RIGGING THE ATHENIAN TRIREME

Interaction of Sail and Hull SLIDE NO:1

The starting point was to understand how and why the ancient Aegean sailor had used his sail. The control characteristics of a sailing boat depend on the indivisible relationships of sail distribution, immersed hull shape, rudder profile and position. It soon became clear that in the Mediterranean this interaction had been understood from the beginnings of sail. The iconographic evidence shows hulls with keels extended as rams, low broad square sails, masts stepped aft of or close to the centre of the waterline, and long narrow rudders hung from overhanging stems. It is possible to infer from the "above waterline" evidence that the seamen had to overcome a problem of directional stability when they took to using sail in the Aegean.

The clues to this are in the relative disposition of the sails and rudders and in the hull profile. Sailing skills of that age would be based on the developments made in vessels of, say, less than 20 metres but would continue to be applied to much larger galleys. The latter, because of their greater beam to length ratio would reduce the problem of directional stability while creating others.

Rudders - or adjustable leeboards?

Let us begin by considering the rudders of these smaller vessels. The rudders are of the balanced type and are long and narrow. Each blade has a high aspect ratio which would be most effective when hung from an easily turned hull but liable to be stalled if used in a deep drafted vessel. Since these rudders may be swung upwards when in use they would be deep, well below keel level. In that position not only would they be rudders but they would also function as lee boards too. The writer believes that in some cases only the lee rudder was used when sailing to relieve the fastenings of the weather rudder to the hull. Their position abaft the water line increases steering effectiveness but places the hydrodynamic lift created by water flowing obliquely across their surfaces an unusual distance from the sail's Centre of Effort. Two assumptions may be made because of the rudders:

a) The hulls of the smaller galleys are shallow and turn easily.

b) The hulls draw most water aft at a point probably just abaft the mast position.

Hull shape and Directional Stability

The usual profiles of the galleys would seem to support two assumptions. The vertical stems would influence the run of the planking and produce "Veed" hull sections below the waterline for some distance aft. A swept up stem post suggests that the garboard and second strake in that area would have had little deadrise, or that subsequent strakes would certainly be flattend out. Consequently the greatest waterline beam would be aft of the mast position. A ram just breaking the surface indicates least draft for'ard. A gently rockered keel leading into a curving stern post would seem logical and is to be seen in some illustrations. An obtuse angle between the keel and sternpost is likely also as in the Giglio wreck.

Whichever construction is used the form of hull described would attain its maximum speed easily when rowed and steer well. It would have its upright Longitudinal Centre of Buoyancy well aft of the mid waterline section, which is useful if at near maximum speed and on an even keel since it prevents the stern's squatting.

Sailing downwind stepping the mast in the fore part of the waterline would suffice. However, this would prevent the steering of a reaching course, ie, with the wind abeam.

In the Kyrenia wreck and subsequently in Kyrenia II the mast step seems to be in the forepart. It has been suggested that she may have been fore and aft rigged, inspite of the presence of lead brail rings (Katzev, 1972). Certainly when the writer sailed in a square sail rigged Kyrenia II that vessel would only sail downwind. Dare the writer propose a reassessment of that wreck's remains, beginning with the hypothesis that when the ancient hull was trimmed properly the mast step would have been close to the centre of the load water line?

A mast stepped at the centre of the waterline would return control to the helmsman who would then experience weather helm. In gentle breezes weatherhelm would be useful since in steering to correct it the combination of rudder angle and leeway would counteract the excessive leeway.

The Vikings and others in Northern Europe solved this problem in a similar fashion. Their hulls were symmetrical. On heeling the Longutudinal Centre of Buoyancy would barely move. The deep side rudder maintained control of the slightly increased weatherhelm. (Roberts, 1984).

The ancient Mediterranean galley, as suggested, had an altogether different form. Kept upright the sailing speed would be very fast. However, the least heel would create exceptional steering problems. The longitudinal Centre of Buoyancy would move aft creating overpowering weatherhelm. The rudders would stall and the vessel would gripe violently. Iconographic support for this scenario is obtained from three illustrations of galleys with the after half of their sails brailed up. The Centre of Effort of the sail is moved foreward to balance the griping action, thus letting the helmsman steer. Knowledge of this problem and how to control it is to be found in the fourth century work **Mechanica.**

This lucid explanation stops short of giving the causes of the needs for such actions which were embalmed in the centuries old traditional concepts of what constituted a proper form of hull. The writer is sure that the brails were never intended for this purpose but lent themselves effectively to being used as a practical solution to an alarming problem. To summarise: it is believed that the smaller Classical Mediterranean galley had a fast, shallow hull which would be considered unbalanced by modern sail boat theory. To counter this the sail not only propelled the hull but was essential for maintaining directional stability. The deep, narrow rudders not only steered, but acted as leeboards.

