

THE TRIERES RECONSTRUCTION “OLYMPIAS”: SOME UNRESOLVED QUESTIONS

Building and operating OLYMPIAS have demonstrated many things about the *trieres* which have been matters of conjecture for centuries. Much has now been proved by experiment, or disproved beyond reasonable doubt. Yet a number of questions remain unresolved as might be expected. Of the more important, three concern construction namely

Design of oars

Use of rudders

Hypozoma

and three concern ship operation

Selection and training of oarcrew

Command and control of oarcrew

Passagemaking

We know how long oars were in *triereis* and nearly everyone now agrees that they were of the same length, except at the ends of the ships. So, they are in OLYMPIAS, but the present oars are too heavy and, as originally designed, too unbalanced to use rapidly and with power. These shortcomings arose from:

1. My fear of oar breakage by clashing together on a costly and demoralising scale at the start of learning how to row this crowded ship.
2. Difficulty, at the time of placing the building contract, in obtaining supplies of suitable spruce or fir, so that a denser timber, *pseudotsuga Menziesii*, had to be used.
3. Lack of working knowledge of high-g geared oars for fast sea-boats, such as gigs, which are now extinct. Those of a 1829 British racing “eight”, now in the Science Museum in London are among the very few of such oars still to be seen.

To achieve the attested performance of a fast trieres under oar, which is to maintain at least seven knots continuously for up to about 24 hours, calls not only for a fit, keen and skilled oarcrew but also for exactly the right oars and oar rig, the best possible with the materials and techniques available in antiquity.

The effective power (Fig. 1) needed to propel a trieres in good condition at 7 knots can be shown to be $8\frac{1}{2}$ kilowatts (+/-) 5% or so if rudders are immersed so little that their resistance is minimal. That calls for an effective power from each oarsman of 50 watts if all oars are in action, or, as is more likely during a long passage under oar, 75 watts if only two files are manned at a time. While a man can produce 200 watts effective power with an oar for a matter of a minute or two (Fig. 2); 130 watts would be a good figure to achieve for half an hour or so, given a good oar and a good oar rig. For longer periods power would fall still further, and the crowded conditions in a trieres would also have their effects on the freedom of oarcrew to develop power. Thus, if a reconstruction is to achieve the attested performance, there is little room for inefficiency of oar or oar rig.

The weight of the present oars in OLYMPIAS could, after the experience now gained, be reduced to half of their weight, 17 kg (including lead counterweighting in the loom), without undue risk of breakage (Fig. 3). Of course, less robust oars will be more easily broken in the hands of an unskilled crew, by clashing together. With such lightened oars, OLYMPIAS could be expected to exceed nine knots in a short sprint and hold not far short of seven knots on a long row, given a suitable oarcrew capable of maintaining a long stroke. To date the two-cubit *interscalmium* in OLYMPIAS has limited length of oar-stroke (Fig. 4). With the heavy oars, oar handle-stroke has been no more than 0.6 metre: with lighter oars and crew training it might be possible to lengthen the stroke of the handles nearer to the geometrical maximum of 0.85 metre. By that means nine knots should be attainable for a short time.

The Trireme Trust proposes progressive experiments with a few new oars made of fir or spruce (Fig. 5), with the aim of developing the best design for the *trieres* to find her potential performance under oar. These oars must be made by techniques known to have been practised in antiquity.

No sprint speeds for triereis have been attested. So we do not know whether their oars were, in effect, optimised in gearing or blade area for endurance or for sprint speed. The fastest recorded average speed by a fixed-seat "eight" known to the author is 9.7 knots in a race lasting just over seven minutes in 1870. The average effective power of each of those oarsmen has been calculated to have been about 190 watts, with a power on the oar handle of nearly 250 watts, a rate of rowing of 40 strokes to the minute and a stroke of about one metre. Long strokes are essential for high power, but as anyone who has tried to row fast in waves knows, waves interfere with making long strokes and therefore limit power, as several accounts of battles between triereis testify.

The steering and manoeuvring of OLYMPIAS are quite outstanding. She could be turned in a circle of a diameter of less than two ship (waterline) lengths. The rudders are light to handle but their resistance in the water when fully immersed is enormous, as indicated by the plume and wake created by them. Maybe I overdid the diameter of the rudder stocks, by comparison with the one shown in the Lindos Relief, but not by very much. I certainly did not want stocks to break and there have been many breakages of stocks of side-rudders in recent reconstructions.

