The Trireme

by Boris Rankov

The trireme was the principal warship-type of the Greek and Roman world. Although it carried two square-rigged sails, a mainsail amidships and a smaller boat-sail forward, these were put ashore before any engagement, and it was propelled in battle solely by its 170 oars. The type was in continuous use with only relatively minor variations from the late 6th century BC to the early 4th century AD. Despite this, no trireme wreck has ever been discovered, and unless we have a remarkable stroke of luck, this situation is likely to continue. The ancient texts suggest that ancient warships continued to float even after they had been put out of action, and could be collected together on the surface or even rowed away after being 'sunk', presumably because they carried no cargo or ballast to take them to the bottom. Our knowledge of the type is thus derived entirely from a variety of indirect sources, including reliefs and vase-paintings, ancient literature, inscriptions and various indications from mainly land-based archaeology. It is not, therefore, possible to build anything which can reasonably be called a 'replica' of a trireme, although over the last 500 years there have been several attempts at what may be termed 'hypothetical reconstructions,' mainly on paper but also physical. The most recent of these projects culminated in the building of the Hellenic Navy vessel *Olympias* (Fig. 1), which was the subject of five series of sea-trials between 1987 and 1994.

The History of the Trireme

The trireme was ultimately derived from the oared vessels of the Aegean and Eastern Mediterranean in the later second millennium BC, which are depicted on Mycenaean vases, alongside paddled vessels in the wall-paintings of Thera, on gold rings, and on gemstones. From around 900 BC, oared ships with a pronounced forefoot appear regularly and in some detail on Greek vases painted in the Geometric style, and are often shown carrying warriors who fight from the decks. Their oars appear to have been arranged on a single level with one man working each oar. These were the ships described in the Homeric epics, and similar single-level vessels continued to be used for centuries. In the later period, such vessels normally had twenty rowers (*eikosoroi*), thirty rowers (triakontors) or even fifty rowers (pentekontors), and were often used to carry important individuals, as troop transports, or as scouting vessels.

By the latter part of the 8th century BC, a new type of ship appears in Greek vase paintings and on Assyrian reliefs, with oars arranged on two levels. The upper level of oars was worked over the topwales by rowers known as zygians (*zygioi*) who as before sat on the cross-beams (*zyga*), while the lower level was worked through oarports cut in the side by rowers known as thalamians (*thalamioi*) who were located in the ship's hold (*thalamos*). By arranging the rowers at two levels, it was possible to build a shorter and more manoeuvrable vessel with the same oarpower as before. A two-level, 50-oared pentekontor would thus have had 12 or 13 'rooms' for the oarsmen at each level. Such ships were usually privately owned as oared merchantmen capable of taking smaller cargoes than could be carried by sailing vessels but with the invaluable ability to make way against the unfavourable winds with which Mediterranean sailors often had to contend. They could be used by the same owners for both trade and for piracy, and were often commandeered by rulers or states to form *ad hoc* war-fleets. Both Homer and vase-paintings of the 6th century BC imply that longer two-level vessels (*nees dikrotoi*) also existed, with possibly up to 120 oars,[1] but it is the fifty-oared pentekontors which appear most frequently in the literary sources.[2]

The subsequent development of the trireme was a natural progression from the *pentekontor*, achieved by adding a third level of rowers known as thranites (*thranitai*) at the top. This was done either by making the hull broader and deeper, so that the thranites rowed over the topwale while both the zygians and the thalamians rowed through oarports, or by attaching seats for the thranites and an outrigger bracket at the top of a hull of the same dimensions as before. The *thranitai* may indeed have derived their name from the large beam or *threnys* to which the two rudders were attached, one each side of the ship, and which marked the sternward end of the outriggers. The trireme probably did not emerge, however, until the latter part the 6th century BC. Although the historian Thucydides, writing at the end of the 5th century BC, attributes its invention to the Corinthians around 700 BC, there is reason to believe that the credit should instead be given to the Phoenicians who lived on the coast of modern Syria and Lebanon a century and a half later.[3] At that time, they were a part of the Persian empire and may have developed the type from the large merchant galleys (*kerkouroi*) which were already being used by their Egyptian rivals. However, the earliest clear reference we have to a trireme (*trieres*), is in a fragment of the Greek poet Hipponax, from Ephesus on the coast of Asia Minor, who was writing in the 530s BC.[4]

It is probably no coincidence that the first recorded naval battle to involve ramming tactics dates to just this period. This was fought around 535 BC off Alalia in Corsica between refugees from Phocaea in Asia Minor and a combined Etruscan and Carthaginian fleet. According to the historian Herodotos, the Phocaeans won the battle but lost their entire fleet, with forty ships destroyed and twenty rendered useless because 'their rams were twisted off.'[5] It is, however, precisely in the qualities required for such tactics, – as opposed to the old-fashioned method of fighting static, pitched battles between marines on deck – that the trireme offered a significant superiority over the two-level vessels. Although the ships which fought at Alalia were probably all pentekontors, it will have been partly the introduction of ramming which made triremes so desirable to the naval powers of the late sixth century BC.

We know from inscriptions that in the fourth-century BC triremes had 170 oars, of which 62 were for *thranitai*, 54 for *zygioi* and 54 for *thalamioi*, giving 31, 27 and 27 rooms at the three levels respectively. A passage of Thucydides which describes trireme crews crossing the Isthmus of Corinth on foot with each man carrying his own oar, cushion and thole-strap, confirms that each oar was rowed by one man.[6] Such a vessel, displacing around 48 tonnes fully manned, would have been about the same length and had the same manoeuvrability as the largest two-level ships but would have had up to 70% more oarpower. This would have given it an advantage of up to a knot in sprint speed, which would more or less have ensured victory in any tactical encounter with such a vessel. The speed advantage over an ordinary pentekontor would have been greater still, around 2.5 knots at both cruising

1 Homer *Iliad* 2.509-10, although the passage only specifies that each of the ships in question carried 120 men.
2 On the overall development of oared vessels in the Mediterranean, see Morrison and Williams 1968; Gardiner and Morrison 1995.
3 Cf. Clement of Alexandria *Stromateis* 1.16.76.
4 Hipponax frg. 45 Diehl.
5 Herodotus 1.166.
6 Thucydides 2.93.2.

and ramming speeds, which would have more than cancelled out the latter's advantage in manoeuvrability.

This extra margin of performance is what would have justified the considerable increase in cost represented by such vessels, both in terms of the hulls and of the much larger crews needed to operate them. The expense nevertheless explains why the Phoenicians and other states subject to Persian rule were the first to develop and adopt such vessels. At the end of the 6th century BC, only a wealthy empire such as that of the Persians could have afforded to equip a whole fleet of triremes.[7] The Greek states struggled to keep up. The island of Samos, which became a major naval power around 525 BC under the tyrant Polycrates, could only manage to build 40 of them, possibly with Egyptian money,[8] and most of the triremes deployed by the Greek states of Asia Minor at the battle of Lade in 494 BC, when they rose up against Persian domination, had been funded by the Persians themselves. It is not clear that independent Athens was able to contribute anything other than twenty pentekontors to the Greek effort,[9] and she probably still had no triremes in her fleet when the first Persian invasion of the Greek mainland was defeated at Marathon in 490 BC.