Two Masted Sailing Galleys

The form the two masted rig took in the large, narrow galleys seems to be different from that fitted in the beamy round ships. The latter had hull balance problems, when under sail, similar to those of the smaller galleys. Being larger a foremast or artemon was fitted over the bows where the small square sail would be most effective. The large galleys of narrow beam had a different problem. The practice was to send ashore all sailing gear before battle (Morrison and Williams, 1968). Therefore the practice of dividing a large sail area into manageable portions was established about this time. Also a single central sail might have had the same effect on steering as an unbalanced hull. The setting of main and boat sail when reaching would make steering easier. Brailing of the main would remain an extra option.

General Sail handling SLIDE NO:2

No reef points were needed as the sail could be partly brailed as required. Some drawings show the tacks hanging down while others were capable of being brailed up with the rest of the sail. What has been considered to be a two part brace is thought by the writer to be a single brace and leach brail together with their belay points adjacent. Under tension the leech brail would be functioning as a brace too. It has been suggested that there were buntlines. It is evident that the lee side of the sail is shown in a primitive perspective. The lines across the lee side of the sail are in fact its horizontal seams. The level way in which the sails are brailed is sufficient to indicate that no buntlines existed. Where no leech brails were fitted the sail area above the tack was lashed in a tight roll. Reefing by progressive brailing would not be detrimental to performance in free winds.

Furling the sail is an extension of reefing. In 1981 the writer had the opportunity to sail around Gotland in a Viking replica boat which set a broad square sail based on drawing found on the sixth century AD Gotland Stones, Dr Erik Nylen of the Gotlandsfornsal, Visby, had interpreted the web of lines drawn beneath each sail as controls necessary for the efficiency of a broad square sail (Nylen, 1983). Before the wind unless controlled, the tacks draw together as the foot curves forewards. Dr Nylen fitted lines beneath his sail for holding by the crew. This drew down the foot and pushed out the tacks. The writer fitted tell-tales over the sail and was able to demonstrate the changes in air flow which resulted (Roberts, 1984). In 1985 while in Kyrenia II the writer suggested tensioning the middle brails. This had the same result as the Viking sail. Some of the iconographic evidence shows sails in this attitude in Severin's "Argos" this point was missed and late Scandinavian middle-sheets were employed (Severin, 1984). For the two masted galleys the mid brailing of the main would ensure a better air flow for the boat sail.

Brails - Problems and Fittings SLIDE NO:3

A brail pulling up a sail pulls down on the yard. This would explain those drawings showing galleys with curving yards. Nowhere was there seen evidence of lifts to support the yards. Therefore in strong winds tensioned brails pulling against taut sheets and tacks must have produced curved yards. To compensate for these stresses fished yards were used. By having a quarter to one third of the yard fished the yard could effectively be made stiffer. The Athenian Trireme's mainyard is fished for a third of its length and the writer looks forward with interest to see how it curves during sailing trials in 1988.

As stated no evidence was found for there having been lifts even in the rig of third century AD Roman ships. The writer believes that those Roman ships displaying what seem to be multiple lifts really show the Roman answer to avoiding a bent yard. Instead of leading directly to the deck the brails are led to a series of fairleads higher up the mast, then down to the deck. This is particularly well illustrated in figs 2 and 12 in L. Foucher's **Navires et Bateaux** (Tunis, 1957) So far only one drawing shows a fairlead for the brail where it passed over the yard. It appears to be a forged staple with its legs bent outwards (Morrison and Williams, 1968), no doubt flattened, so that it may be lashed or nailed in place. This form and others were considered for the Athenian Trireme. To avoid the brails' jamming at the side and to prevent wear over the yard, a design with a totally closed fairlead hole was chosen. These were cast in bronze and nailed in place.

In wrecks where lead brail rings have been found one wonders what happened to the metal brail fairlead. Did the yards float away? The reason might be that wooden fairleads were commonly used. They would be perfectly adequate. The only metal fairleads in the iconography may suggest a limit on their use to the largest of rigs.

The bulk of the evidence shows brails passing over the yards. The Later Roman evidence, as in the Portus Relief and Herodotus' statement that nations "attach the rings and brails to their sails on the outside", ie., the lee side, "while the Egyptians attach them on the inside," support the general view that the Greek galleys used the leeside too.

It seems that having passed through the rings the brails were fastened to the foot of the sail. However the writer believes another an older method of brailing co-existed in the Aegean. It is to be seen in its earliest form in the ships of Ramses III and the Sea Peoples as depicted at Medinet Habu, Egypt dated about 1176 BC (Casson, 1959). These have their sails furled in a way that could only have been achieved by passing each brail under the foot of the sail, up the weather side and fastening the end to the yard, no brail rings being used. It is a logical method if furling is the only purpose of brailing and as such the technique has lasted to the present day. The later addition of brail rings enabled the brails to be used for reefing too.