The resistance of these rudders is due mostly to the stock, so its diameter should be reduced where it is immersed as much as one may progressively dare to do. I doubt if it could be reduced by much more than 15%, after which it would still be responsible for adding about 50% to the resistance of the hull when both rudders are fully immersed. Some further reduction in resistance could be achieved by fairing the rudder section. But when were both rudders fully immersed? Experience in OLYMPIAS has highlighted this question.

When triereis entered, left and manoeuvred within harbours both rudders would certainly have been fully immersed. Indeed any other state could well have been forbidden by regulations. In battle and of course during manoeuvring and battle exercises they would also have been down. Under sail and on passage under oar they would surely have been immersed (and probably only one) to the minimum degree necessary to keep course and general control in the prevailing conditions. More operating experience in OLYMPIAS is needed to find that best usage and to develop rudder gear so that they may be more readily pivoted and hoisted.

The *hypozoma* has been a difficult feature of the reconstruction. What we had hoped to rig in OLYMPIAS was a tension tourniquet, by which ropes are tightened by twisting them together so that it would indeed be "a well-twisted rope from within" according to the words of Apollonios of Rhodes. This device is often but wrongly called a "Spanish Windlass". However an insuperable problem cropped up with the arrangement proposed for OLYMPIAS at the last moment before launch, and we had to substitute a rather unsympathetically unyielding steel hawser for the intended fibre ropes. I hope this will be only a temporary expedient.

The problem just mentioned is not fundamental to the tourniquet. Indeed experiments with one-eighth scale tourniquets have since confirmed the need for an initial tension high enough to dispose of it. These experiments were necessary because I was unable to find any information of practical use about rope tension tourniquets, devices which have probably not been in any heavy constructional

use since the arrival of iron rods and opposed-threaded bottle screws centuries ago. The capacity of this kind of tourniquet as a device for increasing the tension in ropes seems to be limited, largely on account of the unwanted but additional strain imposed on the ropes as they are bent into helices round each other when the tourniquet is twisted. Twisting cannot do more than treble the tension in a flax tourniquet (Ref. 1), and it cannot sustain more than a quarter of the combined breaking tension of its constituent ropes, though that could be improved if twisting were limited to little more than maintaining tension as the ropes stretched under prolonged loading, as in a *hypozoma*. Thus the ropes of *hypozomata* should be rigged with the largest practicable initial tension before being twisted. This view of the matter goes far to explain why fifty men were, by the accepted interpretation, decreed to be needed to rig a *hypozoma*. It was to apply the initial tension, which would then have to be transferred from tackles by seizing the ends of the *hypozoma* ropes to their standing parts to form the tight loops between strong points at bow and stern. Only seizing can do this job without slipping, which is why it was always used in hemp standing rigging of ships, an analogous structural problem.

The combined breaking tension of four 47 mm diameter flax ropes could be expected to be about 65 tonnes force, and so a *hypozoma*, twisted to the limit to maintain tension as its ropes stretched with time, and made of such ropes could be expected to sustain a tension of between 15 and 20 tonnes. When rigged, it should be given a tension approaching 15 tonnes, that is 4 tonnes in each rope passing the length of the ship. A gang of fifty men with luff tackles (4 to 1 ratio) seems about right for the job if frictional forces are taken into account as well as some unavoidable slip in the seizing.

The extent to which flax, like all natural fibres, relaxes and therefore stretches under load amply explains the need for *trierei*s to carry a spare pair of *hypozoma* ropes on board. It would only have been a matter of time, though we do not know how long, before a *hypozoma*, progressively twisted to maintain its tension, reached its limit (or even broke). A new *hypozoma* would then have to be rigged, quite often presumably by the ship's crew. Two of my model *hypozomata* broke unexpectedly, so until we can learn more about flax under heavy loads it must be regarded as too unsafe to use in a *hypozoma*. If we are to move towards a more authentic arrangement than the present, we should out of prudence adopt a synthetic fibre. Polyester would be the most suitable because under load it stretches and relaxes with time relatively little. It is much stronger than flax so there would be no risk of unforeseeable rupture. So, equipped, OLYMPIAS would need no spare *hypozoma* ropes.