Within a few years, however, Athens' situation had been transformed by the fortunate discovery of rich silver mines at Laurion at the south-eastern tip of the Attic peninsula. Faced with a threat from her wealthy neighbour and rival, the island of Aegina, which possessed fifty triremes, a skilful and far-sighted politician by the name of Themistocles persuaded the Athenian assembly in 483 BC to spend their windfall on the acquisition of a new trireme fleet of 100 ships. A further 100 were added soon afterwards when it became apparent that the Persians were about to invade Greece again, but this time on a much larger scale and with a much larger fleet.[10] These 200 ships formed the backbone of the combined Greek fleet which in 480 BC faced Persia's triremes, fighting under the eyes of their king Xerxes, in the straits of between the southern coast of Attica and the island of Salamis.[11] This was the greatest trireme battle of antiquity, and resulted in a total Greek victory which paved the way for the final repulse of the invasion the following year. The trireme was now the dominant warship-type of the Eastern Mediterranean.[12]

Although a very few of the Athenian triremes which fought at Salamis were in private ownership, the overwhelming majority belonged to the democracy. After the Persian withdrawal from Greece, Athens began to use this fleet to carve out an empire for herself as the naval leader of an alliance of Greek states formed to counter any further Persian aggression. By 431 BC, her dominance of the Aegean brought her into conflict with Greece's major land power, Sparta. Although defeated in the Peloponnesian War, and although an attempt was made to destroy her naval infrastructure by destroying her shipsheds,[13] Athens soon recovered and built her fleet back up to around 380 triremes by the 320s BC, when the whole of Greece came under Macedonian control.

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7 Wallinga 1993: 118-29.

8 Herodotus 3.44.2.

9 Herodotus 5.97.3.

10 Herodotus 7.144; Thucydides 1.14.3; Aristotle *Constitution of the Athenians* 22.7.

11 Herodotus 8.40-96.

12 On the emergence of the trireme, see Wallinga 1995; Gardiner and Morrison 1995; Morrison et al. 2000.

13 Isocrates *Areopagiticus* 66.

By then, however, new ship-types had come to prominence.[14] At the beginning of the 4th century AD, the *penteres* (quinquereme or 'five') had been invented at Syracuse at the behest of its tyrant Dionysius I and introduced alongside the city's triremes.[15] This was a three-level ship with twice the displacement of a trireme and an oarcrew of around 300 men. The latter were arranged two men to each oar at the two upper levels, and a single-man to each oar at the lowest level. The *penteres* was significantly slower – by nearly two knots - than a trireme in a sprint, although its cruising speed was only slightly lower, but it could carry 75 troops on deck compared to a maximum of 40 for a trireme. It was also stable enough to accommodate both fighting towers and the large new catapult artillery pieces which had been invented at Syracuse at exactly the same time. Possibly already by the time of Dionysius' death in 367 BC, the Syracusans had developed an even larger type of vessel, the *hexeres* ('six'), with two men to an oar on all three levels,[16] although this offered relatively little advantage over the five. Meanwhile, the Carthaginians in North Africa had invented the lighter and more economical *tetreres* (quadrireme or 'four'),[17] which was a two-level vessel with two men to each of its oars. It offered the performance and troop-carrying capacity of a *penteres* with less than two thirds of the oarsmen (176 in total), although it was lower and did not have the same ability to carry large towers and artillery pieces. All of these types could be used both for ramming and for fighting from the decks, and marked a move towards a mixed style of naval warfare.

Under Alexander the Great of Macedon (336-323 BC), the seven and the ten were developed to carry still more troops, followed over the next century by even larger types – eights, nines, elevens, twelves, thirteens, fourteens, fifteens, sixteens, twenties , thirties and even a forty – with up to seven men to each oar. None of these, however, can have had more than three oar-levels, and all of them must have had at least one level manned by three or more men to an oar (for example, the seven would have had three to an oar at the top or bottom level and two at each of the other two levels, the configuration of the ten would have been four, three, three, and so on). This automatically required a different type of rowing from the seated stroke possible with only one or two men to an oar, and the oarsmen would now have had to stand up and fall back onto the rowing bench in the manner later employed in medieval galleys.[18] Such vessels were much slower and less manoeuvrable than the smaller vessels, and functioned both as ramming vessels and as floating platforms from which troops and artillery pieces could fight what were in effect land battles at sea. There is no record of any vessel larger than a ten ever having taken part in an actual sea-battle, and the purpose of the relatively few examples of the larger types may have been to break through harbour chains and carry siege towers for the assault of defensive walls on the shoreline. Some, including the forty built by Ptolemy IV Philopator of Egypt (221-205 BC), which evidently consisted of two 'twenty' hulls linked side by side, and which had 400 deck crew, 2,850 troops, and 4,000 rowers on board,[19] were built simply to impress and intimidate naval rivals, and never saw action of any sort.

These so-called polyremes, from the sevens to the forty, were the preserve of the navies of Alexander and his successors, who ruled the kingdoms of Macedon, Epirus (mod.

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14 The development of the new types in the Hellenistic period is described in Morrison and Coates 1996, on which the paragraphs which follow are based.

15 Diodorus Siculus 14.41-42.

16 Xenagoras Pref. 12.

17 Aristotle frg. 600.

18 Bondioli et al. 1995.

19 Athenaeus *Philosophers at Dinner* 5.204C; see Casson 1971: 108-12.

Albania), Syria and Egypt as rivals after Alexander's death. The lesser naval powers of the Eastern Mediterranean still used much smaller vessels like the trireme with just one man to an each oar. Meanwhile, pirates employed light vessels such as the *hemiolia* ('one-and-a-half') which are recorded from the fourth century BC and may have been two-level vessels with roughly half as many oars at the lower level than at the upper (e.g. 32 + 18 = 50).[20] By the end of the fourth century, Rhodes had developed an intermediate type from these which became particularly associated with the island. This was the three-level *trihemiolia*, which most likely had a larger complement of oars at the two upper levels and a smaller complement at the lowest (e.g. 42 + 48 + 30 = 120). Such a vessel would have been only about half a knot slower than a trireme either cruising or in a sprint, whilst being significantly more economical in terms of oarcrew.[21]

In the Western Mediterranean, the Carthaginian and Roman fleets of the third and second centuries BC consisted mainly of quinqueremes which fought the mixed style of naval battle employing both ramming and boarding tactics. The trireme, however, continued in use alongside the larger vessels both at Carthage, until her destruction in 146 BC, and at Rome. The fleets of the later Roman Republic also employed smaller scouting vessels like the two-level, fifty-oared liburnians, not unlike the old pentekontors, which had long been used as pirate vessels in the Adriatic.[22] The main technological development of this period was the enclosure of the upper level or levels or even the entire oarsystems of triremes and above within a wooden oar-box, which both performed the function of an outrigger and offered the rowers added protection from missiles and artillery.

