

## PENTEKONTORS AND TRIEREIS COMPARED

Having spent some time designing modern warships according to the physical possibilities of the time, and the changing needs of a naval staff, the author is well aware of the response when the cost of building a new design promises to be sharply higher than of the equivalent ship already in service. If the increase were fivefold — in present terms for frigates from the order of one hundred million Pounds Sterling to five hundred million — the resistance to accepting the new design would be, to say the least, considerable. The designer would certainly have to justify his proposal against searching enquiry of the kind which political contributions might cause to continue indefinitely, and without result. Though organisations and professions within navies may have changed down the millennia, that response to raised cost has been ever thus. Let us then look at the two-level pentekontor and the trieres in this light.

Surviving information, fragmentary and probably therefore misleading, invites us to believe that the trieres was "invented" by Ameinocles in Corinth sometime before 600 BC. Some people believe that that brilliant technical achievement took place in Phoenicia, but for the purpose of this paper it does not much matter where it may have happened. The important question is not so much Where? but How? — How did such a great and very expensive development of the ramming warship ever come to pass? The acceptability of a five fold increase in cost, and weight, per ship would be truly astonishing if it occurred in one great inspired leap from 50 to 170 oars, 24 to 36 metres in length and from 10 to 45 tonnes in weight. Such a leap would need much explanation not merely technically but also as a political reality.

Without benefit of our present knowledge of the physical world and its laws, such a development would more probably have followed a course of groping steps of trial and error, seeking a design better than the extant pentekontor in some particular ways. Even with modern knowledge the prototype would not be quite right first time. In ancient times it must be supposed that a series of many ships had to be built: some would have suffered from insufficient strength, others would have been crank and in many it is likely that the waterline was at the wrong height for oars to work properly. It is likely that the best part of a century of highly motivated development would have been needed to reach something like a trieres from a two-level pentekontor. There is evidence (Iliad Book 2, 509-10) of intermediate — sized ships: the Boeotians are credited with ships having 120 men on board.

No change in technology appears to have been involved in the development so it may be regarded as akin in that respect to that of the sailing warship between the sixteenth and nineteenth centuries AD, though in relative cost terms it was larger and it was certainly faster. What

quality was being so assiduously sought almost regardless of cost?

We are thus led to look at the trieres and the two-level pentekontor to compare their probable performances and the likely naval requirements of that period.

In passing we may recall that Necho built triereis quite early in Egypt (Herodotus 2.159.1), and that they were also built in numbers at Miletus with Persian money, presumably to exercise control of the Eastern Mediterranean for the imperial expansion of Persia.

#### EFFECTS OF DIMENSIONAL CHANGES

When exploring the effects of changing the size of anything, physicists and engineers commonly use a technique which goes by the name of dimensional analysis. It is a broad way of seeing why, for example, the bones of elephants are so much thicker in relation to their length than those of a mouse or bird. By it one can see why birds are limited in size, and so on. We may compare ships in this way, for instance the trieres and some of her predecessors (Figure 1).

#### COMPARISON OF SHIPS

Figure 2 is a table of comparative figures for five types of ship. The figures may be to some extent speculative, but variation within realistically possible limits would not greatly affect the main comparisons between the columns of figures for each type of ship. It is assumed that all five types were built in much the same way with similarly shaped hull sections, though they would have varied in dimensions in different ratios, one type from another.

Keeping to a constant interscalm distance of two Athenian cubits on the assumption that in all of these types one man pulled one oar and that the interscalm would have been no larger than it need have been, one can find the minimum size of hull to accommodate the number of oarsmen in each type. In some cases the section of the hull has to be increased above the minimum to provide adequate stability or longitudinal strength. These calculations lead to the estimates of length, beam, draft and displacement in the table. They show the triakontor to be a large boat rather than what we would think of as a ship. The single-level pentekontor needs a depth of hull (H) greater than the triakontor, though it is also a single-level oared ship, to give sufficient bending strength. The need for that property is indicated at the bottom of the table by the magnitude of the quantity.

$$\frac{\text{Weight} \times \text{Length}}{(\text{Hull depth})^2}$$

The single-level pentekontor would therefore have had much more room in it for carrying people, gear or cargo than the triakontor, and there are references to colonies of people being carried in them to distant waters. The pentekontor may at the time have had some advantage against the majority of pirates — always a consideration in the ancient (and indeed not so ancient) Mediterranean. The single-level oared ship gained in speed, say 12%, compared with the triakontor. She was probably a little down on acceleration, and paid a heavy price in agility, in her rate of turning under oar. As this type was armed with a ram, this is a curious matter for in ships so armed, agility must surely have been valued. Was the ram the principal weapon at that time?

### **TURNING UNDER OARS**

Rate of turning is much affected by the underwater profile of a ship. By comparing two simple profiles (Figure 3) of the same length and to which the same turning moment is applied (assuming for instance the same number of oarsmen in each vessel), a very simplified analysis indicates that Ship No. 2 turns more than one and a half times faster than Ship No. 1. The equations apply more to vertical vanes of the two shapes than to the rounded forms of ships, so that actually the difference in rate of turning will be greater. The profile of No. 2 is a close approximation to that of most Mediterranean warships. This comparison shows how important the tapered ends of the underwater profile were in ram-wielding ships, indeed it is unlikely that any ship thought to have had a profile more like No. 1 was a warship.