The examples of this older method are in one of the merchant vessels on an Attic vase from 500 BC (Katzev, 1972) and in Odysseus' ship on another Attic vase. The brails in the former are heavily drawn around the sail and in the latter not so convincingly. Probably brail rings were used too since no billowing of the sails is evident. The benefit to a merchant vessel is the mechanical advantage to be obtained when sweating up the brails in strong winds with a small crew. The Kyrenia II uses this system, quite rightly in this writer's view. In a galley with plenty of manpower the one side brail is sufficient. It reduces the rope to be hauled by half and halves the time needed to brail.

Brail rings may have come into general use only about 700 BC since some vessels prior to that time are shown with tightly brailed sails on straight yards. Later the yards begin to be shown curved which indicated the use of brails for reefing and that action would be possible if brail rings were fitted.

Herodotus' claim that the Egyptians had brail rings on the weather side of the sail may be a misinterpretation of their use. In the Temple of Edfu on the Upper Nile, where Herodotus had travelled, is a relic from the 2nd century BC (Basch, 1978) showing a sailing boat with such rings but the writer has explained elsewhere that their purpose is to guide lines which trim the low broad sail before the wind (Roberts, 1987).

In the Athenian Trireme lead brail rings are sewn at intervals to the seams of the lee side of the sails. Those for the leech brails are of bronze because of the strains on the leach.

The Sails SLIDE NO:4

Sufficient information exists for many of the technical details of Classical sailmaking to be deduced. In literature reference is made to pieces of cloth needed for sailmaking (Morrison and Williams, 1968). Many drawings show seams in the leeside. In fact it is not so much a seam that is shown but the reinforcing strip sewn over it. This would explain the absence of seams on the weather side. Seams appear to be reinforced in a horizontal direction only to withstand shear in the vertical seams. Perhaps the reason for this is that the brails would support the sail vertically and relieve shear strain in the horizontal seams.

In the Athenian trireme No 6 R.N. flax canvas was used. Vertical seams are in fact false, the canvas being arranged in horizontal cloths. Straight seaming stitches were used throughout. Leather was used to reinforce the seams and as a tabling for all edges of the sail in accordance with the literary evidence and the later Portus Relief (Casson, 1971). In deference to doubts expressed a removable bolt rope has been fitted to the foot, unnecessarily in the writer's view.

The attachement of sheets is an obscure area. In only one case are tack rings in evidence. This method was adopted for the Athenian Trireme. In addition the leech brails are attached to them. These then pull directly against the tension in the sheets.

The head of the sail is bent on with a lanyard. The clews are lashed to the yard arms through sewn cringles.

Parrels SLIDE NO:4

While experimenting with a model trireme type sail the need for a strong parrel to link the yard to the mast became apparent. In the running position this was not necessary. When reaching the yard was displaced to leeward by a certain amount. This varied depending on how much drift was allowed to the halyards. The movement sideways was due to the tension in the brails and braces pulling at an acute angle.

Iconographic evidence shows this problem to have been cured by a simple rope tie. In those galleys whose masts were bound (in medieval terms, woldings), the rope parrel would probably have been loose fitting in order to slide over the woldings as there is no evidence of any crew climbing the mast to attend to it. In later forms of this rig seamen go aloft to set or hand the raffee-type top sails seen in Roman ships. Prior to the Aegean Galley it seems that the only people who went aloft were the Ancient Egyptian seamen. They fitted "crowsnests" to their masts not, the writer believes, for the well recorded military purpose, but as a very important navigational aid. A look out at say 10 metres above sea level would see the low featureless deltaic coastline long before anyone on deck, when making a landfall.

Halyards SLIDE NO:4

The sails of the Athenian Trireme are hoisted by pairs of halyards for which there is more than enough evidence. Indeed double halyards seem to be the norm in the Mediterranean long before the seafaring activities of the Greek galleys. For example the reliefs of Queen Hatshepsut's fleet from 1500 BC.

Reasons for doubled halyards are divers. Two halyards permit two groups to haul in a confined space. The weight on each halyard is halved. Should one part then the other would prevent the yard crashing onto the crew. Of course such advantages may have been apparent only later. Perhaps the real reason was that no one invented a smooth slot in the mast head.

In the Athenian Trireme, whereas all other rigging is of natural fibre rope, it was decided to use a polyester rope having the appearance of natural fibre for the halyards. The reliability of man made fibres was preferred in this case as the replica is inevitably to be exposed to weathering. Experimental archaeology should not include the possibility of killing people as a result of uncertain strength factors in vulnerable areas.

