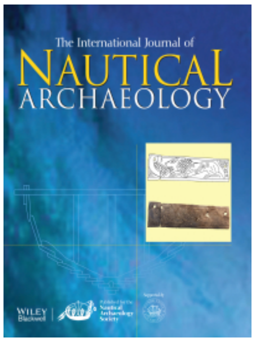

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The *Syracusia* as a giant cargo vessel

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Introduction

The discovery of a Greek merchantman of the early 4th century BC off Alonisos (*New York Times*, 4/13/93) ought to precipitate a re-evaluation of the potential cargo capacity of ancient Mediterranean merchant vessels. Its size (originally estimated as at least 150 tons cargo, or 300 to 400 tons displacement at full load) greatly exceeds any previously documented for wrecks of the Classical Period (for example, *Kyrenia*, 28 tons—see Table 1), or previously considered feasible by theoreticians. The *Syracusia*, a giant vessel built for Hieron II of Syracuse in the 3rd century BC, has often been denied proper recognition on the grounds that its literary description must have greatly exceeded its actual size. This view may now be vigorously challenged.

Given the structure of ancient ships and the conditions governing shallow water wrecks, archaeologists should not expect to recover remains of any of the larger varieties of vessels. The largest merchant vessels cited in archives for Greek and Roman antiquity, apart from a few unusual creations for special purposes, were apparently carriers of bulk foodstuffs, mainly grain. Most scholarship has followed Casson (1971/86: 171–173) who estimated, on the basis of harbour regulations and other considerations, that, in the period subsequent to the sinking of the Alonisos ship, the largest 'classes' of merchantmen were freighters of 350–500 tons cargo capacity.

Their successors, the Imperial Roman grain fleet, mainstay of the run from Alexandria to Rome, have been estimated at approximately 1300 tons, based on Lucian's description (*Navigium* 5) of the *Isis*, which he saw when it was blown off course to Piraeus (Casson, 1971/86: 186–188, passage translated 208–209). (Table 1). No wreck of a Roman grainship of this type has ever been located.[1] In a wreck, a grain cargo can be expected to swell and dismember the hull; marine flora and fauna consume the organic components, and may even disperse recognizable debris over a wide area of deep-sea floor.

Many of the known merchant wrecks were probably being operated on the same economic basis as a modern tramp freighter on which neglect of repairs is typically handled as a calculated risk as, for instance, seems to have been the case with the Kyrenia ship.[2] All the excavated merchant ships were to some extent tramps, carrying very mixed cargo including wine, pottery, metal ingots or utensils, millstones, and even potted vinestocks (Parker, 1984, 1990, 1992a). Giant vessels, and also vessels necessary to the welfare of the state, such as Lucian's *Isis*, represented large investments, and as such would likely have been better maintained. After all, the *Isis did* weather the adverse winds and reach port, albeit not her designated port. The requirement of grain fleets and special carriers for deep water ports, dramatized

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Table 1. *Scale and capacity of ancient vessels (in metres)*

Vessel	L	Beam	Capacity	Cargo type	# Amphorae	# Ingots?
Ulu Burun 14c	+15	?	over 30 tons	'royal'mixed	yes	YES
5th c trireme	(37)	(5·5)		none	warship	NO
Olympias	36·8	5·45	42/48 tons	none	warship	NO
Porticello 5c	16·6	X	X	mixed	yes	YES
Alonisos 4c	± 26	11·6	(150 tons)	wine+?	>1000, est. 2000–3000	?
Kyrenia 4c	12	5	28 tons	mixed+wine	400 amphorae	YES
Greek, average	15–37	—	(100–150) tons	mixed	yes	—
Greek, larger	—	—	350 to 500 tons	freighters		—
Syracusia 3c	(61·5)	(15·4)	1700/3650 tons	grain, grainship/liner, passengers, military		
Ptolemy's *Forty*	103·6	17·4	over 7250 men+artillery	warship, probably catamaran		
Albenga 1c BC	40	10–12	500–600 M tons	wine,	5 layers=11,000–13,500	NO
La Madrague de Giens 1c BC	40	9	225–390 M tons	wine and	3 or 4 layers=	NO
			375–400 tons	pottery	6000–7800	
Roman average	—	—	(350–500 tons)	tramp/freighter	probably	OFTEN
Roman grain fleet	—	—	(1300 tons)	grain, bulk	grainship design	—
Isis 2c AD	55	13·7	1200 to 3500 t	grain, bulk	grainship design	—
Caligula obelisk	104	20·3	1300 tons	obelisk+lentils	grainship, modified for stone	
Nemi ship 1	73	24		cult/cruise	barge-like	NO
Nemi ship 2	71	20		cult/cruise	barge-like	NO

in the story of Hieron's disenchantment with his *Syracusia*, further limits the number and likelihood of theoretically possible wreck-sites.[3]

Among the special freighters of antiquity were two built to carry obelisks from Egypt to Rome for Augustus and Caligula. Their design must have been modified to accommodate the location of the concentrated load of the monuments. The known weights of obelisks and ballast on Caligula's carrier equalled the burthen of the big grain carriers. The Augustan carrier for the Flaminian obelisk has been described as 3000 tons displacement (Torr, 1894, amplified by Duncan-Jones, 1977: 332 n. 5). This was subsequently exhibited at Puteoli until its accidental destruction by fire. Caligula's carrier, by order of Claudius, was filled with concrete and sunk for a mole in the harbour at Portus, where the hull casting has been reported to be 20·38 m wide × 90 m long at the waterline, and for which a total displacement of 7400 tons has been estimated.[4]

The efficiency and versatility of Classical and Hellenistic construction methods, ingenious, albeit labour intensive, are demonstrated in the hallmarks of ancient shipbuilding: (1) shell-first, edge-joined construction; (2) subsequent use of framing for bracing (Casson, 1971/86: 214–216) and (3) painstaking hand-finishing techniques. No evidence exists to suggest that different materials or construction methods were used for the production of cargo vessels of gigantic scale. The *Syracusia* episode suggests that where builders might have been constrained by the limitations of their theoretical and technical knowledge, or by limitations of materials, the genius of Archimedes was adequate to supplement these standard approaches.

Description of the *Syracusia*

The *Syracusia* was built *c.* 240 BC for Hieron II of Syracuse (*c.* 306–215 BC), with construction overseen, at least in part, by his kinsman Archimedes. The primary source for the vessel's description is a passage in Athenaeus (5·206d–209b) attributed by him to 'a certain Moschion'. The account (Casson, 1971/86: 191–199) describes Hieron's acquisition of materials from far and wide, recruitment of craftsmen, including a Corinthian foreman, details of the construction procedure involving Archimedes and his screw-windlass, and a description of the final product complete with decorative art works, cargo and crew. It had apparently been Hieron's intention to use the ship to tour the Mediterranean distributing gifts of grain (other cities were suffering famine) and to demonstrate his naval and military capability in a relatively benign forerunner of early 20th-century American 'gunboat diplomacy'. When he learned that the ship was too big and deep to dock in most ports, he decided not to use it himself and made the best of the venture by presenting it to Ptolemy III as a gift.[5]

One assumes that after docking in Alexandria the ship, renamed the *Alexandris*, remained at anchor and, at least for the duration of Hieron's reign, may have been exhibited rather than sailed. The temptation to cannibalize her for timber, metal and art must have been great, and it seems reasonable to assume that this became her fate, perhaps still during the 3rd century BC, since no later eyewitness accounts were generated. Some of the luxurious elements of the Nile barge built by Ptolemy IV might be identical with those of the *Syracusia*: for instance, the fine woods and valuable stones (Athenaeus 204d–206c). Perhaps a Ptolemaic relief vase or Pompeian mural may yet be found that records some feature of her famous mosaics (scenes of Aphrodite, and of the *Iliad*), the 9-foot *atlantes*, or the terrace-like pattern of decks and garden promenades.