A tension tourniquet would, in my opinion, serve satisfactorily as a *hypozoma* in OLYMPIAS and it seems to be the most probable mechanism to have been used in *triereis*. More experiments are however called for to investigate ancient *hypozomata* including not only the relevant physical properties of flax and any other possible fibres, but also other conceivable mechanisms. In that way future work with this ship could be separated from the question of the *hypozoma* itself.

Passing now to operational questions raised by experimental work in OLYMPIAS to date, we may first consider the selection and training of oarcrew. The care demanded by both of these processes can now be seen to increase quite sharply with the level of performance to be expected. It is enough to say that a speed of 8 knots calls for 60% more power than 7 knots, while 9 knots would call for 150% more, a different league of performance. So far crews have reached only 7 or 8 knots and for a short time only. Over longer periods the ship has been rowed at speeds varying between 2 and 5 knots according to the strength and direction of the wind.

As far as can be judged, OLYMPIAS is about 2 knots short of the attested endurance speed under oar and this shortfall may be ascribed in roughly equal degree to oars and to crews. 2 knots may not seem too much but in terms of power it is a lot: the effective power required at 7 knots is about three times that at 5 knots. It is reasonable to suppose that on a long haul under oar ancient *keleustes* would not have had much of even one rudder in the water, whereas in OLYMPIAS both rudders have generally been fully immersed. The power shortfall is therefore more like 100% and not 200%. We have nevertheless a way yet to go to do as well as those tough ancients with their fully developed ships. If we try hard enough I believe we can close the gap.

Crews will have to be strictly selected for fitness, physique and stature as well as for keenness on the project. There is little doubt that crews aiming at attested performance will have to be male for strength and selected from a large field of volunteers to meet the demanding criteria now being proposed for this purpose. Recruiting powerful crews demands careful organisation across possibly more than one country.

On training crews for OLYMPIAS a whole symposium could well be held for no consensus seems yet to be in sight. Rowing the trieres has been found to differ from rowing any other craft, sea or river, more than most people have expected, indeed so much so that previous experience with an oar seems in many cases to have been of little help. Added to that, a large proportion of sport oarsmen nowadays

are too large to fit the *interscalmium* of the *trieres*. The best field from which to draw the high quality of oarcrew required for the attested performance is therefore a more open question than it might at first sight appear to be.

Probably the most severe training problem of all arises from the short time for which most oarcrews will be available, because paid crews will be very expensive and volunteers will have only limited time between their main commitments. Achievement of significantly improved performance is likely therefore to turn upon the development of some form of "off-ship" training in, for example, a rowing mock-ups on land (Fig. 6) or afloat (Fig. 7) which could be duplicated in a number of recruiting centers. The future programme of experimental archaeology for the *trieres* will largely depend upon the proper selection and effective training of oarcrews.

Much has been learnt about commanding and controlling the large oarcrew in a *trieres*. They are discussed in the reports of the trials of OLYMPIAS. It seems clear that different kinds of oarcrew (eg. paid, volunteer, young or mature) need different treatment to give of their best: there is much yet to be learnt.

On one point, keeping the large crew in time, we have found the notes of a high-pitched pipe very effective and it seems very likely indeed that this was the quite practical purpose of the *auletes*, much needed at higher powers or after long periods at the oar. Drums may be used in the paddled boats of the East but among the "clunking" noises of oars, their note would be too low to penetrate to the ends of the ship. We have not yet tried to extend the use of the pipe into passing orders to the oarcrew after the manner of a modern bosun's call. The number of oar orders would be quite large: nine distinguishable "pipes" would be necessary just to make any combination, port and starboard, of "Pull Ahead", "Easy" and "Back Down", without also being able to pick out particular files and parts of files, which would by our experience be necessary in any confined harbour.

OLYMPIAS has so far made only one coastal voyage and that was permitted only because an accompanying naval accomodation ship could be provided, no doubt at some appreciable expense. Much of the attested performance of *triereis* concerns making certain passages which are identifiable, so there is a desire to gain experience in that aspect of operations. Fleets of *triereis* were deployed over long distaces and it was of course essential to be able to do so to exercise long range naval power. It follows that the ship's programme should include a number of representative passages to gain some understanding of the realities of deploying *triereis* in antiquity.

