THE RIGGING OF BRONZE AGE SHIPS

Abstract :

The ability of Bronze Age boats to sail to windward is analysed here by examining the rigging. The purpose is to shed some light on the ways in which maritime exchanges and passages could have been undertaken in the Aegean in the LBA.

1. Introduction

Local weather conditions and geography are crucial factors in the design of ships and rigging[1]. They will have influenced the way in which the earliest navigators traveled in the Aegean. Thus, some theories about trade and communication will need to be re-evaluated, in particular those which do not address actual sailing conditions. My aim is to present a technical analysis of the ways in which Bronze Age boats were equipped to sail.

The archaeological evidence for increasingly systematic sea communication in the Mediterranean during the Bronze Age is indisputable. Furthermore, the expansion and sharing of technological information between coastal sites is well documented for the LBA[2].

I have argued elsewhere that professional sailing, and by extension trading by sea was not a random activity limited by seasons, weather conditions or time of day[3]. The Aegean islands did not have autonomous economies although they may have come close to it in the EBA and the early MBA. As communities became larger, they were apt to become more reliant on trade. The spread of obsidian and later the common use of bronze and increased technological sophistication demonstrate that contacts were sought beyond the confines of island communities. Given the absolute need for efficient communication by sea, one cannot assume that boat design evolved haphazardly over the centuries. The development of designs allowing for more predictable handling of ships was undoubtedly given considerable attention. Ships were essential for supplies, for communication, and for war. The economic and political growth of islands such as Crete, Thera, Melos and Kea is inconceivable without efficient sea contacts. This essential need will have influenced ship design.

It is especially important to establish the ability of BA boats to sail to windward. The wind is the power that drives a sailing ship. The efficient use of this force will be the primary concern of a ship builder and a sailor. A major misconception about square sails is that they can only be used for running before the wind. The concept of ancient navigators running south with the aetesian winds in the summer and north with the south winds in the winter should be reconsidered. Unfortunately, it has influenced theories about communication and trading systems in the Bronze Age Aegean[4]. The way people sailed in the historical periods is certainly important as comparative evidence, but may not apply fully to the prehistoric period due to differences in economic and political systems.

2. Technical factors and historical evolution depictions of ships and known wrecks

The major sources of information about Aegean BA boats are models, images on miscellaneous objects, ceramics, seals and wall paintings, as well as recent studies of Bronze Age wrecks, and the Homeric poems[5]. Concordances between the rigging in the Thera ship painting and standard Homeric rigging terms have been discussed in detail elsewhere[6].Traditions were undoubtedly strong and many images exist as testimony to designs of earlier periods[7].

A hull propelled by oars has other requirements than a hull propelled by wind or by a combination of the two. White points out the obvious difference in equipping a fighting ship or a cargo ship: oared cargo vessels are unpractical because crew and equipment occupy space at the expense of cargo[8]. This observation is valid for any period of antiquity. While cargo ships may include oars, they will be fewer and less permanently outfitted. The hull will be designed for maximum capacity and not for the accommodation of rowers.

Increased flexibility and stability in conjunction with optimum hull speed have always been the main stimuli for changes and developments in the design of hulls and rigging. The simplest way to achieve balance in the hull design of a shallow keeled ship is to create a symmetrical hull with the greatest beam and depth at the center. On a beamy hull, it is best to avoid extremes of fineness or fullness forward in order to achieve better balance.

Masted ships that rely on wind power require different types of calculations than oared ships. The center of buoyancy will be different. The center of gravity must fall within the same fore and aft line as the center of buoyancy, otherwise the ship will sink by the stern or the head. Even the simplest sailing ship design

requires a practical knowledge of these facts. Once a functioning hull design is achieved, it can be used repeatedly and refined. LBA designs surely reflect knowledge acquired by trial and error[9].

The same can be said for rigging, but here experimentation is less costly of both labour and materials and is likely to be more effective. The rigging of a ship is the most crucial aspect of the design. Because it is not a permanent construction as is the hull, it can be fine-tuned and altered by pressure according to need, individual judgment, wind and weather conditions, and angles of sail. Bronze Age rigs from the various sources mentioned and those described in the Homeric poems were easily adjusted.