Mast Trucks SLIDE NO:5

Mast trucks were designed to be made of bronze for the Athenian Trireme. The curved fairlead slots were given the greatest possible radius so as to avoid nipping the rope. Trucks in the iconography vary from built up wooden structures to what quite obviously are metal casting. The latter form was chosen as being typical and also because it was easier to calculate the strength of the fitting.

Masting SLIDE NO:5

It was decided to conform with standard galley practice and make the Athenian trireme's masts free standing. After raising them in their tabernacles and wedging them in the only support given was a forestay and backstay. The mainmast is expected to bend slightly under sail. Without shrouds a substantial tabernacle is needed. Masts without shrouds suggest that ancient galleys may have had an easy motion, they heeled initially quite quickly in a gust. This would reduce the shock loading on the rig and thus enable the almost free standing mast to remain the norm for so long. Nevertheless all mast loads were transmitted into to the hull via the tabernacle. Consequently in any vessel this must have been a relatively massive. While sailing in Kyrenia II in 1985 a stream of bubbles was noticed emmananting from under the hull. This writer suggests it was able to trace it to air entrainment via a garboard seam which was being forced open at the keel tabernacle position. In her ballasted light condition air was sucked outwards. In the original Kyrenia ship, fully loaded, water would have come in. It is likely that these problems were quite common in lightly built galleys. In Roman times shrouds were used, certainly in their cargo vessels, which would be stiff from their deep laden condition. In this way the mast loads would be more evenly distributed into the hull.

Conclusion SLIDE NO:6

In conclusion it must be said that great pleasure and satisfaction was gained in researching and designing the rig for the Trireme Trust.

The evidence used in support of the writer's decisions when designing the rig for the Athenian Trireme are familiar to all. It is hoped that this interpretation will satisfy some of the experts and lead to a lively discussion. It is intended to record in future publications the practical problems of handling a rig from 2500 year ago.