The problems of the *Syracusia* did illustrate the lack of adequate harbour facilities for outsized ships, but this was not caused by a lack of technical ability, as many fine examples of harbour engineering[6] were already in existence in Punic cities, Etruria and the Hellenistic kingdoms. Social or economic factors must have precluded the use of giant vessels and favoured relatively small craft. Estimating tonnage from ancient documents is necessarily imprecise.[7] It must always have been problems of terrestrial logistics that hindered the use of larger vessels. Pomey and Tchernia (1978) among others have considered some of the logistical factors involved in (1) navigating the Tiber with large draft vessels—recalling that it is always preferable to move heavy freight by water; (2) the need to drydock or overhaul in special facilities; (3) the difficulties of not being able to put to shore nightly, translated into the need to carry large amounts of provisions for crew, passengers and livestock, and also the need for sleeping accommodations; and (4) the difficulties of unloading bulk cargoes, even in deep water ports which necessitated the coordination of an army of stevedores supplied with small transfer vessels.

Syracusia: features noted by Athenaeus/Moschion

The description of Athenaeus/Moschion is summarized below without interpretation:

- contained enough timber to build 60 quadriremes (see Estimate A)
- employed 300 craftsmen plus their assistants
- finished to waterline (necessarily the lower hull) in 6 months, then
- launched and completed afloat (another 6 months)
- hull pinned with copper spikes of 10 and 15 pounds weight [in addition to mortise-and-tenon joints]
- 3 levels of gangways (τριπάροδος)
- crew's quarters floored in mosaics of the Iliad
- shade gardens in tubs along promenades
- Aphrodite chapel paved in semiprecious stones
- gymnasium, library, bath, 20 stables, 20,000 gallon water tank, saltwater fish-tank, ovens, millstones etc.
- upper deck supported outside by monumental Atlas figures (see Estimate B)
- 8 artillery towers, grappling machines etc.
- bronze-clad mast-tops holding marines
- unusually deep bilge bailed by Archimedes' pump
- largest of several ship's boats was 78 tons
- cargo for the maiden voyage:
  60,000 measures of grain, 10,000 jars of Sicilian pickled fish, 20,000 talents of wool, 20,000 talents miscellaneous cargo complete provisions for crew, horses.

Debate of the theoretical possibility of a *Syracusia* as large as described by Athenaeus has provoked strong opinions. Athenaeus specified that the ship was of the same type, albeit on a different scale, as a class of cargo vessel built on Hieron's orders, the grain ships, πλοία σιτηγά. A passage in Plutarch (*Marcellus* 14·8; Casson, 1971/86: 195 n. 29) implies the existence of three-masted vessels of this type, in active service as grainships. The term applied to the *Syracusia*, that she was an εικόσορος, 'twenty-er', is not of much help in estimating her size or appearance, as shown by Casson (1971/86: 169 n. 5) since 20 oars, useful in a merchant galley, would not be effective on a vessel of this size. Casson suggested the analogy 'full-rigged ship'.[8] No dimensions are preserved in the transmitted account, but the volumes described for the original cargo have been used to support various estimates, with the best guesses at either 3650 tons or from less than 1700 to 1940 tons.[9]

The recent work of Levathes (1994: 7, 80) on the Chinese Treasure Fleet (AD 1405–1433) describes ships, built before the modern era, and largely of wood. The vessels were purportedly 390 to 408 feet long and 160 to 166 feet wide, and appropriately deep. Their exact shape may be debated, and thus their block coefficient is uncertain, but they would have been at least 5000 tons displacement, demonstrating that large, wooden, pre-modern ships were feasible, and that such ships have been built and have functioned.

Reasonable estimates of *Syracusia*'s size can be achieved by analysing: (1) the amount of key materials used; (2) the area of floor space and hold depth that are accounted for in descriptions; (3) the area described for the passenger deck; (4) the area required for the horse deck, and (5) the combined weight of passengers, equipment and cargo. All of these estimates will be seen to agree with each other, with a variation of only a few percent. It is surprising that Athenaeus' account, intended as entertainment of sorts, should seem to be so technically accurate. A probable explanation is that his source, Moschion, had relied upon firsthand information, derived from the actual vessel. Other features, such as the tub gardens, water reservoirs, mosaic paved rooms, and artillery emplacements, all point to a construction of massive size and weight.

It may help to rearrange the elements of the prose account by deck features, to give an impression of area as well as weight.

Syracusia: *features by deck*

Deck 1: lowest, i.e. the hold
- reached by many companionways
- contains bilge and Archimedes' screw pump
- contains cargo, mainly grain

Deck 2: gives access to cabins
- contains 30 four-couch cabins
- one stateroom of 15-couch size with three private cubicles
- all cabins have mosaic floors

Deck 3: highest actual deck; 'for the men at arms'
- bases/footprints of eight 9-foot artillery towers
- bases of columns supporting the fighting deck
- 20 stables, 10 on each side
- forward: 20,000 gallon sealed water tank and leaded salt-water fish tank
- aft: Aphrodite chapel (three-couch size), mosaics
- also: reading room (five-couch)
- library (probably three-couch)
- bath (three-couch with copper tubs, 50-gallon basin)
- gymnasium
- 'accommodation for passengers and bilge-watchers'

Deck 4: fighting deck
- parapet raised above promenade deck on columns
- iron palisade
- eight 9-foot towers
- large catapult and many other devices

Working estimate of *Syracusia*'s dimensions

The following estimates of dimensions or volume of the *Syracusia*'s described features will be facilitated by the development of a simple working model for her general size. Since the *Syracusia* has been described only in terms of cargo weight, and *Isis* in Lucian's account was quantified only by linear dimensions, a combination of the two should be considered in creating a full picture of the *Syracusia*. Since both Hieron's ship and the later *Isis* were designed specifically as grain transports, the two probably had roughly similar profiles and proportions. The Isis' measurements (180 × 45 × 43·5 feet or 55 × 13·7 × 13·25 m; see Table 2) show a finess ratio of 4:1, and it is logical to attribute the same ratio to *Syracusia*. The depth to beam ratio of *Isis* is close to 1:1, and was presumably a standard for Roman grain clippers. An alteration of this ratio to 1:1·4 for *Syracusia* is proposed,

Table 2. *Hull dimensions of ancient freighters in feet (top) and metres (lower)*

Vessel	Length	Beam	Hold depth	Draught, loaded
Porticello*	49–50†	X	X	X
Kyrenia*	39	15†	(draught 4 feet)	4
Syracusia	200†	50†	36 total D 18 for hold	26·3
Albenga*	120	30–36†	16·5†	18
Madrague de Giens*	120	26	12	14·8
Isis	180	45	$43\frac{1}{2}$	26 to 33
Caligula's obelisk carrier*	343†	66·5†	?	—
For comparison with ancient wooden vessels:				
*Great Republic**	334·5	53·5	38	—
Ing. Sané,* 118 canon	219	55·7	—	26·6

METRIC Vessel	Length	Beam	Hold depth	Draught
Porticello*	16·6†	X	X	X
Kyrenia*	12	5†	(draught approx. 1·2)	1·2
Syracusia	61·5†	15·4†	†11 total, 6 hold	8†
Albenga*	40	10–12†	†5·5	5·5†
Madrague/Giens*	40	9	4·5	4·5†
Isis	55	13·7	13·25	8 to 10
obelisk carrier*	104†	20·3†	?	
*Great Republic**	112	15	16	—
Sané,* 118 canon	66·8	17	—	8·12

(Sources as cited in the text. Draught estimates after Pomey & Tchernia, 1978.)
*wreck, or actual vessel; †estimated.

since it was designed to carry artillery and for stability in battle needed to be broader than an undefended, swifter grain carrier. Speed was probably less of a concern than stability and passenger comfort. The *Syracusia*'s dimensions can be approximated, given the one relatively certain linear measurement for her, the height of the *atlantes* supporting Deck 3 (see Estimate B). The *atlantes* were 9 feet tall and suggest a deck height of the same (headroom would be less, allowing for heavy deck beams).

Estimate B argues that all true decks visible above the waterline would appear symmetrical to an observer ashore. Since the *Syracusia* was τριπάροδος—with three levels of gangways—and should have had the very deep hold of a grainship, we assume that 'Deck 1', the hold, was actually about twice the height of Decks 2 and 3; that is, 18 feet deep, with at least 9 feet below waterline, and with the ship's lowest πάροδος running through or around the hold at about the height of 9 feet. Because of wetness, a grainship needs a deep bilge; further, a hold only 9 feet deep could have been accessed easily enough with simple ladders and catwalks, equipment that would probably not have elicited the formal term πάροδος. Landels suggested a draft of 4·6 m (slightly over 15 feet) for *Syracusia*, based upon figures established for Roman harbour clearances.[10]

So, given a total 'depth' of 36 feet (9 feet for Decks 3 and 2, 18 feet to the keel for 'Deck' 1, the hold), we arrive at a beam of 1·4 × 36 feet = 50·4 feet. Using a finess ratio of 4:1, on analogy with the *Isis* (after Casson, 1971/86: 189; Pomey & Tchernia, 1978: 245), length may be calculated as 4 × beam = 201·6 feet. For ease of estimation, we round off the dimensions to 200 × 50 × 36 feet (dimensions in metres: 61·5 × 15·4 × 10·8). This represents a vessel just 20 feet longer than the *Isis* and 5 feet broader abeam, but of similar proportions.