The last recorded use of polyremes – up to tens - was in the Egyptian-supplied fleet of Antony and Cleopatra at the battle of Actium in 31 BC. This was defeated by the generally smaller vessels (liburnians up to sixes) of Octavian, the adopted son and heir of Julius Caesar, who four years later took the name Augustus and became the first Roman emperor.[23] Henceforth, the Mediterranean became a Roman lake completely surrounded by Roman territory or that of subject allies, and only Roman fleets or fleets sanctioned by Rome operated within it. Rome's main fleet bases were in Italy: one at Misenum at the northern entrance to the Bay of Naples, and a smaller one at Ravenna on her northern Adriatic coast. Although the Misenum fleet had a single six as a flagship, and each fleet maintained one or two quinqueremes, up to ten quadriremes and up to fifteen liburnians, the most common ship type was once again the trireme, of which there were about fifty at Misenum and around half that number at Ravenna. The other Roman fleets in the provinces had much smaller vessels, perhaps with a single trireme acting as flagship.[24]

The principal role of the Mediterranean fleets was to carry despatches and dignitaries, to act as troop transports between different parts of the empire, and to exist as imperial fleets-in-being to deal with maritime threats from any potential usurper. In the event, after Actium no real sea-battle was fought in the Mediterranean for another 350 years. In AD 324, the trireme fleet of the Eastern emperor Licinius was defeated near the mouth of the Dardanelles by the much smaller vessels of the Western emperor, Constantine, who soon after became sole emperor and founder of Constantinople.[25] Thereafter, we do not hear of triremes again

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[20] Morrison and Coates 1996: 317-9 with Fig. 73, 345.
[21] Morrison and Coates 1996: 319-21 with Fig. 74, 345.
[22] Appian *Roman History* 10.1.3.
[23] Dio 50.23.1-3; Florus 2.21; Orosius 6.19.8-9.
[24] Rankov 1995.
[25] Zosimus *New History* 2.22-8.

and the fifth-century historian Zosimus tells us that the secret of their construction had been lost by his day.[26] The Late Roman and Byzantine empires relied instead upon two-level ships known as dromons,[27] and light, single-level *monereis* or *galeae*, which gave us the word 'galley'.[28]

Earlier Reconstructions

The history of attempts to reconstruct the ancient trireme and other oared types of oared warship is also an unusually long one, which goes back to the Renaissance.[29] Galleys were then still in use as warships in the Mediterranean, for much the same reasons as they had always been, and there was an eagerness to unlock the secrets of the ancient triremes and polyremes as a way of improving contemporary design. Inevitably, the latter also influenced theories about the construction of the ancient vessels, with particular focus on the oarsystem.

There were two different types of oarsystem in use during the Renaissance, one employing several single-man oars – up to four of them - of similar gearing but slightly different lengths rowed from the same bench, which was known as rowing *alla zenzile*, and the other which gradually supplanted it between AD 1450 and 1550 and employed one long oar to each bench being pulled by up to eight oarsmen, known as rowing *a scaloccio*.[30] It was naturally assumed that the same systems were used in antiquity, and indeed the Renaissance types were given classical names – *triremi* for *alla zenzile* vessels rowed with three oars to a bench, and so on. This was the interpretation of Guillaume Budé in 1514, and in 1526, a scholar called Vettor Fausto, citing ancient precedents, built an *alla zenzile* quinquereme for the Doge of Venice to be used against the Turks; he demonstrated its practicality by a race which it won against a contemporary trireme, and other quinqueremes were subsequently built as flagships following his design. [31] A former French ambassador to Venice, Lazare de Bayf, also attributed the *alla zenzile* system to antiquity in his *De Re Navali*, published in 1537. He located the *thranitai* mentioned in the ancient texts in one group at the stern, the *zygioi* in another group amidships, and the *thalamioi* in a third group forward, despite a well-known passage of Aristophanes which clearly implies that individual thalamians suffered unpleasant consequences from sitting immediately behind and below the other rowers.[32] He also noted and illustrated a three-level ship from Trajan's Column, but decided that it could not be a trireme.[33]

Soon, however, other scholars began to take note of the evidence for the use of multi-level ships in antiquity, including Celio Calcagnini of Ferrara in 1544, and a manuscript of the same period entitled *Disegni di Biremi, Triremi, Quadriremi* by Alessandro Picheroni della Mirandola, which included drawings showing oars on four levels.[34] The idea was not taken up seriously, however, until 1591, when Sir Henry Savile, who taught Greek to Elizabeth I, argued from the ancient texts and depictions that Greek and Roman ships were

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26 Zosimus *New History* 5.20.3-4.

27 Leo VI *Tactica* 19.7.

28 Hocker 1995; Pryor 1995.

29 For a comprehensive and witty study, see Lehmann 1995, whom I have followed closely in these pages.

30 Alertz 1995; Bondioli et al. 1995.

31 Lehmann 1995: 27-34, citing Budé 1514, repr. 1528 and Sanudo 1879-1903.

32 Aristophanes *Frogs* 1074-5 and scholia.

33 Lehmann 1995: 35-47, citing de Bayf 1537.

34 Lehmann 1995 : 50-6, citing Calcagnini 1544 and Biblioteca Marciana, Venice, Ms.It.Cl. 7 no. 379).

not rowed by the *alla zenzile* or *a scaloccio* systems but were indeed multi-level vessels.[35] Soon afterwards, in 1606, the great French scholar Josephus Justus Scaliger argued that the numbers in the names of ships indicated the number of levels of oars.[36]

Against those who advocated multi-level systems, with oarsmen arranged in staggered rows to minimise the overall height, others began to promote the single-level *a scaloccio* arrangement which had by now become dominant amongst contemporary galleys; still others postulated *a scaloccio* systems arranged in steps, often with successively more men to an oar with each step upwards, and so the debate continued throughout the seventeenth and eighteenth centuries. One important contribution came from a man whose practical experience gave his opinions some weight. In 1727, Jean Antoine Barras de la Penne, the captain of one of the (*a scaloccio*) galleys of Louis XIV, put forward what was seen as a cogent argument against multi-level vessels, that they would require oars of significantly different lengths at the different levels, and that it would therefore be impossible for the rowers to keep in time.[37] Despite this, with the development of archaeology and the emergence of more and more visual material, by the early nineteenth century most scholars had come to accept some sort multi-level system. Although John Charnock, an Englishman, had rightly postulated in 1801 that 'the oars were even in vessels of the largest size disposed in three ranks only,'[38] most, like Jean Rondelet, the architect of the Pantheon in Paris, continued to reconstruct far more levels for vessels like Ptolemy Philopator's 'forty.'[39]

A new impetus for reconstruction of the trireme arose out of the interest shown by western travellers and scholars such as William Leake (1821), Ernst Curtius (1842) and Heinrich Ulrichs (1843) in the visible remains of the shipsheds in the harbours of the Piraeus which had housed the triremes of Classical Athens. It was quickly realised that these sheds could give an indication of the actual dimensions of these vessels. At around the same time, in 1840, the great German scholar August Boeckh published a series of inscriptions found in the vicinity of the sheds, which contained inventories from the fourth century BC of individual Athenian triremes and their equipment. These inscriptions gave vital details of items such as the oars, which were recorded in three groups – thranites (62 per ship), zygians (54) and thalamians (54) – with an additional 30 spares which were either 9 or 9½ cubits long.[40]