However the safety of this expensive ship with two hundred lives on board must be the first consideration and there is naturally less than full confidence in the seaworthiness of this rather fragile and virtually novel vessel. It will take some years of operating experience with OLYMPIAS to enable the authorities responsible for her to judge her safe sea-going capacity. We should remember that losses of triereis at sea in antiquity were not uncommon, and certainly more frequent than would be acceptable today.

In the tightly programmed and financed modern world, the inability of a *trieres* in face of the weather to keep to any preplanned itinerary with any certainty raises practical problems of servicing her large crew in unpredictable locations and for unpredictable lengths of time, and that assumes that the right kind of crew could be recruited with such an open commitment in the first place. To make some progress with this difficult part of the ship's programme of experiments, some voyages might be synthesised within an accessible area to gain experience, while mitigating the problems raised by any more extended itinerary.

The resolution of the questions raised in this paper and of many others besides would involve OLYMPIAS in quite an extensive programme of experimental archaeology in the years to come. Carrying out such a programme calls for clear aims based on a firm grasp of the physical factors involved, determination and good organisation, and money, even if oarcrews are all volunteers, and a lot more money if they are not.

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ILLUSTRATIONS

- Fig. 1 Effective Power v. Speed for OLYMPIAS.
 Fig. 2 Power sustainable by a man during various periods of time.
 Fig. 3 A modification of OLYMPIAS's present oars.
 Fig. 4 Positions at Catch and finish to achieve a handle stroke of 0.85m.
 Fig. 5 An experimental oar in spruce.
 Fig. 6 Rowing mock-up at Boston, USA, July 1988.
 Fig. 7 Trieres trial section at Hanley, England, July 1985.