Tables 1 and 2 show that these are the proportions of a grain carrier rather than of a wine freighter or a warship, or of a modern Atlantic wooden clipper. While just 10% longer than the *Isis*, the *Syracusia* was much shorter than the Roman obelisk carriers, and shorter than the Nemi ships, the *Great Republic* and the *Wyoming*. As Pomey and Tchernia suggested (1978: 248 n. 76), such dimensions very closely approximate the French men-o-war of 118 canon designed by Ingénieur Sané. *Syracusia*'s displacement, although determined by a different configuration, armament and cargo from that of the warship, will be seen to be relatively close to that known for Sané's wooden sailing ships. It will be shown that a vessel of these dimensions can reasonably accommodate all the luxurious structures, cargo weight and armaments described by Moschion/Athenaeus, in a fashion consonant with the aesthetic and ideological principals of the dynasty for whom it was built.

Estimate A: amount of timber used

A very crude approach to estimating the *Syracusia*'s size is suggested by the statement that the builders used as much timber for her planks and keel as would have been required for 60 quadriremes. Presumably the wood for cabins and other fittings was in excess of this amount, and of different timber species, since warships were never so elaborated. We possess no precise estimate of the displacement of a quadrireme, but the smaller trireme has been well documented by shipshed measurements and the Olympias project. Following Morrison and Coates (1986: 211; 1989: 20), a trireme's displacement would be approximately 25 tons for the empty hull and 40 to 48 tons fully loaded.[11] Sixty triremes at 25 tons would support a total unloaded displacement weight of 1500 tons, with a loaded weight of twice that amount, hence 3000 tons, relatively close to the 'high' estimate for the Athenaeus passage. Since triremes were much smaller than quadriremes, to improve upon the estimate substitute 35 tons for a hull weight (a conservative, 10-ton upgrade for a 3rd-century quadrireme).[12] Sixty vessels of 35 tons would have an empty displacement of 2100 tons and a loaded weight of 4200 tons. This is close to the magnitude of several independent estimates that follow. Further, a loaded warship would be substantially lighter than a finished, loaded freighter.

Estimate B: deck measurements

The ancient account also notes that the upper deck was supported by *atlantes* 6 cubits, approximately 9 feet, high. For ease of estimation we assume an Attic foot roughly equivalent to 30 cm and to an English foot (Meiggs, 1982: 478 appendix 9). Schmidt-Colinet (1977: 48 n. 217) gives a πῆχος of 0·45 m. These anthropoid carvings are said to have supported the *triglyph*, presumably an architrave/parapet wall, and also the ὄγχοι, translated by Casson (1971/86: 197 n. 41–42) as 'deck structures'. The term *atlantes* evokes the appearance of massive, terrestrial architecture, such as the famous colossal flank façades of the Olympieion of Akragas (begun *c.* 480 BC) featuring nude, male bearded and unbearded figures, familiar to most of those who made or saw the *Syracusia*. The Agrigentine *atlantes* are over 25 feet (7·65 m) high, standing seemingly on piers with the semblance of a parapet framed by the engaged columns of the temple's flanks.[13]

The *atlantes* were very probably stylistically and metrologically related to those of Hieron's other massive monument, the Great Altar of Syracuse. Unfortunately, fragments of the figures noted on site have been lost since the 19th century (Schmidt-Colinet, 1977: 48). Koldewey and Puchstein give their size as one-and-a-half times lifesize. In line with the principles of classical art, one would expect that Hieron's *atlantes* were larger than a man, and that the deck below them (Deck 2) was equal to them in height, that is 9 feet high. Their pose must have indicated that they 'carried' a very heavy burden, the upper structure of the ship, on their heads or shoulders.[14]

If the *atlantes* correspond to a uniform visible deck height, a depth for the three decks (Decks 2 and 3, and 1, the hold, that is, from the keel to the ceiling of the Deck 3 cabins) of 36 feet (9 feet times two plus 18 feet for the hold) may be assumed. For the purposes of calculating displacement when fully loaded, of course, much less than 36 feet would be at or below the waterline; for ease of computation, half below waterline, thus 18 feet is postulated.

The subject of ship shape must of course be addressed. Departure of shape from a perfect rectangular solid is expressed as a block coefficient where a shoebox would have a ratio or coefficient of 1·0; compare the sketch in Steffy (1994: 10ff) A ship built to sail well would have a block coefficient less than 0·5 while one designed to carry maximum cargoes would approach 0·9 as in modern, oil supertankers. A high block coefficient, 0·07, has been assumed for the *Syracusia* since she was primarily a showpiece, rather than a working ship.

As established above, dimensions of 200 × 50 × 36 (or here, one half of 36 = 18) may be used to determine the volume of the combined decks/hold, and a rough estimate of displacement achieved by taking into account the block coefficient (0·7) and weight of sea water (64 pounds per cubic foot).

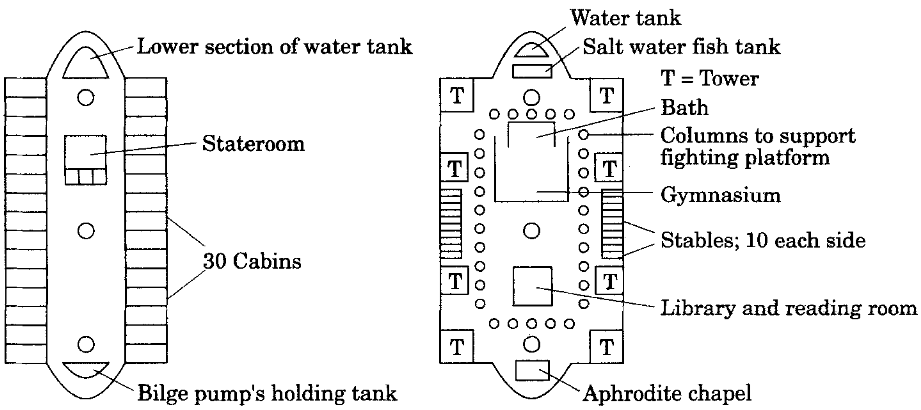
$$L \times W \times 1/2\ D = 200 \times 50 \times 18 = 180{,}000 \text{ cubic feet}$$

$$\text{Displacement} = 180{,}000 \times 64 \times 0{\cdot}8 \div 2000 = 3950 \text{ tons.}$$

Estimate of deck sizes (Fig. 1)

The unusual deck/superstructure configurations of *Syracusia* suggest that her three decks varied in linear size. The fighting deck is simply a partial platform supported by columns and the roofs of the deck structures; models can be seen in numerous ancient representations (Casson, 1971/86: 51ff, 55ff, Figs 65–69, 80, 84; Basch, 1987: Figs 482, 878.) Deck 2, with its cabins of regular dimensions, would be slightly larger, assuming a projection of the deck beams near bow and stern that extended the hull slightly abeam. A measurement of 155 × 50 feet for the rectangular platform comprising Deck 2 exclusive of the tips of bow and stern will be suggested. This gives a surface area for Deck 2 of 7750 square feet.

Deck 3 would be a rectangle formed of the cantilevered deck beam ends plus small stern and bow decks within the hull. A rectangle similar to the decks of the Nemi ships would, for *Syracusia*, be approximately 165 × 70 feet, for a surface area of 11,550 square feet exclusive of the tips of bow and stern. This affords ample space for all the features described. All the deck extensions, supports for towers, garderobes and ovens could be built in a suitably symmetrical and aesthetically satisfying style, on expanded analogy to the support structures shown for Roman freighters (Casson, 1971/86: Figs 114, 130, 135, 144; Basch, 1987: Figs 747–758, 792–802, 1030, 1038).