Then, in 1852, a French archaeologist by the name of François Lenormant found a 52-cm long marble relief on the Acropolis of Athens, which was immediately recognised as depicting the central portion of a vessel with three levels of oars. Because it almost certainly depicted an Athenian capital ship of around 400 BC, this could only be a trireme (Fig. 2). When the relief was brought to the attention of the antiquarian emperor Napoleon III in 1860, he immediately ordered the building of a three-level trireme based on the relief, although he wished it to be a reconstructed not as an Athenian vessel but as a Roman trireme of the first century BC since he was writing a history of Julius Caesar at the time. The ship was designed by France's leading naval architect, Stanislas Charles Henry Dupuy de Lôme, who had built the world's first steam-powered warship, *Le Napoléon*, in 1850 and the first seagoing ironclad, *La Gloire*, in 1859. Dupuy de Lôme worked in consultation with the official

35 Lehmann 1995: 65-7 and Morrison et al. 2000: 11-13, both citing Savile 1591.
36 Lehmann 1995 : 63-5, citing Scaliger 1606.
37 Barras de la Penne 1727, cited by Morrison et al. 2000: 15.
38 Charnock 1807: 76, quoted by Lehmann 1995: 136.
39 Lehmann 1995: 137-40, citing Rondelet 1820.
40 *IG* 2^2 1604-32, originally published in Boeckh 1840, cited by Lehmann 1995: 144.

historian of the French Imperial Navy, Auguste Jal, who also published a book in association with the project entitled *La Flotte de César*.[41] The ship herself was built in Clichy, a suburb of Paris, and launched on the 9th of March, 1861.

A fortnight later she was rowed along a two-mile stretch of the Seine in Paris by 130 French sailors, with Napoleon himself and the Empress Eugénie aboard. The forty-four thranite oars were 7.4 m long, the forty-four zygians 5.7 m, and the forty-two thalamians 4.5 m. Although she had forty oars fewer than the Piraeus inscriptions indicate, despite her copper-sheathing and heavy build with a displacement of 122 tonnes, and notwithstanding Barras de la Penne's observations about the difficulty of synchronizing oars of such disparate length, she is recorded as having managed 5.5 and 5.4 knots downstream on successive days, and perhaps even more surprisingly 4.8 and 4.5 knots upstream. Nevertheless, her performance apparently failed to impress, and she leaked badly. In June, she was towed downstream to Le Havre and thence to Cherbourg, where she was laid up. The next we hear of her is fourteen years later in a series of letters of 1875-6, in one of which we read that 'le ministre désire qu'il serve de cible dans les expériences de torpilles par M. le vice-amiral Cloué' ('the minister wishes it to be used a target in Vice-Admiral Cloué's experiments with torpedoes'). In the event, she escaped this ignominious fate and was ordered to be broken up in April, 1878.[42]

Meanwhile in 1864, Johannes Bernard Graser, a German naval historian who had been taught by Boeckh, had written a treatise reviving the theory that the name of each ship type indicated the number of levels, and two years later he built a model of a five-level quinquereme with three masts to demonstrate the viability of such an arrangement.[43] More importantly, in 1871 he conducted a three-day survey of Mounychia and Zea harbours in the Piraeus, and was the first to take detailed measurements of the remains of the shipsheds which he found both on land and extending into shallow water. Graser was sufficiently practical to realise that the sheds were likely to have been only slightly broader than the ships themselves, in order to give them lateral support when they were slipped and to avoid the risk of damage to ship or shed from accidental sideways toppling. This meant that the measurement between the walls or colonnades of the sheds should be a good indicator of the overall width of the ships, and he was gratified to find that, at between 16 and 18 English feet (c. 4.9 m to 5.5 m), the clear width of many of the sheds accorded perfectly with the reconstructions he had previously published.[44] Graser's other important contribution to the debate was the publication in 1875 of an early 17th-century drawing, from the collection of the Cavaliere Cassiano dal Pozzo. This was of a Classical relief, since lost, which depicted the forward portion of a trireme and may have been the missing right-hand section of the Lenormant relief.[45] In 1885, following on form the work of Graser and other German scholars, a schoolteacher, Iakob Dragatzes, conducted excavations on well-preserved shipshed remains in Zea harbour, assisted by the German archaeologist, Wilhelm Dörpfeld who drew the plans and sections.[46] Dörpfeld later became famous as Heinrich Schliemann's assistant and successor at Troy, and his meticulous draughtsmanship at Zea still provides the best evidence for the dimensions of an Athenian trireme of the fourth century BC.

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41 Jal 1861.

42 Basch 1987: 31, 39-40; Lehmann 1995: 142-54.

43 Graser 1864 and 1866, cited by Lehmann 1995: 155-6.

44 Graser 1872, esp. 22-31; cf. Dupuy de Lôme's trireme which had a beam of 5.5 m (presumably at the waterline, so she will have been significantly wider at the outrigger) and was 39.7 m long (see Lehmann 1995: 149).

45 Graser 1874-5, cited by Lehmann 1995:

46 Dragatzes 1886.

One legacy of the discovery of the Lenormant relief and the work on the harbours of the Piraeus was that discussion henceforth tended to focus on the Athenian trireme of the Classical period, although it was assumed that this would also provide the key to the interpretation of the triremes and polyremes of other states and periods. Graser's ship reconstructions came under criticism from the French scholar Auguste Cartault (1881) because they ignored evidence from the Roman architect Vitruvius that oars were nomally arranged two cubits apart,[47] and both Cartault and Ernst Assmann (1887) also recognised that the oarsmen at the top level of the Lenormant relief are shown rowing through outriggers. As a result of this realization, the latter device featured in subsequent three-level reconstructions by J. Kopecky (1890), Cecil Torr (1894), A. Haack (1895), R. Busley (1918), R.C. Anderson (1962) and others.[48]

Despite the accumulating evidence in favour, a reaction now set in against multi-level theories. In 1883 an Italian naval officer, Rear Admiral Luigi Fincati, once again championed the *alla zenzile* arrangement while in 1896 a German scholar, L. Weber, returned to the *a scaloccio* explanation.[49] One of the most influential of the reactionaries was Dr (later Sir) William Woodthorpe Tarn. In 1905, Tarn published a paper in which he argued that ships with four or more levels of oars were a physical impossibility, and that the if the ship on the Lenormant relief were a three-level ship, it would have been impossible to row for the very reason which had been adduced by Barras de la Penne in 1727: 'it demands (judging by eye) an upper bank of oars that shall be more than twice the length of the two lower banks. Such a ship is impossible; for if one thing be more certain than another, it is that oars of different lengths, where the difference bears more than a certain proportion to the length, cannot be rowed together, by one man to an oar, so as to be of any real use or turn out an efficient ship. That they might be rowed together in a certain way for a short time I do not deny; but the huge increase in the ratio of dead weight to power would at once put an end to all idea of speed or efficiency.' Tarn therefore deduced that the Lenormant relief showed a single-level ship and advocated Fincati's *alla zenzile* solution. In the same year, a similar reconstruction was advocated for the trireme by the classical archaeologist, A.B. Cook, and was illustrated by a model constructed by Wigham Richardson of Swan Hunter and Wigham Richardson Ltd, who were at the time building the *RMS Mauretania*.[50]