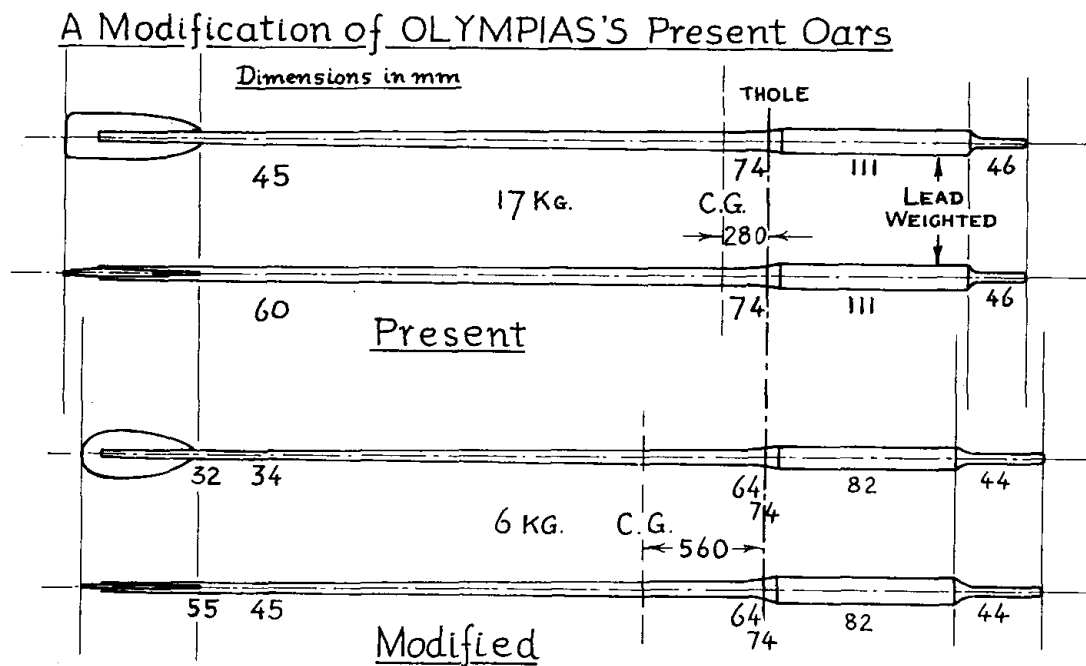
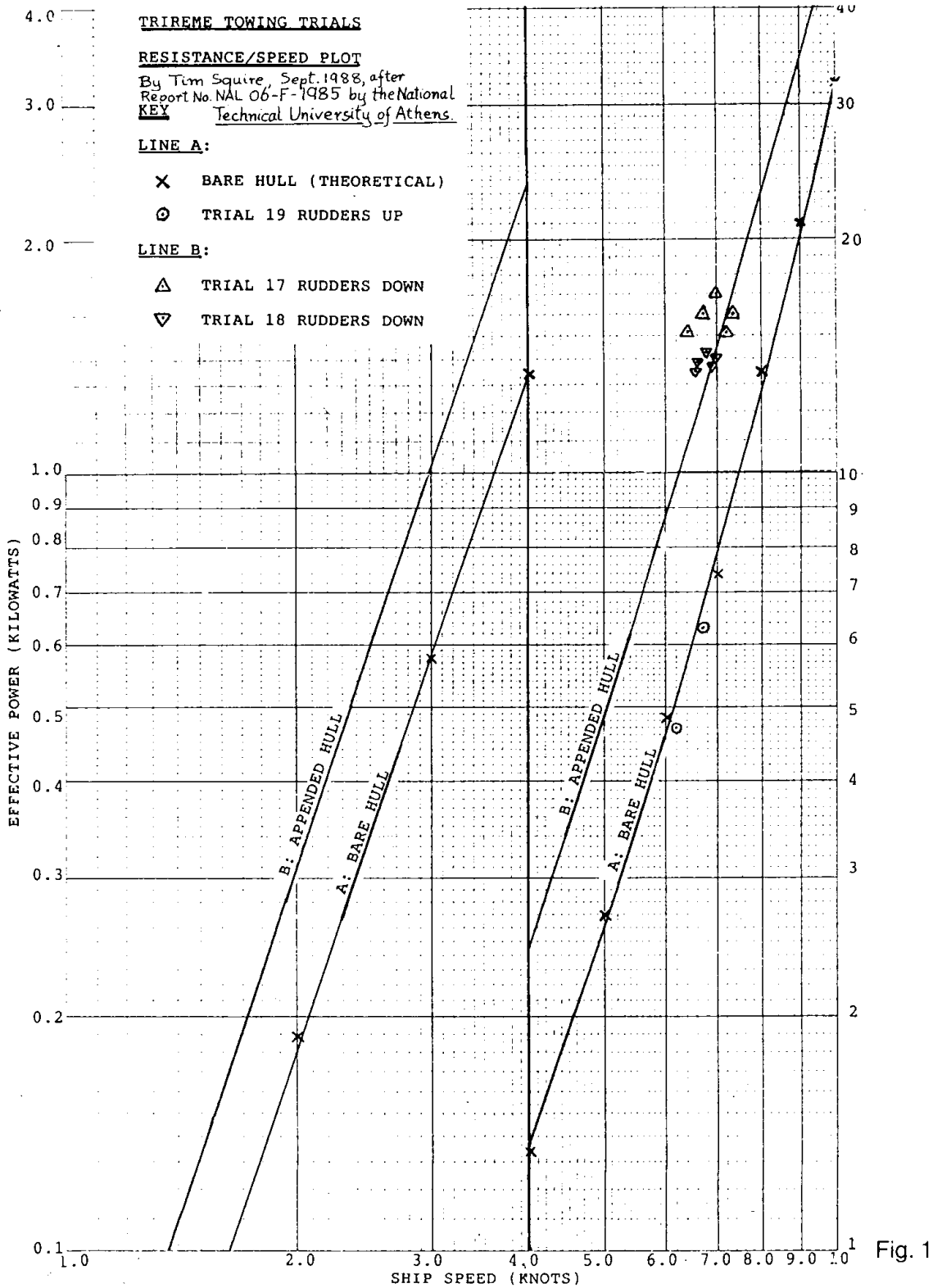


