests it was determined that steering was more efficient on a tack when using only the leeward rudder. Downwind steering could
be accomplished equally well with one or two oars. This assumption remains to be tested on the replica.

These were but a few of the many three-dimensional approaches to our study of the Kyrenia hull and rig. I do not mean to infer that models can replace graphic and archival studies in historical ship interpretations. Both are very important ingredients of reconstruction. But models can often make significant contributions where results cannot be acquired by other means.

There are weaknesses and shortcomings in these three-dimensional vehicles, though. One needs a certain degree of manual dexterity to design and produce them. They are rather time-consuming and, therefore, can become drains on project funding. For these reasons, our laboratory is experimenting with graphic computer methods of some phases of cataloging and reconstruction. But I predict that models will always have an important niche in the study of shipwrecks. The green screen of the computer and the milar surface of the drafting paper present only modern technological atmospheres. Nor do they possess the ability of wood to restrict and discipline the thoughts of the researcher. When one builds a faithfully executed model, even in scaled-down size, he is forced to duplicate the same processes, suffer the same problems, and feel the same strength and soundness in his wooden reproduction. There is no better way to crawl into the mind of the ancient shipwright.

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Notes

1. Two examples of holka illustrations are the paintings on a 6th century B.C. Attic black-figure cup in the British Museum (see J. Morrison and R. Williams, Greek Oared Ships, 109, pl. 19), and the 6th century Cypriote clay model in the Cesnola collection of the Metropolitan Museum of Art in New York (see L. Casson, Ships and Seamanship in the Ancient World, ill. 94).


4. Steffy (supra n. 3), 95-99.

5. A number of drawings and models with rounded stems were produced as part of the research for reconstructing nonexistent bow areas. When overwhelming evidence favored a bow as on the replica, the rounded hull experiments were abandoned. Unfortunately, some of these earlier drawings and photographs inadvertently reached the public, resulting in a few paintings and models by others showing the Kyrenia ship with a round stem.

Fig. 1. Patch tenons on replacement planks and installation details (author).
Fig. 2. Two views of a simple mould —and— batten development model (author).

Fig. 3. The lines of the Kyrenia hull (author).
Fig. 4. A fragment type of development model (photo Cemal Pulak).
Fig. 7. The reconstructed mast supporting system as used on the replica (author).
Fig. 5. Mast and partner stanchion steps as excavated (author).

Fig. 6. Copy Cypriote clay model. (In the British Museum).
Fig. 9. The blade of the quarter rudder excavated near the stern of the vessel (author).

Fig. 10. The reconstructed rudder blade (author).
Fig. 8. The sailing model. (Susan Womer Katzev).
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