Length of hull impedes turning. In similar hulls the moment resisting turning increases directly with draft, with the square of angular rate of turning and with the fourth power of the length. Thus single-level pentekontors could be expected to have turned little more than half as fast as triakontors, a considerable penalty. In a ramming battle the pentekontors would probably be rammed first. On the other hand, being faster, the pentekontors could always escape from the triakontors. Was the ram in pentekontors a weapon of opportunity whose main purpose lay in reducing wavemaking at the bow by extending and so fining the waterlines there?

The two-level pentekontor is shown in the table to be a ship very well suited to wield a ram as its main weapon. The shorter hull greatly increases rate of turning: speed is up and so is acceleration. Agility has been improved all round. Cost is actually less than that of the single-level ship and longitudinal bending troubles with the hull have been disposed of. In this type of two-level ship hypozomata may have been unnecessary. In view of so many virtues it is not surprising that the two-level pentekontor was in service for several centuries extending well into the period dominated by the trieres.

The gain in speed achieved in the two-level pentekontor would have arisen from a reduction in the frictional resistance of the hull owing to its smaller wetted area compared with the longer single-level ship with the same number of oarsmen. On the other hand sprint speed would have been a little less than that advantage by itself would indicate on account of increased wavemaking at higher speeds, another quite separate effect of shortening hulls. In its time the two-level pentekontor would have been able to catch and ram any other type of vessel then extant as far as we know.

### **WHY WAS THE TRIERES DEVELOPED?**

What stimulus arose in the Eastern Mediterranean during the seventh century BC to push this economical and balanced design of warship further? What qualities beyond those of the two-level pentekontor became so much desired? They may well have arisen from the growing prosperity in that period. Trade and therefore shipping flourished, rich pickings for pirates who could have grown prosperous enough to ply their trade in pentekontors themselves. If so, a faster type of ship would have been needed to destroy them. In support of these suggestions it seems that Necho used trieris against pirates.

If speed were the aim of the development, a natural first step would be to lengthen ships

to accommodate more oarsmen on two levels. The longer hulls would probably have run into trouble with longitudinal bending and so leakage and short ship life. To remedy that, greater depth of hull would have commended itself and suggested the addition of a third, top, file of oarsmen on each side. That could have been Ameinocles' invention — and to do so with the help of an outrigger. Elsewhere, for instance in Phoenicia, others may have come to other structural solutions.

It is particularly notable that the development was taken so far in length of hull and numbers of oarsmen. Herein lies the great increase in cost. The figures in the table indicate how the improvement gained was confined to speed and numbers of men on board but in both the gain was spectacular. Length of hull, as in the single-level pentekontor, became stretched to the limit structurally and hypozomata were again clearly necessary, as indicated by the figures at the bottom of the table.

The key to the apparently high value put upon speed probably lies in the naval operators' problems of the time, and those quite likely centered on protection of trade as much as the ability to challenge a hostile fleet for the command of an area of sea. Higher sustainable speeds enable fleets to be deployed more quickly: a trieres could reach in two days a destination for which a pentekontor would need three. May be that had become a crucial advantage worth its very high cost even at the loss of some ramming agility. These are questions which historians working on this period might find rewarding to ponder.

A single trieres among a group of merchant ships would certainly have made any pirates in the area keep their distance. The trieres could take her pick of beaches for refreshing her crew, forcing the pirate to go elsewhere to his discomfort and fatigue. A trieres could tow merchant ships at about twice the speed possible for a pentekontor — fast enough to beat the Bosphorus current. There was much shipping to the Black Sea and there is evidence of trieres towing grain ships, quite possibly on the outward voyage.

Lastly, in considering the size of the step from two-level pentekontors to triereis, it is not impossible that the change proceeded at a rate at which the real increase in ship cost kept pace, in this prosperous period, with the growth of real wealth in the city-states rich enough and with sea trade enough to be interested in the emerging new type of warship. In those circumstances it would be possible for a navy to maintain the same number of hulls in service as they evolved from pentekontors to triereis on a fixed naval vote when expressed as a percentage of Gross National Product, or its ancient equivalent.

It is hoped that this paper may stimulate historians of the Eastern Mediterranean of the eighth to the sixth centuries BC to relate naval requirements in the region as they may be indicated by their studies, to the factors affecting the performance and cost of the warships of that period.