Design of the rigging and considerations such as the height of the mast on BA boats are limited by specific technical considerations such as center of gravity above the waterline, weight of the rigging, balance and type of rigging[10]. These features are related, and in order to create a sea-worthy ship, the shipwright must take all into account.

A major concern has been and still is to increase the angle which a ship can sail effectively to windward. Downwind runs and broad reaches are easier to accommodate with almost any type of rigging, especially with square sails. However, a sea going sailing ship must have the flexibility to confront changing weather conditions. Although in theory the highest speeds may be attained when running before the wind, in practice, higher speeds are achieved in reaching winds. A reach is the fastest and smoothest tack. Thus, although one might expect following winds might to have been preferred when using a square sail rig, in actuality, they can be extremely dangerous, particularly in combination with high seas, rapidly leading to a loss of control. A large sail area will make matters worse. There is always a fear of broaching and swamping. Due to their rigging and low freeboard, Bronze Age boats would have been subject to these problems in addition to considerable lateral drift, especially on downwind tacks. Thus downwind is not the easiest angle to sail, nor is it necessarily going to get you to your desired destination.

a. Egyptian Ships

Some of the best comparative material for the Aegean comes from Egypt[11]. Egyptian merchantmen at the beginning of the New Kingdom are depicted with the mast planted amidships, and the sail attached to two very long yard arms made of two poles each and tied together at the mast[12]. Such exceedingly long yards naturally suggest a vast sail area, ballooning out from the mast to carry the

ship downwind on smooth waters with maximum speed. This rigging may well have been practical for linear N-S passages on the Nile and the Red Sea as well as hauls close to shore in the Levant south of Cyprus[13]. It is quite another matter to set out with such a rig for the purposes of trade, barter or piracy among the Aegean islands.

Indeed, the Aegean has very different weather conditions for which considerable flexibility is required. This island studded sea with its variable wind and water currents, its rocky shores and hidden shoals is subject to sudden changes in the weather[14]. In unpredictable and stronger winds a smaller sail area will be safer and more flexible.

b.The Ulu Burun Wreck

Ballast and disposition of the cargo is especially important to the handling of a boat under sail, especially a shallow keeled boat. The evidence of the Ulu Burun ship is most informative on this point[15]. Although the timbers have yet to be raised, some observations are possible. The volume of the cargo is evident as well as its disposition: the heaviest items appear to be placed along the longitudinal axis and centered near the mast. The loading of the ship indicates practical knowledge that concentrated ballast will reduce the effect of fore and aft pitching. In the opinion of G. Bass, this ship probably capsized as a result of a sudden off-shore squall while running along a lee shore[16].

c. The Theran sailing ships

i. Iconography

At present, the Akrotiri ship painting is still the best source of information. It includes three masted ships and five others with lowered masts and rigging[17]. Although the ship under sail is very fragmentary[18], enough remains to suggest the original appearance[19]. Iconographically, the Egyptian and Thera depictions share an attention to detail which aids interpretation[20]. However, certain artistic conventions apply and one cannot expect abbreviation to shift to photographic realism whenever convenient to the interpretation. The requirements of art do not coincide with those of a technical manual on naval architecture. First and foremost, questions about rigging must be put to the test of what can and will work.

ii. Hull

The masted boats have long, narrow hulls with a curving prow which appears to narrow towards the tip. There is an affinity with earlier Cyladic designs in that

the shape favours a variety of angles to the wind[21]. The pointed bows are also effective in slicing through waves. More importantly, a shallow and narrow hull with a relatively small angle of heel will perform reasonably well when reaching as opposed to running downwind or close hauled.

On the sailing ship, three deck hands are seated forward of the mast, and all are, of course, looking up at the sail. The crew is placed forward for greater stability. Two other men stand at the stern. One handles the steering oar, and the other may be handling a second steering oar and the sheets. Other oars or paddles are conspicuously absent. In this respect the sailing ship is unique among the larger craft and may well be a cargo ship[22].