Tarn's explanation took hold in English-speaking scholarship and held sway for the next three-quarters of a century. When the distinguished American historian, Chester G. Starr, produced his article on the 'Trireme' for the second edition of the *Oxford Classical Dictionary*, published in 1970 and not superseded until 1996, he was able to write that 'The long-accepted view that the rowers sat in three superimposed banks is now generally rejected; it seems probable that, the rowing-benches being slanted forward, the rowers sat three on a bench, each rower pulling an individual oar.'[51]

Morrison, Coates and the Olympias *reconstruction*

John Morrison (1913-2000) (Fig. 3), whose early interests were in Greek philosophy, first became involved in the trireme controversy whilst attempting to understand a difficult passage in the tenth book of Plato's *Republic*, in which the structure of the universe is

47 Vitruvius *On Architecture* 1.2.4.
48 See Morrison et al 2000: 17-20.
49 Fincati (1883) and Weber (1896), cited by Morrison et al. 2000: 20.
50 Tarn 1905 (quotation at p. 214); Cook and Richardson 1905; see Morrison et al. 2000: 20-2.
51 Hammond and Scullard 1970: 1095.

described as being held together by a shaft of light 'like the undergirdings (*hypozomata*) of triremes'.[52] When he came to the reconstruction of the oarsystem, he took to heart Barras de la Penne's observation about oar lengths but drew exactly the opposite conclusion, having noted that only two lengths of spare oars were recorded in the naval inventory inscriptions and these differed from each other by only half a cubit (about 20 cm). Morrison argued that it was in fact possible for oars of the same length could be arranged over three levels. He explained the small discrepancy in the lengths of the spares by reference to passages of Aristotle and the second-century AD medical writer Galen, which both implied that in a trireme the oars amidships were slightly longer than those at the bows and stern because the ship narrowed there. Morrison's father, Sinclair, built a model based on the Lenormant relief to demonstrate this arrangement, and the findings were published in *The Mariner's Mirror* in 1941 and in the *Classical Quarterly* in 1947.[53] There, Morrison also explained the numbers in the names of different ship types not as referring (impossibly) to levels of oars, but as corresponding to the files of rowers on each side of the ship. Thus a trireme had one rower to an oar at three levels, a quadrireme two an oar at two levels, a quinquereme two to an oar at two levels and one to an oar at the lowest level, and so on, as already explained above. These propositions failed to find favour with the academic community, and Tarn, who was a Fellow of Morrison's own college, Trinity, Cambridge, advised him to stick to philosophy.

Morrison was not deterred, however, and returned to the topic in 1968 in *Greek Oared Ships 900-322 BC*, which he wrote with Roddi Williams of Durham University where Morrison had been Professor of Greek. The literary evidence had been known for centuries, but the book brought it all together for the first time, citing the texts in the original languages but explaining them in English. It also added recent archaeological discoveries and a large collection of visual evidence from Greek vases, coins, models and reliefs. The latter included an Attic vase found at Ruvo in Italy which is of the same period as the Lenormant relief and apparently shows the mythical *Argo* as a three-level trireme, a vase fragment at the University of Vienna also showing details of a three-level ship, a second fragment of the Lenormant relief monument, and a Roman copy of a similar relief from L'Aquila in Italy. Morrison's former pupil, David Blackman, provided a chapter summarizing the shipshed evidence for the dimensions of ancient vessels.[54] The value of the book as a major resource for the field of ancient maritime studies was recognised immediately, but once again Morrison's three-level reconstruction of the trireme failed to convince and was criticised for technological inadequacies.

After a distinguished academic career, during which he was centrally involved in the foundation of two new institutions at Cambridge, Churchill College and University College which became Wolfson, Morrison retired as the first President of the latter in 1980. He had continued to publish on ancient ships throughout the 1970s, and in 1975 had provoked a correspondence in the Times about the trireme which ran for a record four weeks from 6th September to 4th October. Now, with more time available for research, and in order to address the criticisms made of *Greek Oared Ships*, he followed the lead of previous participants in the trireme controversy and entered into a collaboration with a naval architect. This was John Coates, who had himself just retired as Chief Naval Architect and Deputy Director of Ship Design at the British Ministry of Defence, for whom he had designed the Royal Navy's County Class guided-missile destroyers in the 1960s. Coates had a strong interest in historical wooden vessels, having been a lifelong friend of Eric McKee, author of the classic *Working*

52 Plato *Republic* 616B-C

53 Morrison 1941; 1947.

54 Morrison and Williams 1968 (chapter by Blackman at pp. 186-92).

Boats of Britain.[55] His role was, as he put it 'quite simply to take the historical requirements, laid before us so clearly by Morrison and Williams in their book *Greek Oared Ships*, to treat them as Owner's or Naval Staff Requirements and design a complete and feasible ship to accord with them.'[56]

Coates was also able to make use of a number of important archaeological discoveries which had been published since the book's appearance. These included the wreck of a merchant sailing vessel of the late 4th century BC found off Kyrenia on the northern coast of Cyprus in 1967,[57] which provided an excellent example of the mortice-and-tenon construction found in other Classical wrecks and which has herself since been the subject of no fewer than three full-scale physical reconstructions as well as numerous models. Also important was a Punic wreck or wrecks of the 3rd century BC found off Marsala in Sicily in 1969, the only ancient seagoing oared vessel(s) so far discovered in the Mediterranean;[58] they are probably oared merchantmen rather than warships, but the wine-glass cross-section of their mortice-and-tenon hulls was adopted for the reconstruction. Finally, the bronze ram-sheathing from a 2nd-century BC Cyprian warship larger than a trireme was found off Athlit near Haifa in Israel in 1980, and this preserved within it parts of the ship's keel and bow-timbers, confirming the use of mortice-and-tenon construction for warships as well as merchantmen.

On the basis of all the evidence available to him, the key requirements for Coates' design (Fig. 4) were to be as follows:

i) The ship would have three levels of oars, based on the interpretation of the Lenormant relief, the dal Pozzo drawing, the L'Aquila relief and the Ruvo vase as well as other evidence such as the passage in Aristophanes' *Frogs*.

ii) There would be 62 oars at the upper, thranite, level, 54 at the middle, zygian, level, and 54 at the lowest, thalamian, level, as implied by the fourth-century naval inventories from the Piraeus; each oar would be rowed by a single man, as indicated by Thucydides, and the longitudinal distance between each thole pin, and therefore the 'room' for each rower, would be two cubits, as implied by Vitruvius. The oars would be 9.5 cubits long in the middle portion of the ship and 9 cubits long at the ends, as indicated by the naval inventories and by Aristotle and Galen; although a variety of cubits were used in the Greek world, that adopted for the reconstruction would be the standard Attic cubit of 0.444 m, giving a 'room' of 0.888 m and oar-lengths of 4.0 m and 4.22 m respectively.

iii) The thranite level of rowers would row through an outrigger and would have a deck running the length of the ship over them, as shown in the Lenormant relief, the dal Pozzo drawing, the L'Aquila relief and the Ruvo vase, from which hair or linen screens could be suspended for to protect the thranites from missiles or the weather; the zygians would row through an open oar-hole, as shown on the Ruvo vase; the Thalamians would row through an oar-hole large enough to accommodate a man's head, as indicated by an anecdote from Herodotus,[59] and enclosed by a leather sleeve (*askoma*), as indicated by Aristophanes[60] and