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Type of ship	Triakontor	Pentekontor 1 level	Pentekontor 2 levels	Trieres Open	Trieres Covered
Length on WL, m. (L)	17.5	26	18	33	33
Breadth on WL, m.	2.2	2.2	2.3	3.5	3.8
Hull depth, m. (H)	1.0	1.2	1.6	2.4	2.4
Draft, m.	0.55	0.6	0.6	1.0	1.1
Block coefficient of hull	0.33	0.35	0.37	0.39	0.39
Weight fully loaded, tonnes (W)	7	12	9.5	45	50
Number of oarsmen	30	50	50	170	170
Number of files on each side of the ship	1	1	2	3	5
Max. continuous speed, knots	4	4.5	5.5	7.6	7.2
Speed increase type-to-type	—	12%	22%	38%	-5%
Acceleration inc. type-to-type	—	-3%	26%	-28%	-17%
Rate of turning inc. type-to-type	—	-45%	109%	-38%	-5%
Capital cost inc. type-to-type	—	75%	-20%	360%	20%
Number of soldiers on board	31	50?	5?	14	14 to 40
Number of men available to fight (ship remaining mobile)	13?	70?	30	100	100
W x L	122	216	67	258	286
H <sup>2</sup>					
Hypozoma	?	Yes	?	Yes	Yes

Figure 2 - Table comparing ship types

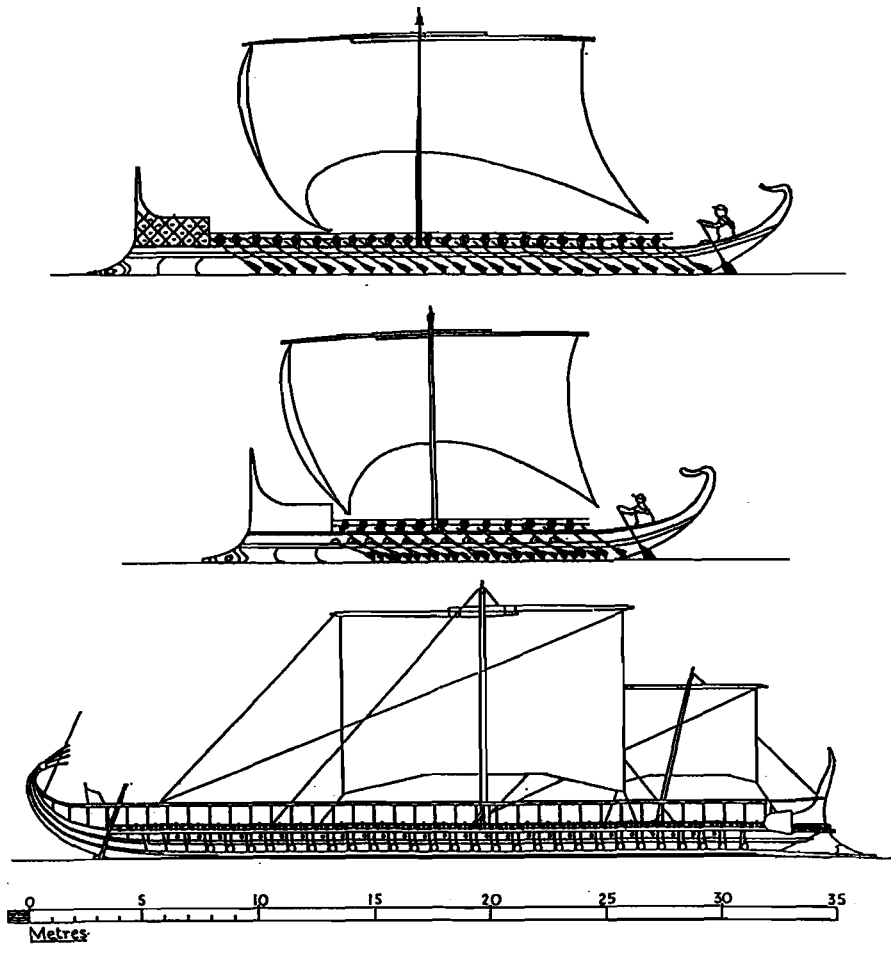


Figure 1 - Single and two level pentekontors and trieres drawn to the same scale.

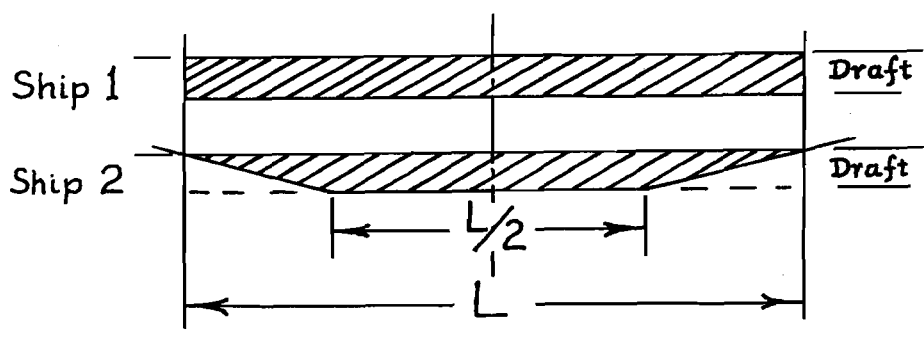


Figure 3 - Two simplified underwater profiles