Syracusia deck 2; suggested layout   *Syracusia* deck 3; suggested layout

Figure 1. (a) *Syracusia*, Deck 2, suggested layout; (b) *Syracusia*, Deck 3, suggested layout.

Estimate C: cabin dimensions and size of Deck 2

Another very crude estimate of size is suggested in Athenaeus' description of the 'passenger' deck:

- 30 cabins of four-couch size
- One cabin of 15-couch size with three cubicles of three couch size

Overnight passenger travel was not common in the 3rd century BC, so no 'standard' cabin dimensions exist. The dimensions suggested by Rhodian sea law for passengers' personal space are 3 cubits length by 1 cubit breadth,[15] or 1·33 × 0·44 m[16], perhaps intended simply as personal baggage space. The use of 'couch-size' units in describing the *Syracusia* suggests instead a close relation to terrestrial, domestic architecture.[17] Bookidis indicated, from her study of built-in couches in the Acrocorinth Demeter sanctuary, that 'a person 1·61 m tall requires a couch at least 1·46 m long to recline [for dining] with legs extended', and a diner 1·75 m tall would need a couch 1·58 m long.[18]

An estimate of the area required for the cabins of Deck 2 may be developed from measurements of excavated terrestrial rooms with built-in couches, and compared with the deck space suggested in Estimate B. If we use the length and width estimate of Estimate B above, we can calculate 200 feet (estimated length of ship) × 50 feet (beam) × an adjustment for deck taper assumed to be about 0·7 = 7000 square feet, or, given the slight outboard extension of Deck 2 and treating the useable space there as only the area of that rectangle, the available deck space would be 155 × 50 feet = 7550 square feet. It will be seen that this easily accommodates the estimated cabin area.

Many terrestrial dining halls had couches estimated or averaged by their excavators at 2 m long (6·56 feet)[19] for instance:

- Perachora sanctuary, 5th century standard size 1·80 × 0·85 m. (5·9 × 2·7 feet)
- Corinth, Demeter Sanctuary, 4th century range: 1·7 to 2·4 m
- Vergina, East wing private rooms, est. 2 m long (6·5 feet)

A realistic estimate of couch size might be 6 × 2·5 feet, an analogy with the standard at Perachora, a sanctuary frequented by seafarers.[20] A room of four 6-foot couches would be 8·5 × 12 feet, for a room area of 102 square feet. Thirty such rooms would total 3060 square feet.

As for the larger room of 15 couches, terrestrial dining rooms of that magnitude are quite large:

- At Perachora, an 11-couch room was a square 6·30 m (20·66 feet) on a side, with an area of 39·69 square m (425·68 sq. feet).
- In the Macedonian palace complex at Vergina, two 7-couch private dining halls were placed side by side. Each room was square, 5 m (16·4 feet) on a side, yielding an area of 25 square m (270 sq. feet).

Athenaeus states, however, that the large stateroom included 'three cubicles of three-couch size' (presumably all in a row along one side of the square, cf. Vergina). A 15-couch room of 6-foot couches could be planned in a space 26·5 × 32·5 feet in area, thus 860 square feet. Maintaining the requirement of three attached three-couch cubicles, with three 6-foot couches fitting in a square room of 8·5 feet on a side, the additional area would be 3 × 72·25 square feet=217·5 square feet. Again, more passage room should probably be added. Christides (1985/89: 81–82 Figs 4–8) illustrates cabins on medieval Red Sea vessels).

Total dining room space thus equals 3060+860+217+20% for passages, etc.= total area of 4965 square feet, easily fitted onto a deck of 7550 square feet area, with room to spare for light wells, cargo ramps and machinery.

Estimate D: area of stables on Deck 3

When worn-out Athenian triremes were pressed into service for equine transport, they apparently allowed minimal space for stabling (Morrison & Coates, 1986: 226–228), but speed, journey time and the need for nightly landfall made such a cramped situation feasible. The open structure of a trireme (with some benches removed and the 30 horses carried relatively high in the ship) would have allowed for unpleasant but manageable loading. *Syracusia* would have required more space devoted to passages and storage.

Although Roman shipping seems to have included horses at times (Parker, 1990: 342), the next available data to provide useful quantities in Mediterranean horse transport are medieval archives for the Crusades and the Venetian and Genoese transport hired by various Frankish rulers. Pryor (1982: 105ff.) has analysed a contract of AD 1270 for the construction and hire of two Genoese *salandria* by Louis IX, each to carry 100 *destriers*, somewhat larger than classical warhorses.[21] The space allowed for an individual stall may be estimated roughly at 1·5 sq. m. Further to the area needed for stabling, Venetian Crusader transport contracted to provide, *per diem*, for each horse, large amounts of grain and hay, requiring storage space, and 28 litres of water: for 100 horses, that would be 2800 litres or 2·8 tons of water for one day.

The number of horses on the *Syracusia* has not been preserved, and the term used by Moschion/Athenaeus, ἱππῶνες, is not quantifiable, being used alternately for a stable or a stall.[22] The fact that 20 separate structures are specified suggests more than 20 horses, and if each of the 20 'stables' held just five horses, it would support a total of 100 horses, or the equivalent of one Genoese *salandria*'s horse population. If the total deck space on Deck 3 is 11,550 square feet, the 612 square feet. (including gangways and storage) required for 100 horses is easily allocated, as is the space for a mere 20, just 34 square feet.

Estimate E: weight estimates for Deck 3

Several items of cargo or equipment on the *Syracusia* may easily be assigned weights. These form the bulk of the weight estimate for burthen/displacement, and thus support, on grounds of internal consistency, the reality of a super-sized sailing vessel. Several other parts of the full complement of a *Syracusia* voyage may be estimated

Table 3. *Cargo on* Syracusia *(Est. in metric tons)*

Item	Weight	Original units	Minimum		Maximum
grain	60,000	[sc.'measures']			
		if *modii* of 15 kg, then	400		
		if μεδίμνοι of 40 kg, then			2400
pickled fish	10,000	jars κεράμια, 50 kg)	500		500
wool	20,000	talents (of 26 kg)	520		520
miscellaneous	20,000	talents (of 26 kg)	520		520
		TOTAL is either	1940	or	4340
		(In 'short tons'=	2134	or	4780)

with less precision, but even minimal figures ascribed to them necessitate the higher estimates of the ship's displacement.

Estimate E-1: official cargo of Syracusia's maiden voyage

No-one has disputed Athenaeus' assessment of the *Syracusia*'s official cargo for her maiden voyage, although many scholars differ in methods of calculating its weight in modern units,[23] see Table 3.

Lucian's comment (*Navigium* 5) that the grain on the *Isis* (estimated at 1300 tons) would feed all of Athens for a year may shed light on the *Syracusia* grain manifest. If Hieron intended to make political capital by the gift of his surplus grain to some other city, he would have expected to donate a substantial amount—surely a large fraction of a city's needs, at least a few months' supply. We are in favour of the larger estimate of the 60,000 'measures'. Other gifts of grain from Hieron, made to Rome, were on occasion more than ten times larger than this.

Estimate E-2: armaments, partial estimate: stone missiles

Although much more armour and weapons are known to have been installed on *Syracusia* and carried/worn by her crew, a minimal estimate of the catapult stone will show that great weight was involved. Athenaeus notes (208c) that (1) the eight towers were 'crammed' (Casson, 1971/86: 197) with stone and missiles, and (2) that the central, largest catapult could throw an 18 foot bolt or a 180 pound stone. He further indicates (208e) that, under battle conditions, slaves using block and tackle would keep the artillery supplied with stones, presumably from the extra storage in the hold.

For purposes of estimation, we assume the use of limestone or marble as missiles. Limestone weighs 2·68 to 2·76 grams per cubic centimetre (167–171 pounds per square foot), while the relative density of marble is 2·6 to 2·8 grams per cubic centimetre or 160–177 pounds per cubic foot.[24] A limestone missile of 180 pounds need not be much larger than one cubic foot.

Assume that the stones used for catapult missiles are approximately one cubic foot in volume, and that just one layer of them covers the floor of each tower, with a pile equivalent to two towers' quota available to the central catapult mounted on the fighting deck. Since the towers were 9 feet tall, a proportionate footprint/ground plan for each tower would be perhaps 6 × 6 feet (needed to accommodate the marines and archers stationed there).