Owain T.R. Roberts
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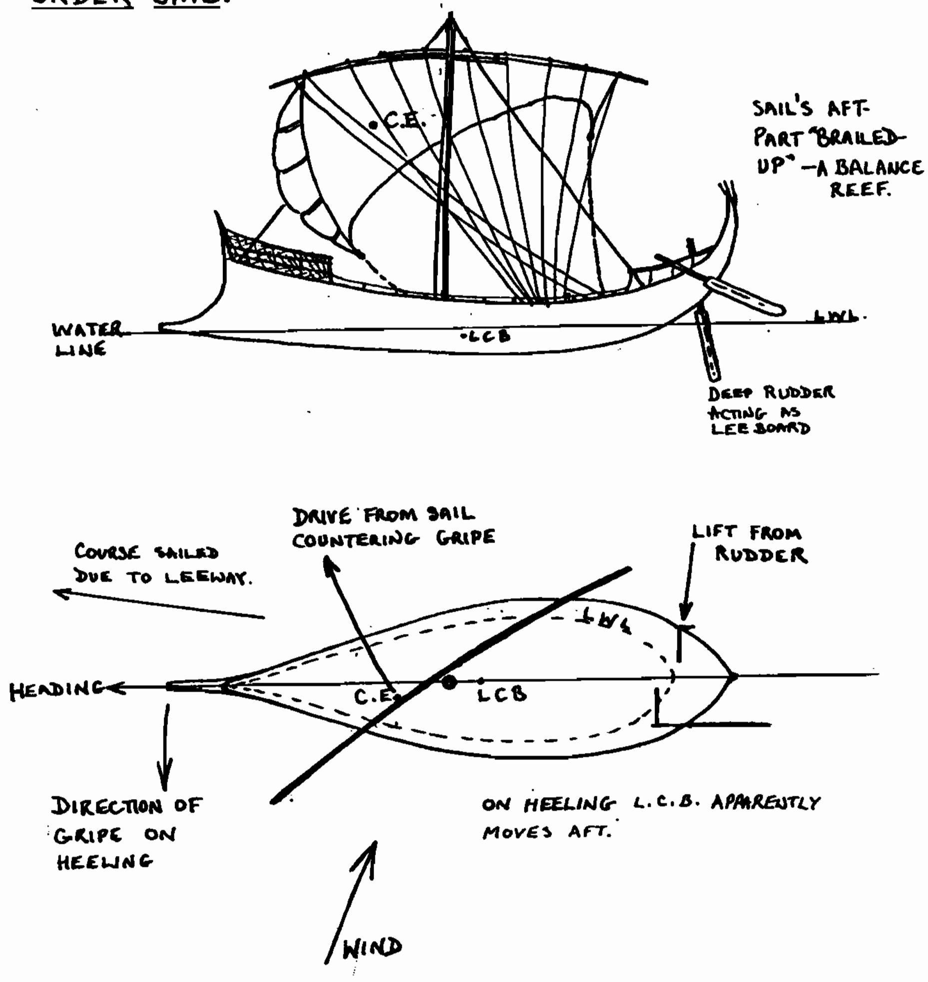
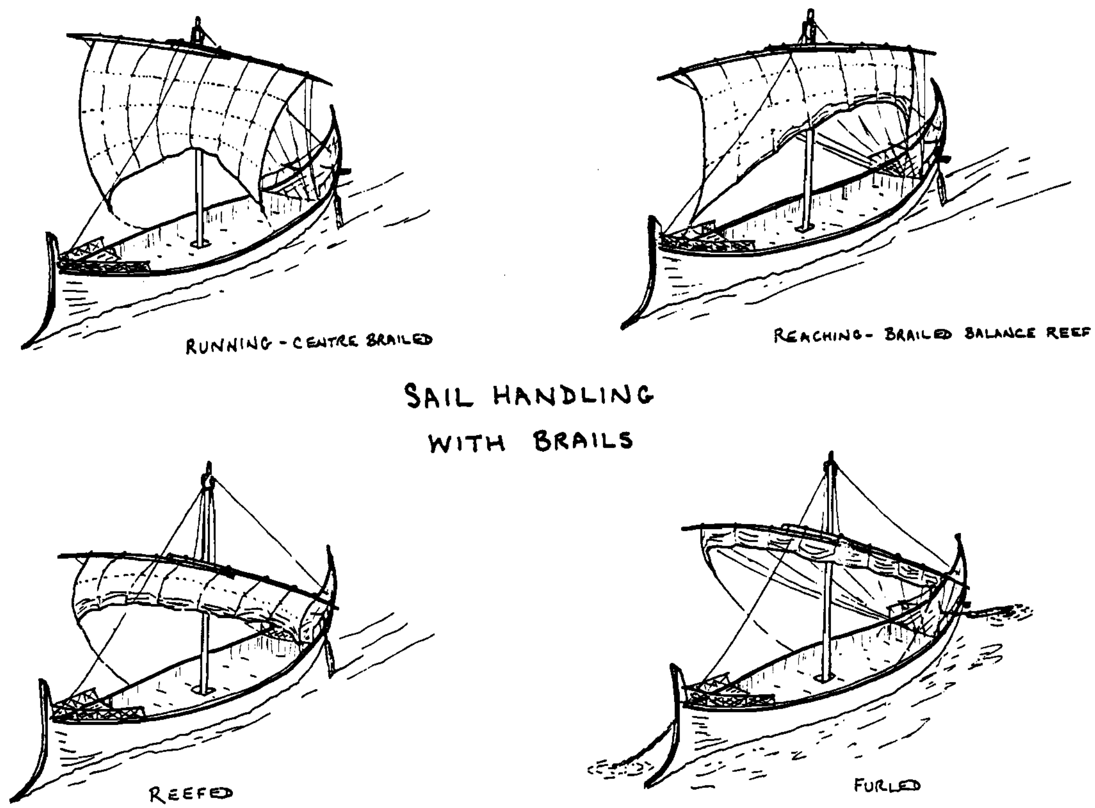
FORCES ACTING UPON A CLASSICAL GALLEY WHEN UNDER SAIL.



C.E. = CENTRE OF EFFORT.
L.C.B. = LONGITUDINAL CENTRE OF BUOYANCY
L.W.L. = LOAD WATER LINE

OWAIN T.P. ROBERTS 1987

(1.)