55 McKee 1983.
56 Coates and McGrail 1984: 51.
57 Swiny and Katzev 1973; Steffy 1985; 1994: 42-59.
58 Frost 1981.
59 Herodotus 5.33.2.
60 Aristophanes *Acharnians* 94-7; cf. the scholiast to Arsitophanes *Frogs* 364.

the naval inventories and as depicted on the Lenormant relief and the Ruvo vase; rowers would be seated on individual cushions, as indicated by Thucydides.

iv) The ship would have a beam overall of a little less than 5.9 m wide at the widest point, i.e. the outriggers, and an overall length of around 37 m, these being respectively the estimated clear width and known dry length of the Zea sheds excavated by Dragatzes and Dörpfeld.

v) The hull would be of light, shell-first, mortice-and-tenon construction in fir and oak, based on the timbers found inside the Athlit ram and Greek merchant-shipwrecks of the fourth century BC, such as the Kyrenia ship; the ram and its timbers would be scaled from the Athlit ram; the form of the bows and outriggers would be as shown by numerous coins and pottery models of the Classical period; the cross-section of the hull (Fig. 5)would be based on that of the Marsala oared vessels; the hull as a whole would require some form of undergirding (*hypozoma*), as indicated by Plato and the naval inventories, and be capable of being slipped and launched on a gradient of about 1:10, which is that of the Zea sheds.

vi) The ship would be steered by two rudders, each fitted with a tiller and attached through the outrigger on either side of the stern, and capable of being stowed in a horizontal position as indicated by the Lindos relief on Rhodes (Fig. 6), by other iconographical evidence including vase-paintings, and by literary evidence.

vii) The ship would carry a mainmast and a small boat-mast forward, as indicated by the naval inventories from the Piraeus; the sails would be square-rigged and fitted with brailing ropes, as shown in numerous vase paintings of the Classical period, and could be removed and taken ashore in anticipation of a battle, as indicated in several literary texts.

viii) The ship would be stable under oar and sail, would be capable of achieving sustained cruising speeds under oar of 7 to 8 knots and of still higher sprint speeds in battle, would be highly manoeuvrable, and would be able to resist the forces generated by ramming, as implied by literary texts.

Initially, the intention was simply to publish an improved three-level reconstruction, but soon there was a significant change of direction. At a dinner party in Westmoreland in May, 1982, Frank Welsh, an author and former banker and industrialist, suggested to Morrison that since he and Coates were aiming to produce a complete design for a trireme, they should take the obvious next step and build a real ship. Together, Welsh, Morrison and Coates formed the Trireme Trust and arranged a conference which was held at the National Maritime Museum, Greenwich in April, 1983. Coates' provisional design, together with supporting papers by Eric McKee and by Richard Steffy from the Institute of Nautical Archaeology at Texas A & M University, were presented for discussion to an international group of experts on ships of the ancient Mediterranean. This led to some modifications, including adjustments to the oar geometry, the interpretation of the *hypozoma* as a hogging truss necessary to support the long narrow hull, the adoption of a more gently sloping cut-up following the Lindos relief rather than the steep cut-up of the Marsala ships, the rejection of a rockered keel in favour of a straight keel to facilitate slipping and launching and to allow the oars to be arranged parallel to the waterline, and an increase in the depth of the keel to improve performance under sail.[61] Subsequently, further improvements were made to the oarsystem on the advice of physicist and rowing coach Timothy Shaw, who served as

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[61] Coates and McGrail 1984; cf. Rankov 2004: 51-2.

helmsman and trials director in the reconstruction, while the sailing rig was designed by Owain Roberts who served as the ship's first sailing master.[62]

After the Greenwich conference, John Coates and Eric McKee were invited to Greece by one of the participants, Harry Tzalas of the Hellenic Institute for the Preservation of Nautical Tradition, to view the building of the first Kyrenia ship replica. While they were there, a lecture by Coates at the Hellenic Maritime Museum sparked the interest of senior officers of the Hellenic Navy, which in turn led to an undertaking that, if a reconstruction of an ancient trireme were to be built, the Navy would look after her. This proved to be of the utmost importance, because it both ensured that the ship's maintenance and offered a logistical underpinning for the operation of sea-trials in Greece.

John Morrison and Frank Welsh now turned their efforts to fundraising. The mock-up which had been shown at Greenwich of a small half-section of the ship with four rowing positions was put on display at the 1984 London Boat Show to stimulate further interest. Morrison and Welsh then travelled to Greece for discussions with the Hellenic Navy who had offered to pay for half the cost of the reconstruction if the Trust could come up with the rest. Despite the Navy's generosity, Morrison and Welsh were still faced with the daunting task of raising at least £200,000 pounds, and there seemed to be little real hope that this could be done. It was therefore with surprise and delight that they heard a few months later that the Hellenic Navy and the Greek Ministry of Culture would jointly fund the entire cost if the Trust would provide plans and specifications of the design and a trial-piece to guide the builders. Moreover, the Trust would then be allowed to carry out trials of the ship with the Navy's assistance. This was an extraordinary gesture and impressive demonstration of Greece's interest and pride in her maritime past.

A trial-section, designed to float on a raft oil-drums and with fifteen port-side rowing positions, was already being built by the Coventry Boatbuilders' Co-operative, and was then tested at nearby Coombe Abbey. After this, it was exhibited at the 1985 Henley Royal Regatta (Fig. 7), where some 200 passing rowers of both sexes tried out the oarsystem and immediately signed up to row the ship at Poros. After that, it was shipped out to Greece to the boatyard of the Tzakakos brothers at Keratsini, near the Piraeus overlooking the bay of Salamis, where work on the reconstruction began in May, 1985.

The hull was built up by the mortice-and-tenon method, strake by strake from the keel. At first three, and later six shipwrights were employed, overseen by Lieutenant Christos Lelentzis and Commander Stavros Platis of the Hellenic Navy's constructors department, with regular visits by John Coates. Although in antiquity the lines of the hull would probably have been developed by eye, perhaps with the assistance of moulds, the modern shipbuilders were provided with formers against which they could fit the strakes (Fig. 8) but which would later be removed to allow the insertion of floors, futtocks and top timbers. The build did not go entirely smoothly, however. Serious delay was caused by the loose fitting of several thousand tenons in their mortices. This would have very significantly reduced the longitudinal bending strength of the hull, whose structure was supposed to function as a monocoque, had not the problem been rectified by the injection of glue into the spaces left in the mortices. Thereafter, the mortices were cut to provide a much tighter crush-fit with the tenons, but the build was not completed until the summer of 1987, about six months later than had been anticipated. A final problem was encountered with the fitting and tensioning of the *hypozoma* rope, made of polypropylene for safety, and a wire cable had to be fitted to do the

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62 Shaw 1993 : 29-47.

job instead. This did not, however, further delay the launch of the ship, which took place on Saturday, 27th June, 1987.

The aims and sea trials of the Olympias *reconstruction*

The Trust had decided for a variety of reasons that the ship would not be built 'archaeologically pure', using only authentic materials and tools. Since there were no wrecks to replicate and since the literary texts indicated that a various woods might be used to construct triremes, there was no definitive choice available. Moreover, the use of machine tools and easily obtainable woods, with properties and densities similar to some of those which had been used in antiquity (e.g. Douglas Fir for Silver Fir, Iroko for Turkey Oak) but which were no longer accessible in the same quality, quantity or lengths, would allow for a very significant reduction in overall costs, although these would still amount £750,000 sterling at 1987 prices. In addition, the application of modern varnishes and preservatives would ensure longevity and therefore value for money.