Volume of stones in towers

- Area of one tower = 6 × 6 feet = 36 square feet

- Eight towers' area=8 × 36=288 square feet
- Plus floor/pile space equivalent to two more towers' footprint, to supply central catapult=2 × 36=72 square feet
- Thus, the total surface area=360 square feet
- Assume just one layer, 1 foot deep, of stones,
- Volume of stone=surface area × 1 foot depth=36 sq. feet × 1 feet=360 cubic feet
- Weight of stone=360 cubic feet × W per cubic foot (average)=360 × 169=60,840 pounds
- 60,840 lbs÷2000=30·42 tons

Estimate E-3: weight of water carried

It would be logical to assume a separate reservoir to supply water for the stables and gardens; and one could also guess at the size of the saltwater fish tank. It is certain, though, that the sealed fabric tank carried in the bows held 2000 μετρῆται (20,000 gallons). As Pomey and Tchernia noted (1978: 248 n. 76), this tank's contents alone must weigh 78 metric tons. Such a tank would require a volume of 78 cubic metres, which could be fitted into a rectangular space 7·8 × 5 × 2 m, or a cube of less than 4·5 m on each side. A fabric and wood tank could have been built to conform to an oddly shaped space in the bows that might otherwise have been unusable. The problems of balance ensuing from filling or emptying the tank could have been counteracted by judicious use of the bilge-collecting tank which must have been in the stern.

If, as in the Crusader archives (Estimate D above), approximately 28 litres of water were allowed each horse daily, 20 horses would require 0·56 tons per diem, or 2·8 tons for a 5-day cruise, easily met from the original 78 ton tank, so no extra water reserves need be envisaged.

Estimate E-4: weight of personnel and livestock

Estimate E-4a: weight of stabled horses. For a maiden voyage, a complement of 20 horses—divided among the 20 'stables'—is assumed. It may well be that more horses were actually stabled on board. Thirty to a trireme and 100 to a Genoese *salandria* must have been efficient enough, and with careful planning *Syracusia* could easily have allowed for 100 horses. Assume 750 pounds per horse—currently the weight of a yearling American thoroughbred—and much less than a *destrier* or shire horse.[25].

750 lbs × 20 horses=15,000 lbs
15,000÷2000=7·5 tons

Estimate E-4b: personnel on board. Athenaeus' text shows damage at the point which must have cited the full census of the *Syracusia*, but a number of details concerning her battle stations remain:

- Marines stationed on *Syracusia*
  60 marines on each side of ship=120
  60 marines stationed around main-mast=60
  4 marines, 2 archers in each tower × 8 towers=48
  3,2, and 1 man in mast-tops=6
  '600 men stationed forward'=600
  Total soldiers described=834
- Remainder of personnel
  To the total should be added an unspecified number of:
  sailors
  officers, helmsmen *et al.*
  'bilge-watchers'
  grooms, at least one per horse
  servants, slaves for menial household, military duties
- Presumably dignitary passengers should be added to this list, and an officer or passenger represented by each 'couch space' enumerated on Deck 2,
  i.e., 30 cabins × 4 couches=120

owner's staterooms: 15 couches + 3 × 3 couches = 24
Total cabin 'residents' = 144

Estimate E-4b: total personnel on board. The total of specifically listed personnel is thus 834 + 144 = 978. With an equal number to represent the remainder of personnel, sailors, *et al.*, the total is 1956 men. The giant polyreme warships carried large crews in addition to oarsmen,[26] and Roman sailing grain freighters are known to have carried large numbers of paying passengers.[27] To provide a minimal estimate, the incomplete census of 978 rounded upward to just 1000 is retained. The marines were probably quartered on the fighting deck and not provided with cabins.

Assume 150 pounds weight per person (many will have weighed less, some more, while Hellenistic hoplite armor could weigh 70 pounds).
Thus, 150 lbs × 1000 men = 150,000 lbs ÷ 2000 = 75 tons.

Estimate E-5: weight of mosaic floors in cabins, chapel
On Deck 2, all 30 cabins, as well as the stateroom complex, and the Aphrodite chapel on Deck 3, had floors of mosaic pavement, the cabins decorated with scenes from the *Iliad.* The chapel was especially ornamented with agate; the other stones are not specified, but the weight of agate illustrates the density of any materials involved, at 2·5 to 2·7 grams per cubic centimetre (156–168 pounds per cubic foot), averaged to a weight of 162 pounds per cubic foot (2·6 grams per cc).

Total square feet of cabin floors = 4279 sq. feet
(this is the average of 4206·75 from Estimate C-2, plus an additional 72·25 sq. feet for the chapel of three couch size)
Round off to 4300 for additional ornament (and ease of computation)
and assume the pavements are uniformly only 1 cm or about 0·39 inch thick
4300 sq. feet × 0·0325 = 13·975 cubic feet of mosaic
13·975 cubic feet × 162 lbs = 2263·95 lbs
2264 ÷ 2000 = 1·13 tons of mosaic stone.

Estimate E-6: weight of lead sheathing
Athenaeus (207b) describes the sheathing of the hull from marine growth with lead plates, particularly necessary because *Syracusia* was one ship that could not be beached for maintenance. In wrecks on which enough lead is preserved to permit measurement of thickness, the lead, attached over resin-soaked wool or linen, is now usually just 1 mm thick (5 mm on the Grand Congloué). More often it has become lead oxide and cannot be handled or measured.[28] It is likely that sheathing depth was not a uniform 1 mm over an entire vessel, but would run to greater thicknesses (less would not be useful).

While it seems logical to assume the greater thickness (5 mm) for an armed vessel like the *Syracusia* (see Table 4), 1 mm is also calculated for the totals in Estimate F.

- Weight of lead sheathing = p A d,
- where p = density of lead in grams per cubic cm
  A = wetted surface area of vessel, i.e. length + beam × depth × block coefficient
  d = depth of lead sheathing
- W = 11·34 × (L + B) × D × (0·7) × 0·001 (in most cases)

We assume that depth is twice the draught of a ship—although this can vary from ship to ship, this should be sufficient for purposes of estimation. In Table 4, for conformity to this formula, Kyrenia's depth is given as a construct of twice its known draught. All measurements are metric, including metric tons of 1000 kg; most depths are estimated. Note that if the hull is sheathed only to a depth of 6 m,

Table 4. *Weight of lead sheathing on selected hulls*

Vessel	Length	Beam	Depth	Thickness of lead	Volume Pb cubic m	Weight tons
Kyrenia	15	5	(2·4)	0·001	0·0384	0·43
Madrague de Giens	40	9	4·5	0·001	0·1764	2
Grand Congloué	23	6·8	2·5?	0·005	0·298	3·4
Nemi #1	73	24	4?	0·001	0·3104	3·5
Isis	55	13·7	13·25	0·001	0·7282	8·3
Syracusia	61·5	15·4	11	0·001	0·6767	7·7
Syracusia	61·5	15·4	11	0·005	3·3836	38·4
Syracusia	61·5	15·4	6	0·001	0·3691	4·2
Syracusia	61·5	15·4	6	0·005	1·8456	20·9

Table 5. *Total weights derived from estimates*

	Metric tons
official cargo:	
pickled fish, 10,000 at 50 kg	500 tons
wool, 20,000 talents	520
miscellaneous, 20,000 talents	520
grain, modern equivalent disputed	400
total cargo	1940
non-cargo manifest:	
catapult stone, estimated	27·65
water tank	78
horses, estimated	6·8
personnel, estimated	68
mosaic pavements	1·03
lead sheathing	7·7
total non-cargo	189·18
total plus undisputed cargo	2129·18
wooden hull, exclusive of superstructure and trim (see Estimate A)	2100
hull, equipment, cargo, total	4229·18

there is still a significant weight of lead involved.

Estimate F: total weights derived from estimates

With a displacement figure in excess of 4200 tons,[29] it no longer appears worthwhile to argue the exact size of the grain cargo (Table 5). Even on this deliberately low estimate, the ship so described is huge, and a feat of construction equal to the building of the *Great Republic* or of an 18th-century man-o-war.

Strengths of ancient shipbuilding

In the ancient ship, the stressed skin construction was reinforced by substantial framing. In the exceptional case of the *Syracusia*, the skin was also attached to the frame with 10 and 15 pound copper spikes.