Fig. 3 Not to Scale. For Details see Trieres Plan No. 15e

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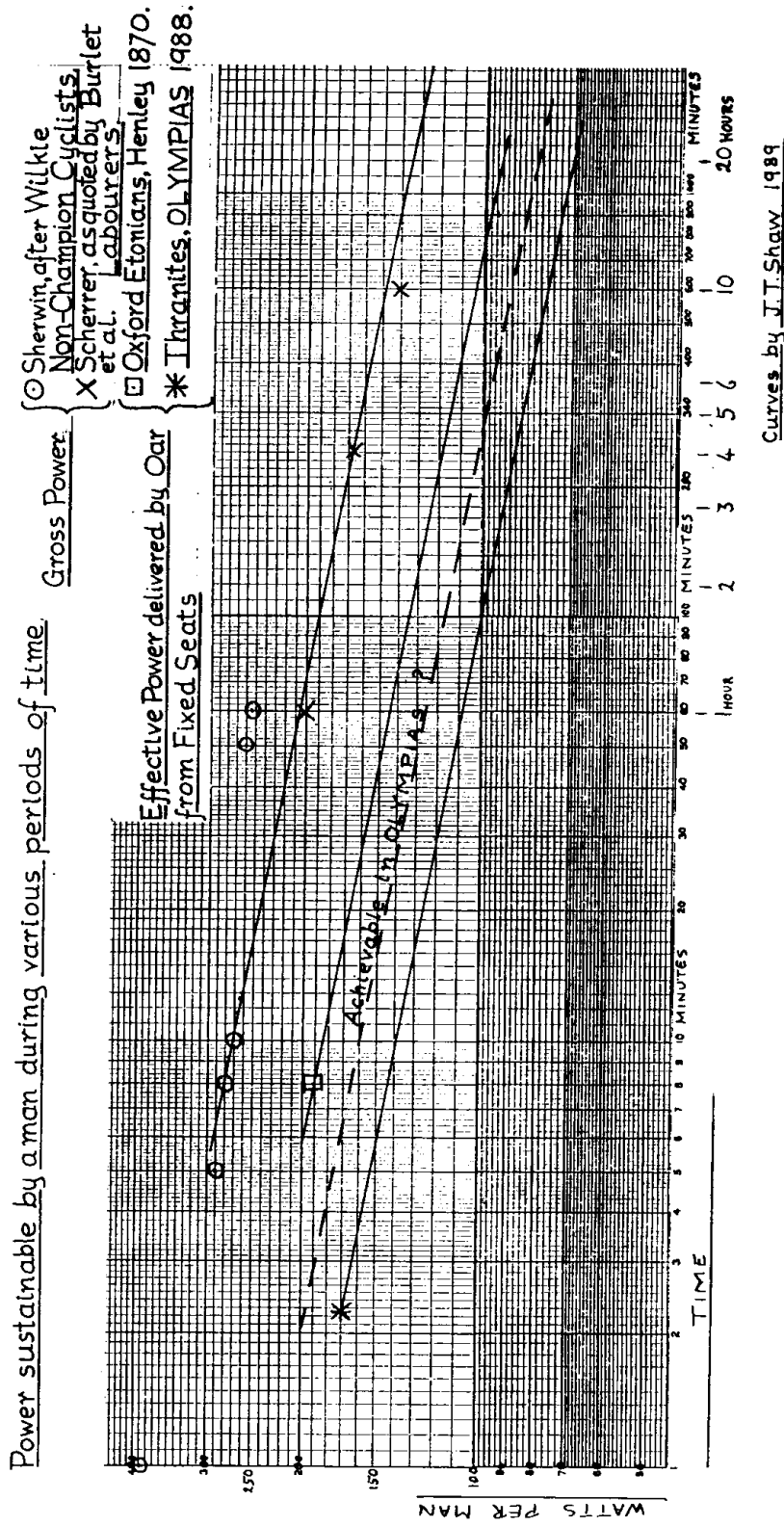