This meant, of course, that the aims of the reconstruction could not be holistic. It was felt in any case that other reconstruction projects which *were* archaeologically pure, such as the Roskilde Viking vessels and the Kyrenia replica, were already investigating aspects such as the use of ancient tools, construction man-hours, and durability, and that to adopt that approach would to some extent be duplicating their work. Moreover, by not doing so, one could for instance use polyester rather than hempen ropes, which would add an extra margin of safety, an important consideration in a vessel which would be manned by 170 volunteer rowers. The demands of safety and crew morale also limited what could be achieved in the sea-trials.[63] Such ships are known to have been vulnerable to bad weather in antiquity, so rough conditions had to be avoided, and whilst the oarcrew often welcomed short periods of sailing as an opportunity to take a rest, they found prolonged sailing boring and preferred to row. Experiments for the sea-trials thus had to be designed with such considerations in mind.

These limitations were not considered to be particularly problematic, since the Trust felt that it was not necessary for an experimental archaeology project to pursue all possible lines of investigation.[64] *Olympias* had been built as an hypothetical reconstruction of an Athenian trireme of the fourth century BC or, in Seàn McGrail's felicitous description, as a floating hypothesis.[65] The historical background of the trireme question determined that the Trust's primary focus would be on the viability of the proposed oarsystem and the related question of performance under oar and whether it matched the evidence of the ancient texts. If the ship could be rowed effectively with three levels of oars, then the main objection to a three-level reconstruction – that first voiced by Barras de la Penne - would fall away. The validation of the oarsystem would also allow a more confident reconstruction of the later oared vessels, including the quinqueremes and polyremes, since if a trireme could be rowed on three levels, so could they. Finally, a successful reconstruction would undoubtedly attract widespread media attention, and would publicise a major example of ancient technology to a worldwide audience. The Trust's interests and approach were thus historical and educational rather than archaeological – to understand, explain and present the working and performance of an important lost artefact from the past, rather than simply to replicate its structure.

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63 Coates and Morrison 1987; Morrison et al 2000: 233-6.
64 Cotes et al. 1995.
65 McGrail 1992.

The initial experimental trials were conducted by the Trust at Poros, under an Hellenic Navy captain and with Hellenic Navy logistical support, in the first three weeks of August, 1987, and a few days later she was with due ceremony commissioned as HN trireme *Olympias.* In addition to the Navy's own trials, during which she was proudly displayed to the Greek nation around the islands of the Aegean, there followed another four series of trials conducted by the Trust in 1988, 1990, 1992 and 1994, as well as a visit to the River Thames in London in 1993, to celebrate the 2,500th anniversary of the founding of Greek democracy.[66] In the first year, the Trust's oarcrew was largely composed of British university students, but from 1988 onwards many rowers were recruited and brought over from the United States by the newly-formed Trireme Trust USA, and others came from all over Europe and indeed the world.

The first year's trials were largely occupied with learning, from scratch and by trial and error, how to co-ordinate the rowing. The thranite rowers had a clear view along and out of the ship, were well-ventilated, and soon learned to cope easily with the relatively steep angle of their oars. The zygians could not see their oar-blades but could see along the ship, and still benefited from a little cooling breeze. The thalamians, on the other hand, found their rowing positions cramped and hot, and could see neither out of nor along the ship (Fig. 9). The rowing master coaching the crew up on deck could not easily see both the oars and the rowers at the same time, and had difficulty making himself heard throughout the vessel, even with a megaphone. Keeping the whole crew in time was difficult, and mistakes in timing often caused unfortunate thalamians to get their oars caught in the water and 'catch a crab'. This sometimes had alarming results, as these rowers were pinned to the cross-beams immediately behind their heads.

Although many of the crew went home after three weeks feeling that the design was essentially flawed and unrowable, a great deal had been learned and the main problems had essentially been solved. The rowers had already been organized to work in vertical groups of three which became referred to as 'triads'. The thranite of the triad would verbally direct the rowing of the zygian and thalamian, so that they started to move together as small team. Then, with the help of 'team-leaders' coaching from the central gangway, they would gradually blend in with the triads either side of them, so that the crew gradually grew together. A way had also been found to prevent actual injury to thalamians if they caught a crab, by tying a restraining rope from their oar-handle to the cross-beam astern of their position, and by developing a method of extracting them from their predicament without having to stop the crew as a whole.

At the beginning of the 1988 trials, the crabbing was already much reduced, and soon effectively eliminated. Moreover, a microphone and six electronic speakers had been installed throughout the hull to enable the team of rowing masters to give orders and keep the crew in time. This produced much greater cohesion, and gave the crew the ability to recover much more quickly from mistakes. The introduction of a piper standing by the mast, in accordance with hints from the ancient texts, allowed the rowing master to concentrate on coaching, since the rowers could pick up the rhythm of suitable tunes, and the high-pitched sound could be heard throughout the ship. In subsequent trials, it was also found that having the crew hum along together could produce superb timing. With these improvements, when the electronic speakers broke down as they often did, it was found to be possible for two rowing masters to watch each other and give orders simultaneously in different parts of the ship so that everybody could hear.

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[66] Morrison and Coates 1989; Coates, Platis and Shaw 1990; Shaw 1993; Morrison et al. 2000: 231-75.

As communications became easier and experience grew, the rowing got better (Fig. 10), and this was aided over the first three years of trials by the shaving down and rebalancing of the oars, which had initially been over-engineered and too heavy, and by the re-shaping of the oarblades to reduce clashing. As a result, performance improved dramatically. By the end of the 1987 trials, the ship could barely manage 7 knots under oars for even a few seconds. By contrast, the same speed was attained easily on the first morning of the 1988 trials, and subsequently an average of 6.65 knots was maintained over 2,000 metres at 38 strokes per minute, and a peak speed recorded of 8.0 knots. By 1990, 8.3 knots was attained in a short burst, with a momentary peak speed of just under 9 knots. Over longer distances, 7.0 knots was averaged for one nautical mile (Fig. 11), and 4.6 knots averaged whilst actually rowing in shifts over a distance of 31 miles en route between Poros and Nafplion. Simultaneous rowing and sailing was also tried out, with 6.6 knots being attained in a 20-knot tailwind. The 1992 trials crew was under-strength numerically and was unable quite to match these speeds, although their calculated power per oar was actually greater than in 1990, and they managed to cover 5.77 nautical miles in one hour of sustained rowing. With an even smaller number of rowers in 1994, no improvement was made on any of these figures.

The ship proved to be extremely manoeuvrable and responsive to the rudders, and it was possible at higher speeds to steer easily with one rudder lifted completely and the other rudder half out of the water. Rates of turn were about 3° per second, and the ship could be rowed by the whole crew at 7 knots into a complete circle of 110 m diameter (3.4 ship lengths) with a speed loss of only 28%. If one side of rowers dropped out and held water, the turn could be tightened to a diameter of 62 m (1.9 ship lengths), accomplished in the same time of about 2 minutes, but with a loss of 50% speed. In another test, the ship was easily slowed by holding water from 5.7 knots to 1.1 knots in only 33 m (0.9 ship lengths).