A wooden ship overdesigned enough to be rigid, as suggested by the presence of mosaic floors on Deck 2,[30] would certainly be sufficiently strong for summer service in the Mediterranean (Casson, 1985: 13–14).[31]

The subjects of rigging and stability signal questions when an attempt is made to flesh out a ship based upon a descriptive and non-technical literary portrait. Rigging most likely was conventional three-masted with short masts, but with Archimedes as the architect this vessel could well have departed markedly from the conventional rigging of the period. With a very high block coefficient and short masts would come a very slow speed. A top-heavy appearance would seem to be consistent with the description offered by Athenaeus. How was stability maintained? Archimedes most certainly would have considered the subject. Perhaps a mass of metal and strict operating rules to never sail without ballast was the answer.

Available prototypes for *Syracusia*'s design

Relatively large vessels are attested even for the Bronze Age Aegean (*c*. 1900–1200 BC) on the evidence of sizes and weights of anchors or ballast. The Ulu Burun merchantman[32] with an incomplete cargo estimated at well over 25 tons and a total weight of over 30 tons including stone anchors/ballast, is a small ship compared with some Cypriot and Levantine vessels represented by stone anchors.

The divergence in design types in the 7th–6th centuries BC which saw round ships built as merchantmen must have made possible a substantial increase in tonnage. Phoenician ἵπποι and the σαμαίνα class of the time of Polykrates seem to have been characterized by their capacious holds. Even the Phoenician warships of the Assyrian palace reliefs (Nineveh: Casson, 1971/86: Fig. 79) appear to have had multiple decks and therefore deep holds. The Etruscan merchantmen of some 7th and 6th-century vase paintings and the 5th-century vessel docking in the Tomba della Nave, Tarquinia (Casson, 1971/86: Figs 80, 93, 97), all had especially deep holds. Non-Greek shipbuilding traditions would have been particularly accessible to Archimedes and the shipbuilders of Sicily, where Syracuse had earlier profited from research and innovation in the design/reconfiguration of her warships.[33]

Foerster Laures (1985/89) has also emphasized the necessity of a true bilge and pumps to reduce the wet surface and humidity problem for grainships: 'only with a bilge could this wet surface and the moisture in the hold be reduced. Therefore we can suppose that the decisive motivation for the creation of the bilge was the transport of grain and the use of the pump the logical result. This could explain why Archimedes tried in Siracusa [*sic*], one of the grain exporting ports of antiquity, to use the screw to get the water out of the bilge of a big ship.'[34]

The deck buildings could have been designed and built by a different technician, not the naval architect whose responsibility was the seaworthy hull. The superstructures no doubt bore a great resemblance to terrestrial fortifications and public buildings. For instance Athenaeus cites [207e] a feature 'made to look like the sundial at Achradina' (Casson, 1971/86: 196).

A giant ship known to ancient scholars (Athenaeus 5.203e–204b = Casson, 1971/86, 108–112, 140) was of course the famous *Forty* warship commissioned under Ptolemy IV (Philopator, 221–203 BC). As a warship, it was ungainly, intended for display (Plutarch *Dem*. 43.5), but its measurements lend credence to the scale of a functional *Syracusia* (Table 6). The text gives measurements in cubits, extrapolated to metres following Meiggs (1982: 138–139) and to feet following Casson (1971/86:

Table 6. *Specifications of Ptolemy's* Forty

	Cubits	Metres	Feet
Length	280	103·63	420
Beam	38	17·37	57
Height waterlevel to tip of stern	53	24·08	79·5
Height to top of prow	48	21·94	72
H/L of four steering oars	30	14	45
Length of thranite oars	38	17·37	57
Draft (empty) (under	4	1·8	6)
Personnel: 4000 oarsmen			
400 officers, ratings, deckhands			
2850 marines Total 7250 men			

Figure 2. Engraved gemstone in Berlin (lost), 1st century BC–1st century AD. (After Furtwängler, 1900, *Die Antiken Gemmen*, pl. 46 no. 51).

108–112) and using the cubit of 1·5 feet (Meiggs, 1982: Appendix 9).[35]

Persson (1935: 146–149) associated the *Syracusia* with a group of engraved gems which depict the same unusual ship (Fig. 2), characterized by eight towers, a gigantic mainmast with single sail, and a deep, rounded hull. In the more detailed gems, the towers at the stern are rounded, with conical roofs and a gateway, while the prow towers seem to be rectangular. The four flank towers are much smaller, and depicted as if in line, with two at each gunwale. Some gems seem to show not crenellations atop the towers, but spherical, helmeted heads. Other distinctive features in the gems are a huge bull figurehead (Casson, 1996: 262), long steering oars, and two heavy wales or projections, one at gunwale level, and one lower. A few gems (Persson, 1935: pl. II nos 7, 8) show the space between these horizontal elements covered with diagonal raised lines which at first glance appear to be oars. If so, the ship depicted would not be *Syracusia*. However, the 'oars' do not reach the waterline, as indicated by the level of the steering oars and dolphins. An onyx in Braunschweig[36] shows a hull of three distinct segments: dolphins in relief against a deep, curving hold; a central level punctuated by several rounded, shield-like protuberances; and an upper deck with triangular ridges outlining arcades. The same ship, in a lost example illustrated by Furtwängler[37] (Fig. 2), has a middle deck with rounded diagonal reliefs that might just be shorthand for the *atlantes* of *Syracusia*. Certainly, no single gemstone could have been engraved with all of the visible features of *Syracusia*, and Persson's dismissal of the lack of two more masts is quite sensible. On the other hand, their production in the 1st century BC to AD makes an association with Roman large-scale vessels more likely (Basch, 1987: 471).

The Doric aspects of Hieron's artistic commissions were integral to his public relations agenda, as noted by Athenaeus (209d–e): an inscription on the *Syracusia*'s prow, quoted in a poem for which Archimelos of Athens was rewarded by a gift of grain, declared that the ship was launched by 'Hieron, son of Hierocles, bearing gifts of a rich harvest to all Hellas and the isles, wielder of the sceptre of Sicily, the Dorian. Nay, then, Poseidon, guide this bark homeward over the blue surging sea' (Gulik, 1957: vol. II, 446–447).

The battlement-like appearance of *Syracusia*'s towers can only have enhanced

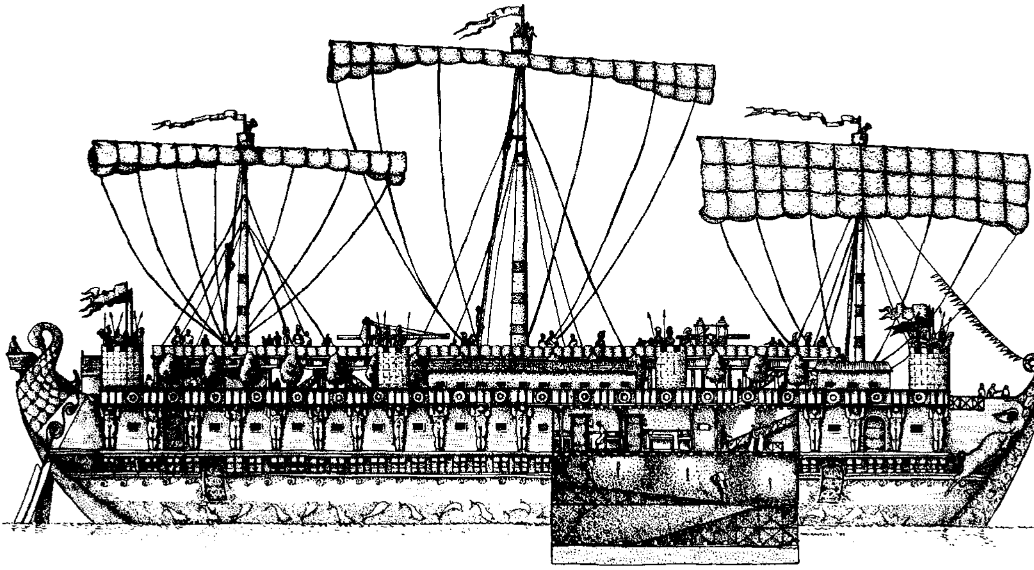


Figure 3. Artist's conception of the *Syracusia*, viewed from dockside. (Drawing: N. Holmes Kantzios.)

the image Hieron intended to project. The dolphins are not mentioned in the literary account, but, on analogy with Ptolemy's (IV, Philopator) *Forty, Syracusia* could well have had its hull ornamented in encaustic (the *Forty* had ivy leaf and thyrsos ornament: Athenaeus 204b). In fact, the gems' bull figurehead recalls the scale of the *Forty*'s 'figures at stern and bow not less than 18 feet high' (Athenaeus 204a–b). Figure 3 has incorporated the figurehead, and other aspects of the gems, with the literary description of the *Syracusia*, as well as features known from other famous vessels.