In the reconstruction, a passenger is shown seated in a protected area in the stern. This cabin is a feature common to all the larger ships in the scene but may not accurately belong here[23].

The stern projection attached to the larger paddle propelled ships has been the subject of extensive speculation[24]. The high, upward curving shape of the stern does not favor the placement of a boarding plank in this position. The argument that the journey undertaken is short[25] cannot account for a boarding plank being engaged horizontally at sea level while a ship is under way. This is tantamount to traveling with the ship's ladder down. There has to be a nautical reason for this option. Visually and functionally, it is an extension of the hull to the stern. It extends the waterline without increasing hull size and may act as a stabiliser. Whatever the final word on this piece of equipment may be, any explanation must take into account its usefulness in the handling of a ship in motion.

iii. Placement of mast

The placement of the mast here is very important: it is set just forward of the center. It is not a coincidence that the mast of the Ulu Burun ship may also be placed just forward of center[26]. The Theran shipwrights were surely aware that placing the mast forward allows a ship to sail closer hauled and provides more stability in downwind situations. This significant technical advance marks an improvement over contemporary Egyptian boats and serves to demonstrate that the island and coastal populations of the Aegean were motivated and successful in seeking to improve the performance of their ships.

iv. Mast

The mast is made of a single pole. The means of support is not visible in the painting, presumably because it is located behind the gunwale. The extant mast-

heads on the larger sailing ships have five sockets or pegs on either side. At least ten lines can be accommodated.

v.Rigging

a. yards, sail area

The rigging of a sailing or cargo ship of the Theran type must be relatively stiff, the mast as straight as possible and the sail area proportionately reduced in order to avoid stress. The importance of the shape of the sail and its flexibility cannot be underestimated. It is the essential tool for increasing maneuverability.

Theran sailing ships have two yards. The lower yard is the boom. Unlike Egyptian examples, each yard appears to be made from a single pole. There is nothing in the fragments of the ship under sail or in the other masted ships to indicate that the yards consist of two joined poles[27]. Furthermore, the yards are proportionately shorter than the Egyptian ones, indicating a smaller sail area. The hull is also proportionately shorter. The sail area remains greater in width than height, but is considerably smaller compared to Egyptian merchantmen of the same date. A longer boom with a squatter sail will be relatively stable, but a narrower sail will be more effective in sailing to windward. The reduction of the sail area indicates a preference for greater maneuverability over speed in order to facilitate sailing at a closer angle to the wind. Indeed, small adjustments in design all seem to share this goal.

b. halyards and lines

The presumed lack of standing rigging[28] raises interesting questions about the way that ships traveled. Morgan believes that it is evidence that voyages (or the specific voyage depicted in the Thera painting) were of short duration[29]. This does not necessarily follow. One cannot be sure that all the actual lines are depicted on the painting. When moored or under oar power, fore and back stays are not needed. The fragments of the ship under sail are of no help here. But stays and shrouds would have to be rigged and tightened before hoisting the sail.

Organic rope or cable kept under permanent pressure is easily undermined and consequently unreliable. For instance, Agamemmnon's rigging at Troy is out of commission, presumably from exposure and lack of replacement parts[30].

Square sails are rigged with the same number of lines on either side of the mast. On the sailing ship, two halyards run parallel to the best preserved side of the mast[31]. Therefore, one can reconstruct at least two lines on either side. The artist may have abbreviated the actual number of lines needed.

Four lines are insufficient to handle the rigging of a sailing ship with two yards[32]. Anywhere from two to seven or eight lines are seen on various examples in glyptic and on other ships of the Thera fresco. In the Odyssey, a double headstay rig with one yard and possibly without brails will have at least nine lines running through the mast[33]. Brails (or lifts) will require at least two more lines. A ship with a double yard rig and brails, single back and forestays and side stays needs at least ten lines and this accounts for the five loops on each side of the mast-head (Fig. 3).