To the surprise of many, she also turned out to handle extremely well under sail (Fig. 12), being stable in winds of up to 25 knots, rolling and heeling 10° to 12° in a 22-knot wind on the beam, and sailing within 65° of the apparent wind, her long keel keeping leeway down to between 5° and 7°. With a 15-knot wind on the quarter, she easily maintained 7 knots under full sail, and momentarily touched 10.8 knots in a following gust of 20 knots.

Speeds were calculated quite crudely in 1987 by means of a Dutchman's log, then much more accurately in 1988 using a shore-based geodimeter which repeatedly measured the ship's position at short intervals by shooting a laser beam at a 360° bank of prisms set up on deck, and by 1990 and 1992 hand-held GPS systems had become available. The 1988 data, however, remain particularly valuable, since they were recorded on computer and the printouts show the track of the ship through the water whilst carrying out turning and other manoeuvres.

After the 1994 trials, the ship unfortunately became infested with shipworm (*teredo navalis*), and much of her underwater planking had to be replaced. She was taken out the water and put out on display at the Hellenic Navy Museum in Neo Faliro, but her hull was then attacked by a fungal disease which by 2003 was threatening to eat her away altogether. This was recognised in time, however, and she was cosmetically refurbished in that year at the Elefsina shipyard, in anticipation of her carrying the Olympic flame across the main harbour of the Piraeus just before the opening of the Athens Olympics in August, 2004. Although she is no longer fit to undertake sustained trials at sea, *Olympias* is now looking her best again and has been provided with a roofed shed as a permanent exhibit of the Naval Museum.

The lessons learned from the Olympias *reconstruction*

The principal lesson learned from the *Olympias* reconstruction is clearly that three-level oarsystems can be made to work, thus settling an argument which goes back to the sixteenth century. This does not in itself prove that the ancient trireme was a three-level ship, but it does remove once and for all the principal objection. This in turn has opened the way for the acceptance of quinqueremes and larger polyremes as ships with up to three levels. Morrison and Coates presented possible reconstructions on this basis in their *Greek and Roman Oared Warships*, which was published in 1996.[67] Meanwhile, the media attention attracted by the ship, and its repeated appearance in books and documentaries have ensured that the educational aims of the Trust were fully achieved. In these aspects, the project has quickly fulfilled all the Trireme Trust's hopes and expectations.

Beyond this, however, a great deal has been learned and many more questions have been raised.[68] The performance of the ship under sail is impressive, and she has sailed close enough to the wind to make tacking possible if cumbersome. Her manoeuvrability under oar has also exceeded expectations and fully matched both what is implied in the ancient sources and the manoeuvrability of modern warships. The data measuring this are likely to give an excellent insight into how oared vessels of the dimensions could have been handled in battle, and they await further exploitation. The speeds achieved under oar have, however, been thought by some, including most members of the Trireme Trust, to be disappointing. Whether this is so depends on whether one interprets the ancient texts to imply that triremes in antiquity normally achieved sustained cruising speeds of around 5 knots under oar, in which case *Olympias* met or exceeded expectations, or whether one adopts a more severe interpretation and regards 7 to 8 knots as achievable. Since the trials have suggested that even with the best possible crew *Olympias* would have difficulty in attaining such a speed, this implies that there are some shortcomings in the oar geometry, even allowing for gearing problems caused to the thalamian by some minor mistakes in construction.

In particular, it was felt that the room available to the oarsmen restricted their stroke-length and therefore the power they could produce. Thus, when a new metrological relief from Salamis was published in 1990[69] showing a long cubit of 0.49 m, it was welcomed as enabling the oars to be set 0.98 m apart and allowing a significantly longer stroke. It would also permit the position of the crossbeams to be adjusted upwards so that thalamians could no longer be trapped against them, and the rowing positions could be canted outwards so that rowers would no longer be restricted by the back of the man astern and could take a stroke limited only by their own physiology. Calculations suggest that canting the rowers in this way would increase their effective power by some 25%. Even though the ship's beam would also be increased from 5.45 m to 5.62 m at the outrigger and her length from 36.8 m to 39.6 m, such a trireme, manned by a top-class crew, might be able to cruise at the 7.5 knots demanded by the most severe interpretation of the ancient evidence.

Beyond her performance, considerable insight was gained into the practicalities and logistics of operating such vessels. The difficulties of co-ordination and communication between rowing master (*keleustes*) and crew have already been described, and the trials have shown that they could be overcome either as they were in *Olympias* or in entirely different ways not yet considered. The importance of carrying sufficient drinking water for the oarcrew

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67 Morrison and Coates 1996.

68 Shaw 1993: 108-9; Morrison et al. 2000: 267-75.

69 Dekoulakou-Sideris 1990.

also became apparent. Trialling at the height of summer, the Trust's rowers were each drinking a litre of water per hour, which is in fact a conservative amount for athletes, however well acclimatized, exercising in these conditions. That implies the consumption by an ancient oarcrew of around 1.7 tonnes of water in a typical ten-hour rowing day. The daily replenishment of this amount of water, especially when ships were travelling in squadrons and fleets, would have had major logistical implications which have rarely been considered by historians

Other operational aspects which came to the fore were the need to minimize movement by non-rowers around the ship while she was under oar to avoid disturbing the balance and rhythm of the ship, and the importance of maintaining morale during long periods of rowing in such cramped conditions. Both of these issues are hinted at in our sources, but the reconstruction brought them to life as factors of some importance. It must be stressed that the observations from *Olympias* cannot be used as though they were direct evidence of how things were done in antiquity, but they can sensitize us to the ancient evidence and even raise questions which have not previously been considered.

From the Trireme Trust's point of view, the *Olympias* reconstruction has been a considerable success. It has not, however, been without its critics.[70] Many maritime archaeologists have been particularly hostile, questioning the legitimacy of any reconstruction which is not based on material remains. This somewhat misses the point of why the reconstruction was made in the first place, and both discounts the value of other types of evidence and ignores the historical background to the debate. A few scholars have questioned the three-level solution, although the alternative offered – a two-level ship which on each side alternates single rowers with two men to a bench *alla zenzile* – is largely based on an interpretation of the so-called Siren Vase depicting Odysseus' ship as a single-level vessel.[71] Most classicists and the general public have, on the other hand, embraced *Olympias* as an authentic representation of an ancient trireme, which has brought its own problems. The very cost of the experiment makes it difficult to replicate – as evidenced by the fact that over the last 500 years the only physical reconstructions have all been built at state expense – Venice's quinquereme, Napoleon's trireme, and the *Olympias* herself. Meanwhile the attractiveness and very tangibility of *Olympias* as an object makes it hard for people to remember that she is only an hypothesis, albeit one based on a good deal of solid evidence. The Trireme Trust remains convinced that her design does reflect, at least in some degree, an ancient reality, and the most recent research has tended to confirm both details and the general dimensions of John Coates' design. Nevertheless, the long history of the trireme controversy should warn us that the debate is unlikely to be at an end.

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70 See Rankov 2004: 55-7.

71 Tilley 1992; 2004, followed by Jordan 2000.

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