The frivolous aspects of *Syracusia*'s ornamentation have made it easy for modern scholars to view the ship's size and value as having been exaggerated, but surely historians should credit the existence of a 4200-ton *Syracusia*, especially in considering the involvement of Archimedes, particularly when emerging evidence of ancient engineering and materials has begun to offer confirmatory support. Dissenters will have to demonstrate some alternative explanation for the the great internal consistency of the Athenaeus/Moschion account—which stands as an eyewitness account of a very real, albeit fabulous, vessel.

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Notes

[1] Saint Gervais B, a wreck of the 7th century AD, apparently carried grain (rivet wheat) in barrels as part of its cargo, but this is very different from the massive carriers of early Imperial Rome. See Parker, 1990: 342; 1992a: 94.

[2] M. L. and S. W. Katzev, 'Kyrenia II': Building a replica of an ancient Greek merchantman. *Tropis*, I: 163–175, here 164. Kyrenia 'I' is believed to have been sunk by pirates. See also Steffy, 1985: 95–99; Katzev, 1989.

[3] Cf. Parker, 1984: especially Fig. 2, plotting preservation against depth of wreck-sites and discussing other factors such as ancient salvage efforts (e.g. Saint Gervais C). Deep sea exploration would be desirable: cf. Bascom, 1976.

[4] Parker (1992a: 179 M), quoting O. Testaguzza, 1970, *Portus. Illustrazione dei porti di Claudio e di Traiano e della città di Porto a Fiumicino.* Rome, 105–120; Casson, 1971/86: 367. O. Testaguzza, 1964, The port of Rome. *Archaeology*, **17**.3: 73–79, especially 177, 175 Fig. 3, identifies the concrete filled hulk as the foundation of the famous lighthouse; dimensions differ slightly from the final publication (and Tables 1 & 2) at 95 × 21 m. The 104 m length has been questioned by several scholars, including Casson and Duncan-Jones. Basch (1987: 471) also reports a 90 m length for the hull. Either the three moles/towers sunk on it (Pliny N.H., 16.202) have obscured the original shape, or its modification to carry the obelisk resulted in a radical extension of its hull.

Duncan-Jones (1977: 332) and Meiggs (1982: 476–477) impugned their seaworthiness, but the fact remains that each obelisk carrier succeeded in its voyage from Egypt. An 'unseaworthy' vessel fails either because of materials failure or inadequacy, or because it is a light structure, designed or manufactured with flaws that make it unable to withstand normal stresses. Materials inadequacy would be tested by the very first voyage and, obviously, both carriers passed that test.

[5] The *Syracusia* cannot be located with great precision within Hieron's reign, but the recipient was probably the third Ptolemy (Euergetes, 246–221 BC) and not to be confused with Ptolemy IV (Philopator), builder of the *Forty* warship. Strabo (792.6) says that the busy Great Harbour at Alexandria had deep water quays for even the largest ships. On Hieron's policies and giveaways, see H. Berve, 1959, *König Hieron II.* Munich: 69 ff.; especially 70–75 on *Syracusia.*

[6] For instance, B. Frau, 1985, From the Etruscan Ports of Graviscae and Martanum, Elements for a New Methodology in the Field of Maritime Archaeological Research. *Harbour Archaeology*, Ed. A. Raban, B.A.R. IS **257**: 93–104. See also Casson, 1971/86: 362–366; E. B. Shuey, 1982, *Etruscan Maritime Activity in the Western Mediterranean 800–400 BC: An Archaeological Perspective on Historical Interpretations.* Ph.D. thesis, University of California, Santa Barbara (Univ. Microfilm 8321540): 227–238. D. J. Blackman, 1982, Ancient harbours in the Mediterranean. Parts 1, 2. *IJNA*, **11**.2 and **11**.3: 79–104 and 185–211. Recent works suggest well-constructed harbours even for archaic cities, e.g. A. Archontidou *et al.*, 1989, Excavations at Thasos, Greece. *IJNA*, **18**.1: 51–59. Bascom (1976: 66) offers tantalizing estimates on the number of ships harboured during Classical antiquity in the major maritime cities.

[7] Cf. Casson, 1971/86: 170–173, 187–189. The confusion in tonnage descriptions is well indicated by H. T. Wallinga, 1964, Nautika (I). The Unit of Capacity for Ancient Ships. *Mnemosyne*, **17**: 1–40. Tonnage data on both old and ancient ships are analysed by F. C. Lane, 1964, Tonnages, Medieval and Modern. *Economic History Review*, **17**.2: 213–233. See now E. Hadjidaki, 1997, The Classical Shipwreck at Alonnesos, in *Res Maritimae. Cyprus and the Eastern Mediterranean from Prehistory to Late Antiquity* (Nicosia/Atlanta, 1994) Eds S. Swiny, R. L. Hohlfelder, H. W. Swiny: 125–134.

[8] An historical analysis of the εικόσορος category has recently been presented by H. T. Wallinga, 1993, *Ships and Sea—Power Before the Great Persian War.* New York: 41–45. He notes it is the oldest Greek term for a specific type of ship, namely a 'beamy freighter', the equivalent of a medieval merchant trireme. Homer alludes to its unusually large mast and hull broader than that of the average trader. Presumably the term, by the 3rd century BC, merely reflected a broad freighter or carrier of bulk cargo.

[9] 3650: Duncan-Jones, 1977. Smaller tonnages: Casson, 1971/86: 185, achieved by changing the presumed unit of measure, the μεδίμνος, to a smaller one, the Roman *modius*. Within a few years, Syracuse would fall to a Roman army (with particularly tragic results for Archimedes), and no doubt the Roman *modius* would thereafter replace Greek regional standards of measure. But during the *Syracusia*'s short lifetime, when Moschion wrote his account, an eyewitness would surely have registered her cargoes in Syracusan μεδίμνοι, or perhaps Alexandrine units. See Duncan-Jones, 1977 for arguments against use of *modii* here.

[10] J. G. Landels, 1978, *Engineering in the Ancient World.* Los Angeles: 66; J. P. Oleson, 1984, *Greek and Roman Mechanical Water-Lifting Devices: The History of a Technology.* Toronto: 60–61,

22–23, 91–93, discusses the Archimedean screw-windlass and ancient references to it. He describes it as provided with treads so that a single man could turn it by walking on its barrel—as in Egyptian figurines (Figs 71, 86 and 101). He notes (60–61) the need for it to discharge into a collecting tank above the waterline—probably more than a single screw was needed for such a deep hull. Room for even a dwarfish bilge-watcher to work the screw-pump without interfering with cargo handling etc. implies a very deep hold, possibly 6 m (18 feet) as suggested in Table 2.

[11] The authors discuss this elsewhere, in Effects of Shipworm on the Performance of Ancient Mediterranean Warships. *IJNA*, **25**.2, 1996: 104–121. No criticism of the *Olympias* project is implied—modern safety considerations and economy of resources dictated the divergences from ancient methods, and all have been acknowledged by the reconstructors.

[12] A possible size measurement for the Hellenistic quadrireme is provided by the slips identified at Apollonia in Cyrenaica, which suggest vessels of the same beam as Athenian triremes (and the Piraeus shipsheds) and almost 40 m (131·16 feet) in length (Casson, 1971/86: 364). If the quadrireme is merely 8% longer than the trireme, we may add 3·2 tons (8% of *Olympias*' 40 tons) to the displacement figure plus at least another 3·2 for the extra weight of equipment for the larger vessel. If an additional 6·4 tons displacement is a minimum estimate, a 10-ton 'upgrade from trireme' does not seem unreasonable. A strict 8% upgrade would be 43·2 tons × 60=2592 tons. The *Victory*, for example (104 guns, 186 feet long on gundeck × 51·5 breadth, hold depth 21·5 and burden 2162 tons), was built from over 2000 oak trees, said to be equivalent to 60 to 80 acres of mature forest.