RUNNING - CENTRE BRAILED
REACHING - BRAILED BALANCE REEF
SAIL HANDLING
WITH BRAILS
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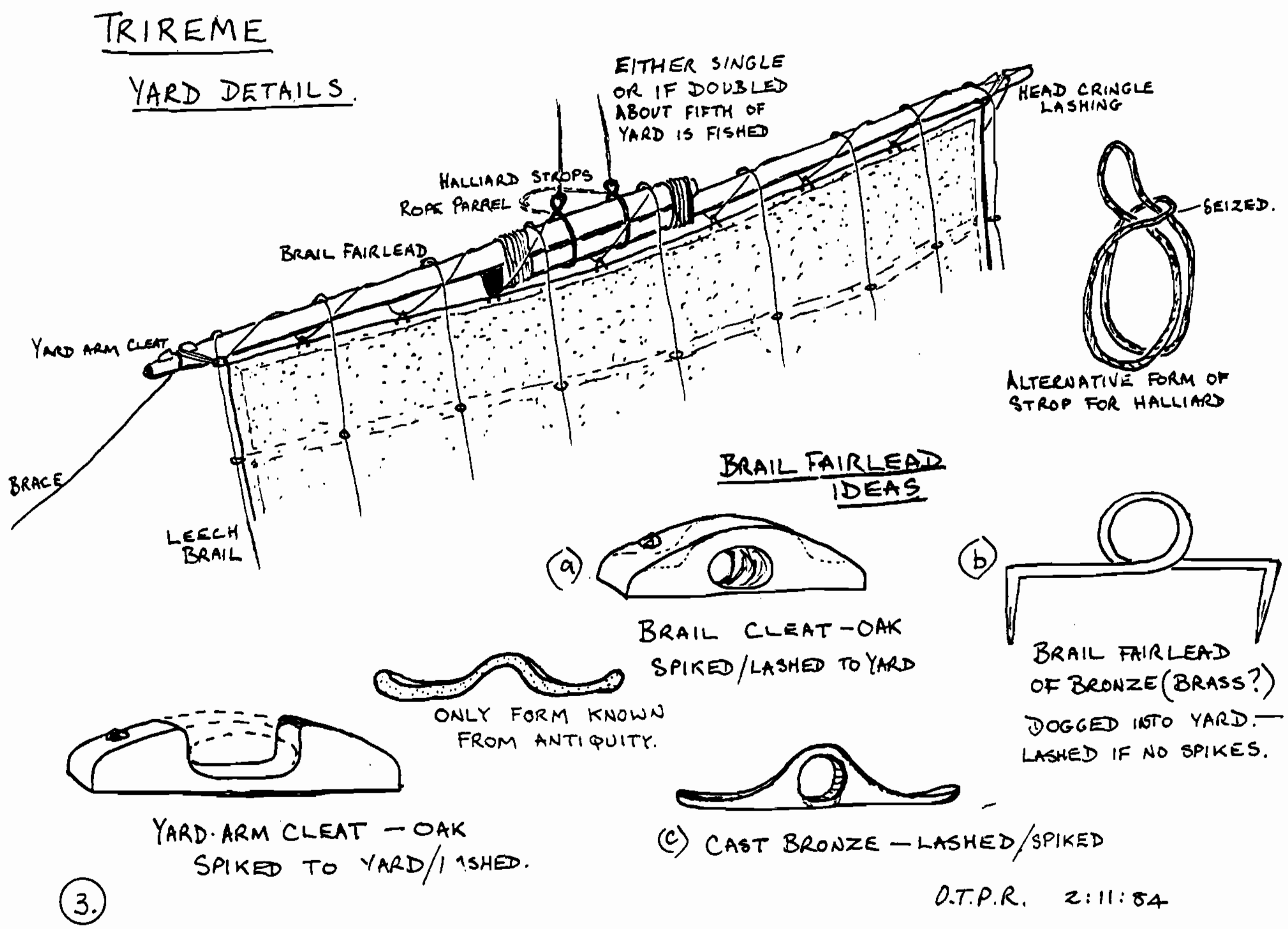
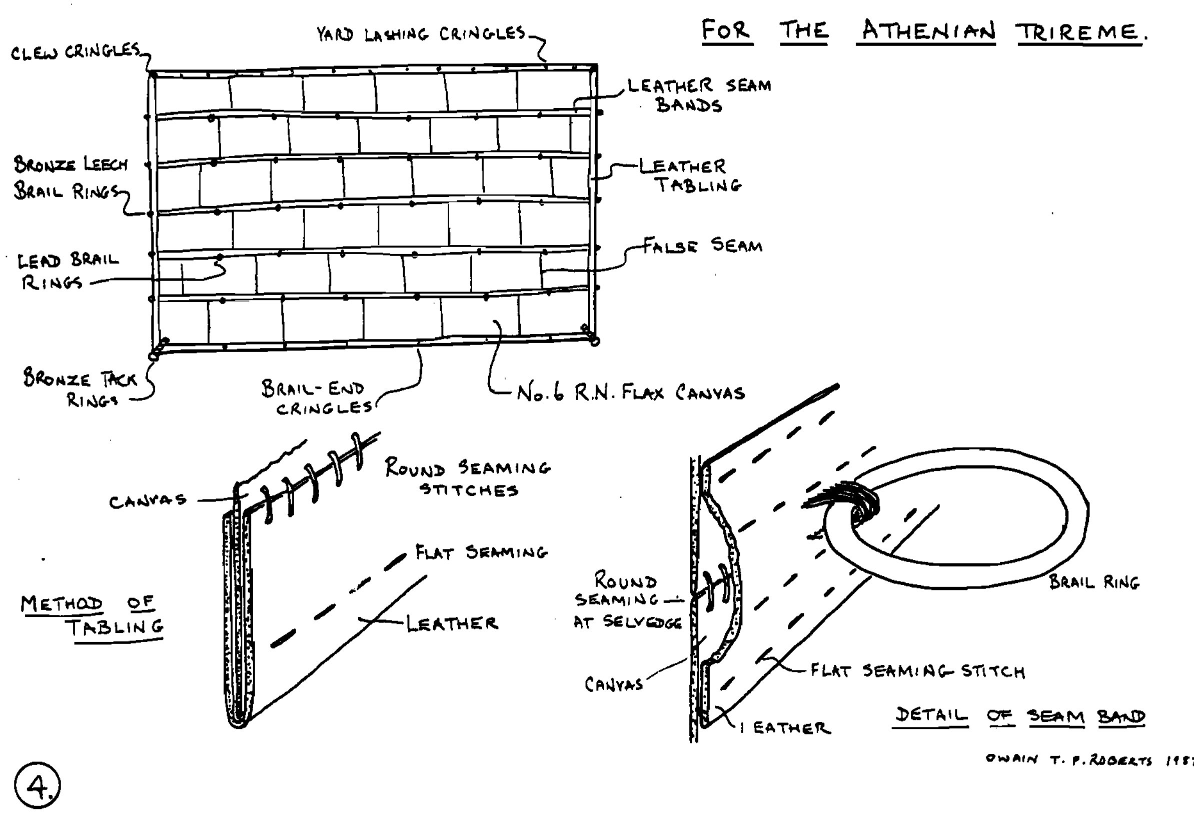