Fig. 2

THE TRIERES RECONSTRUCTION
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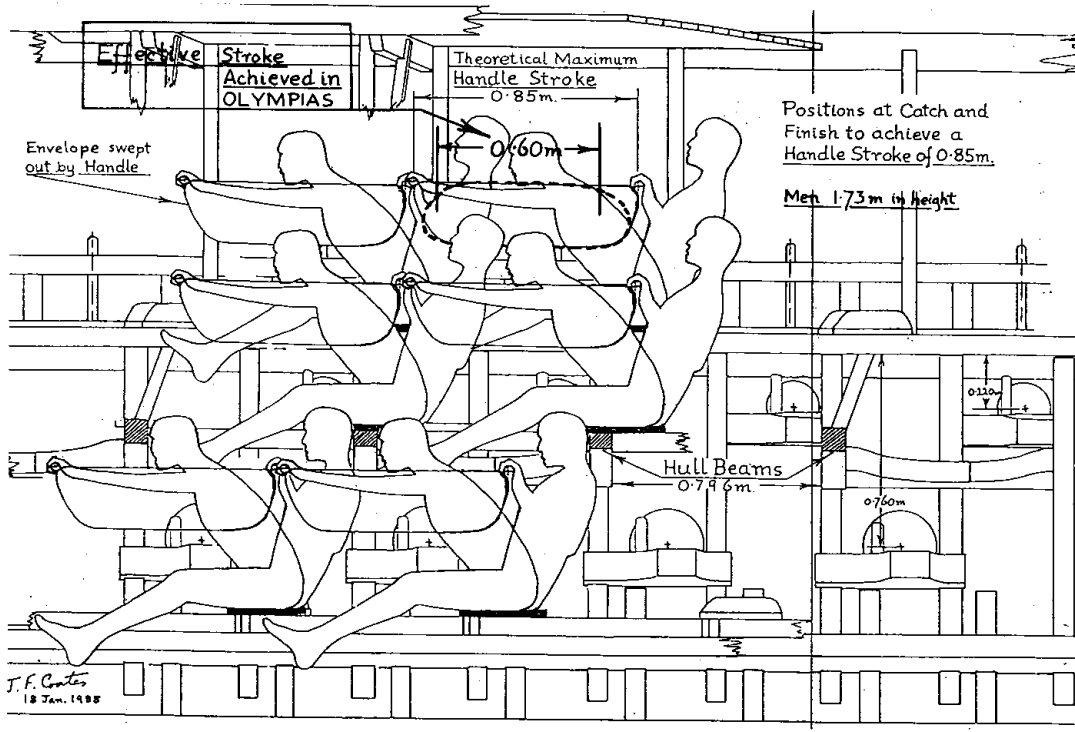