[13] Dimensions of the Olympieion, Akragas: 173 × 361 feet/ 52·74 × 110·09 m, with flank walls over 14 times the length of the *atlantes*. Unfortunately, the photographs and drawings of the latest publication for Akragas, G. Pugliese Carratelli and Gr. Fiorentini, 1992, *Agrigento. Museo Archeologico*. Novecento, Palermo: 92–95, Figs 94–96, follow a superseded reconstruction offered by De Miro, in which the *telamones*' legs were placed wide apart. The crucial fragments proved to be parts of an arm, however: see *JHS*, A.R., 28, 1981–82: 97.

[14] Sources on size, configuration of architectural *atlantes* and caryatids: Schmidt-Colinet, 1977, Sicilian and related examples, 242 ff. On Atlas figures, see also B. de Grito and R. Olmos, Greek and Etruscan Atlas. III. Atlas as an architectural support: Atlantes. In *LIMC* III,**1**: 11–13, with possible interpretations of Hieron's use of defeated Titans. Greek *telamones* were generally monumental, Etruscan versions smaller and with funerary associations. Most examples fall into the period of the Syracusia, the 3rd–2nd centuries BC.

[15] Cited by Christides, 1985/89: 76, citing W. Ashburner, 1909, *Nomos Rhodiôn Nautikos. The Rhodian Sea-Law*. Oxford, reprint 1976: 60.

[16] In a nautical context, Bonino (1985/89: 45) used 0·4425 m for a cubit. J. Coates, 1991, The 1990 sea-trials of the reconstructed Greek trireme Olympias. *IJNA*, **20**.1: 70–71, has suggested the need for a correction in the equivalent size of the Attic cubit, traditionally estimated at 0·444 m, to 0·490 m. This could mean a slight increase in width for the Rhodian personal allowances, 1·3 × 0·49 m, still not a proper berth.

[17] Bonino noted that, in the case of the Nemi ships, the ship's architect was probably responsible for the hull up to the waterline or upper deck, and that a domestic architect took over to build the deck structures (Bonino, 1985/89: 41).

[18] N. Bookidis, 1993, Ritual dining at Corinth. In *Greek Sanctuaries: New Approaches*. Eds N. Marinatos and R. Hägg, London: 45–61.

[19] For discussion of standard/average dimensions of public and private dining rooms, see J. Travlos,1974, *Pictorial Dictionary of Ancient Athens*. New York: 534–536, on Agora, South Stoa I (also 553–559 on the Tholos).

[20] In fact, in support of wider, 2 m couches, at South Stoa I in the Athenian Agora, excavators found a slightly raised border approximately 1 metre wide running along the sides of Room V and apparently intended to support seven dining couches. (H. A. Thompson, 1968, Activity in the Athenian Agora: 1966–1967. *Hesperia*, **37**: 36–72).

[21] From the 8th century AD, the Byzantine navy transported small numbers of horses in galleys, but the first fully sailed vessels actually designed for horse transport were probably the *salandria* of the 13th century. These embarked horses in deep water, through a port.

[22] The term occurs in only five texts besides this account: a 3rd-century BC Zenon papyrus, *IG* 1^2.336 (Eleusinian building account), *SEG* 2·481 (Scythian, 3rd century AD), and two passages in Xenophon, *Eq*., 4.2 where it appears to be a single-horse stall, and *Cyrop*., 8.6.17 where it refers to multiple horse posting stations. No actual Greek stable has been identified.

[23] The main references are Casson, 1971/86: 183–187 and Duncan Jones, 1977, also Pomey and Tchernia, 1978: 235 ff. Casson (1985) offers the 40 kg equivalent for the μεδίμνος, and 50 kg for the *amphora*. This agrees reasonably well with excavated amphorae (of the 5th–4th centuries BC) known to have contained salt or pickled fish. Casson used the Attic- Euboic talent of approx. 26 kg (26·02 according to Benoît, 1961: 160, who notes its equivalency to the Rhodian 'amphora' unit of the 3rd–2nd centuries BC). An Athenian/Solonic talent of 36·6 kg (Benoît, 1961: 160) would provide a weight of 732 metric tons for the last two categories, but it is quite unlikely that this was used in Syracuse. As for the κεράμια of fish pickle, a number of Punic amphoras of the 5th–4th centuries have been identified either containing fish (Corinth) or having a hole in their bases, presumably to allow transport of dried or cured fish (Porticello wreck). The Porticello Punic amphoras were found to be of varying capacities, the large intact vessel holding over 29 litres, the small amphoras ranging from 20 to nearly 27 litres (Eiseman & Ridgway, 1987: 52). A weight of 50 kg for an amphora full of fish seems reasonable.

[24] Source for these and other specific gravity data: R. C. Weast and M. J. Astle (Eds), 1983, *CRC Handbook of Chemistry and Physics*, Boca Raton.

[25] Recent bibliography, mainly on draught or slaughter animals rather than riding horses: A. Riedel, 1982, The Paleovenitian Horses of Le Brustolade. *St Etr*, **50**: 227–256.

[26] The *Forty* carried 3250 in addition to 4000 rowers; the more viable *Leontophoros* carried 1200 marines alone (Casson, 1971/86: 107–115).

[27] 600 travelled with Josephus in AD 64, and 276 with St. Paul in the off season of AD 62.

[28] Grand Congloué: *Under the Mediterranean*. London, 1963: 248; Benoît, 1961: 152–154 and 169 ff. Nemi: G. Ucelli, 1950, *Le navi di Nemi*. Libreria dello Stato, Rome: 153, 265. Kyrenia: Steffy, 1985: 98–99. On lead analyses, ingots, and classical shipping, see Eiseman and Ridgway, 1987: 53–60. The depth of 2·5 m offered in the table for the Grand Congloué is the average of 2·40 *creux* and 2·70 *tirant d'eau en charge* suggested by Benoît, 1961: 164. Depth for Nemi #1 is estimated. For analyses of lead sheets, see H. Frost *et al*., 1976, *Lilybaeum (Marsala)—The Punic Ship: Final Excavation Report=NSc* 1976 suppl. 30: 262.

[29] Incidentally, this is the loaded weight suggested by the simplified method of Estimate A.

[30] Mosaic floors were apparently not uncommon in Classical shipping—references in Casson, 1971/86: 181 n. 65.

[31] Ships designed for heavy cargo such as stone were apparently deliberately strengthened with thick ceiling planking over a flat bottom—as in La Luque A (2nd century AD)—Parker, 1992a: 95, 97.

[32] See Bass, 1985/89: 25–35, updated by Dr G. Bass, AIA lecture 2/10/1994. C. Pulak, see also The Uluburun Shipwreck, in *Res. Maritimae*, Eds S. Swiny, R. L. Hohlfelder and H. W. Swiny, 1994, Nicosia (published Atlanta, 1997): 233–262.

[33] As demonstrated at Erineus, cf. Morrison and Coates, 1986: 167. The description of hull construction procedures on the *Syracusia* has been linked by Meijer to traditions practiced in the Mediterranean, but not seen in the well-known Classical wrecks: F. Meijer and A. W. Sleeswyk, 1996, On the construction of the *Syracusia* (Athenaeus V. 207A–B). *Classical Quarterly*, **46**: 575–578 (we thank Professor Meijer for kindly sharing a pre-print of this article).

[34] The sources on Archimedes' screw are Moschion in Athenaeus 207b, used to launch the hull; 208f, used to bail the bilge; Agatharchides and Posidonius in Diodorus Siculus (1.34.2 and 5.37.3–4) on its invention/Egyptian associations; and Plutarch, *Marcellus* 14, used to launch a fully laden three-masted freighter. See also note 10.

[35] Also presented by L. Casson, 1969, The super-galleys of the Hellenistic Age. *MM*, **55**: 185–193, dimensions, 188.

[36] Basch, 1987: Fig. 1071; V. Scherf, 1970, Die Gemmensammlung im Herzog-Anton-Ulrich-Museum Braunschweig. In *Antike Gemmen in deutschen Sammlungen, III*, Ed. P. Zazoff, Wiesbaden: 52 no. 184, pl. 22. Scherf dates the gem 1st century BC to 1st century AD.

[37] A. Furtwängler, 1900, *[Die] Antiken Gemmen*. Berlin: pl. 46 no. 48; denoted as '*verschollener Stein*' by Scherf, previous note; Persson, 1935: Fig. 7.

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