TRIREME
YARD DETAILS.
EITHER SINGLE OR IF DOUBLED ABOUT FIFTH OF YARD IS FISHED
HEAD CRINGLE LASHING
HALLIARD STROPS
ROPE PARREL
BRAIL FAIRLEAD
YARD ARM CLEAT
BRACE
LEECH BRAIL
SEIZED.
ALTERNATIVE FORM OF STROP FOR HALLIARD
BRAIL FAIRLEAD IDEAS
(a)
BRAIL CLEAT-OAK
SPIKED/LASHED TO YARD
(b)
BRAIL FAIRLEAD OF BRONZE (BRASS?)
DOGGED INTO YARD.—
LASHED IF NO SPIKES.
ONLY FORM KNOWN FROM ANTIQUITY.
YARD·ARM CLEAT — OAK
SPIKED TO YARD/LASHED.
(c) CAST BRONZE — LASHED/SPIKED
3.
O.T.P.R. 2:11:84


FOR THE ATHENIAN TRIREME.
CLEW CRINGLES
YARD LASHING CRINGLES
LEATHER SEAM BANDS
BRONZE LEECH BRAIL RINGS
LEATHER TABLING
LEAD BRAIL RINGS
FALSE SEAM
BRONZE TACK RINGS
BRAIL-END CRINGLES
No. 6 R.N. FLAX CANVAS
CANVAS
ROUND SEAMING STITCHES
FLAT SEAMING
LEATHER
METHOD OF TABLING
ROUND SEAMING AT SELVEDGE
CANVAS
BRAIL RING
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I EATHER
DETAIL OF SEAM BAND
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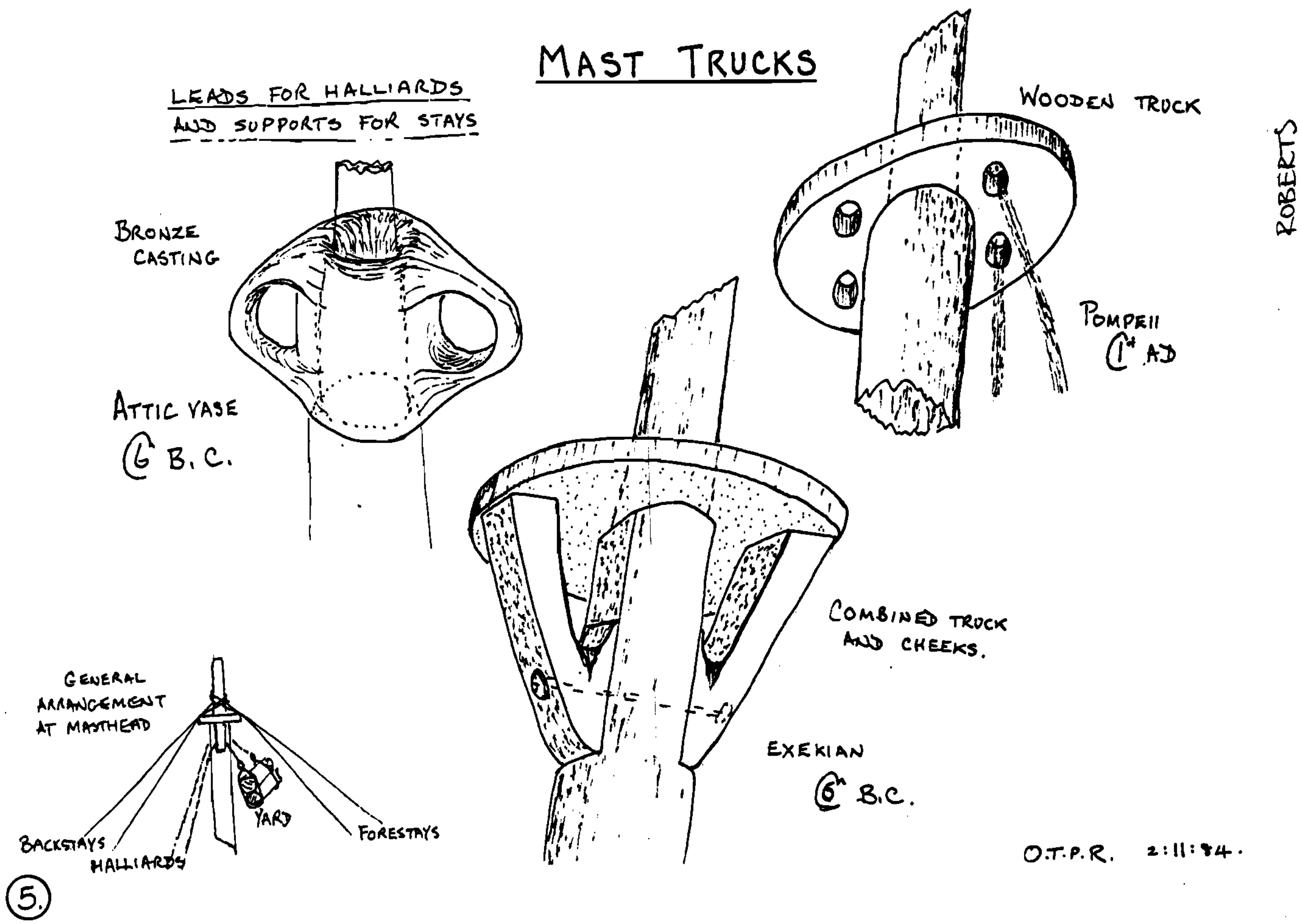
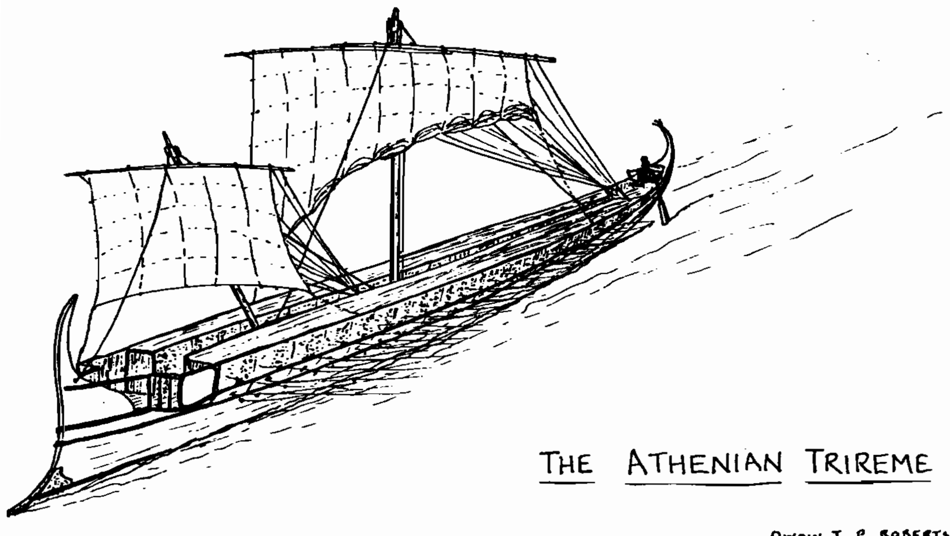
4.


MAST TRUCKS
LEADS FOR HALLIARDS
AND SUPPORTS FOR STAYS
BRONZE CASTING
ATTIC VASE
6 B.C.
WOODEN TRUCK
POMPEII
1st AD
COMBINED TRUCK AND CHEEKS.
EXEKIAN
6th B.C.
GENERAL ARRANGEMENT AT MASTHEAD
BACKSTAYS
HALLIARDS
YARD
FORESTAYS
O.T.P.R. 2:11:84.
ROBERTS
5.



(6.)