Fig. 4

An Experimental Oar in Spruce

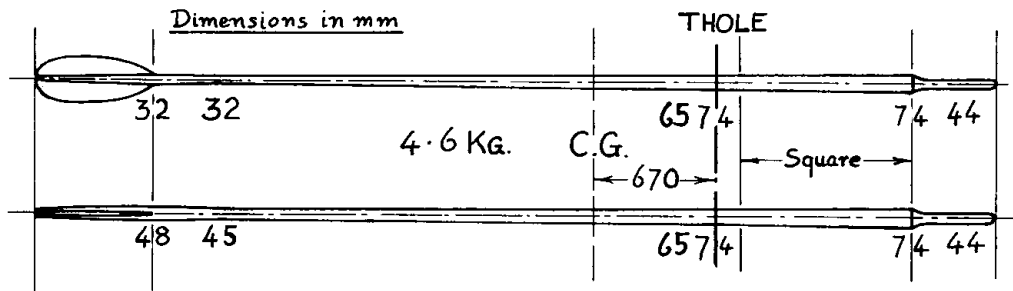


Fig. 5

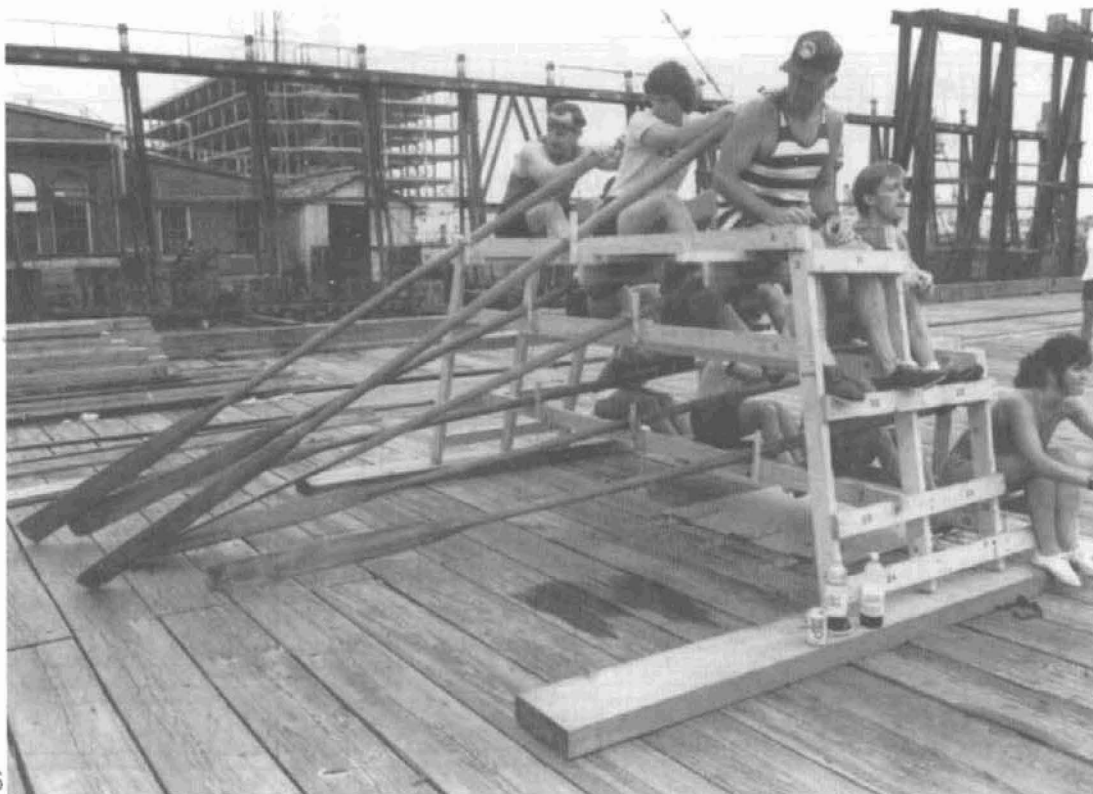


Fig. 6

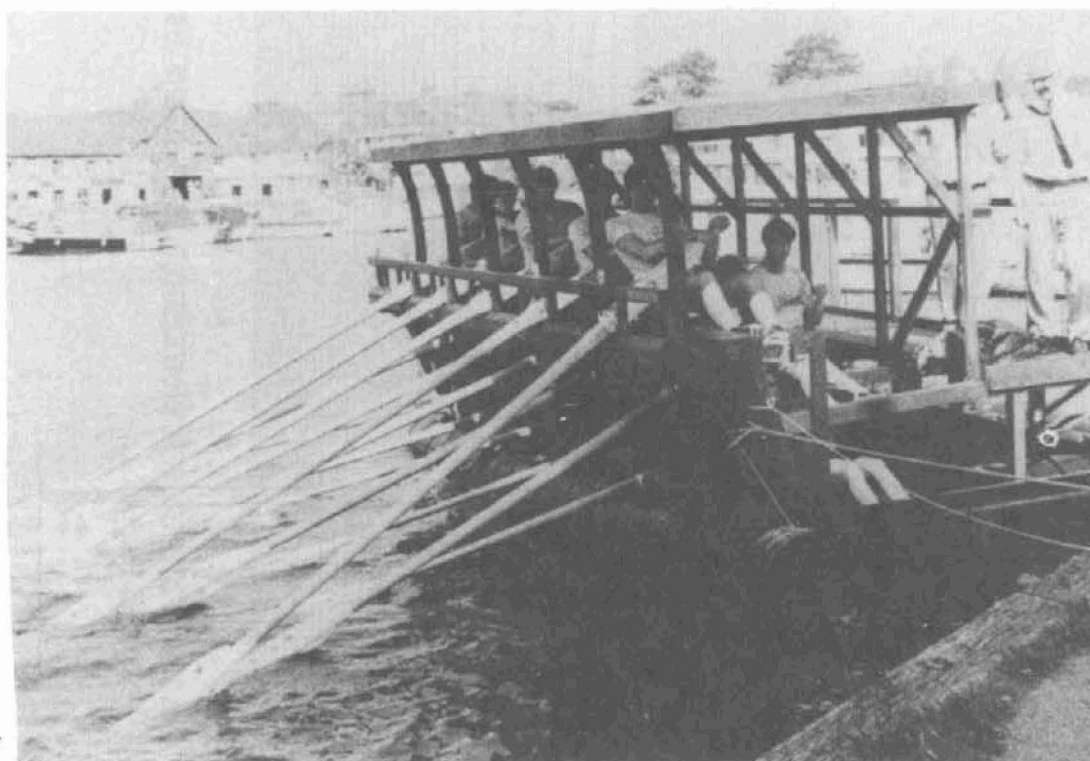


Fig. 7