Two topping lifts connect the upper yard with the mast on either side. They are for hoisting the upper yard and the sail which it supports. These are the heaviest lines in the running rigging because they carry the entire weight of the sail. In Morgan's reconstruction (Fig. 2) they appear to connect the upper yard with the mast-head rings[34]. Yet Morgan recognises that the topping lifts must have been fed through the rings and run parallel to the mast- they cannot be permanently attached between yard and mast as shown in her drawing because there would be no way to raise or lower the entire sail from the deck[35].

Sheets control the lower part of the sail[36]. The downhauls or braces attached to either side of the upper yard are for lateral adjustments. These are attached to the yards and do not need to connect to the deck through the mast-head rings.

c. reefing and furling systems

The rigging includes lifts or leechlines for reducing sail area (reefing). Two lines cross the sail together on either side at a diagonal leading from the end of the boom to the center of the yard. It is logical to assume that they passed through the rings in the mast-head at this point. The lines either attach to the boom or pass under it. If these are attachments to the sail they are brails. If they are attachments to the booms they are lifts. It is not at all clear from the original drawing how these lines are to be interpreted. One cannot exclude the possibility of some type of brailing system. In the unrestored fragments of the sailing ship, the lifts on both sides of the mast terminate at the edge of the boom and not above it as in Morgan's reconstruction. These lines can conceivably pass under the boom, through a small loop or even a tie in order to ascend diagonally on the other side of the sail. This will allow the boom to be rolled while being supported by the lifts, a cumbresome system at best. In the Cycladic islands, sails of wind-mills were furled this way in the past. In any case, each line must then pass independently through a mast ring and continue down to the deck. When reefing, the boom is adjusted by tightening or slackening of the brail lines through the mast rings. In addition, the system of topping lifts will allow the upper yard arm to be lowered and adjusted accordingly. Both yards or the boom alone can be adjusted when reefing.

The other masted ships in the Thera painting demonstrate that the upper yard was lowered to furl and stow the sail. Thus, to reef the sail, the lower yard is raised or both are adjusted. To furl the sail, the upper yard is lowered by slackening the topping lifts. In later examples at Medinet Habu and later Greek illustrations, the single yard remains stationary and the lower part of the sail is raised for reefing. But these sails had reefing points which could be secured.

Brails were effectively used in later squaresail rigs for reducing sail area and for changing the shape of the sail. A combination of two yards with either brails or lifts will allow the shape of the sail to be changed in order to take advantage of various wind directions[37]. The reefing system proposed in Fig. 3 has great potential for sailing to windward. One side of the sail could be reduced by narrowing the space between the two yards to form a triangular sail area with a leech. The raising and lowering of the topping lifts also serves to change the angle of the entire sail and the way in which it will perform. This is surely the first step in the development of the lateen rig[38]. The double yard rig is clumsy but it gives the sail rigidity and shape. Tacking with this rigging is difficult but feasible[39]. I suspect that jibing would be preferable, using the steering oars to pivot the boat. Most importantly, this rigging will allow the boat to sail on a closer reach[40]. The Kyrenia ship though differently rigged and with a single upper yard sailed far closer to windward than any one had expected[41].

At Medinet Habu the lower yard arm has been eliminated, and a more complicated system of brails has been introduced to reef the sail upwards[42]. Indeed, even the Egyptian boats at Medinet Habu are a new type of warship[43]. This change may have occurred as a result of influences from the Aegean[44]. Another possible source may be the inhabitants of the NE coasts of the Mediterranean in the second half of the 13th C. BC[45]. Clearly, ethnic origin of the boats or of the design cannot be determined from the Medinet Habu depictions alone. To determine the origins of the invention, some examples must be found of similar rigs in earlier contexts. The rig with a single upper yard arm and with a loose footed sail adjusted by brails is a major breakthrough in sailing which could not have occurred without prior experimentation. The iconographic record of the Aegean gives some indication that this may have been the case.

Either the lower yard was abandoned in the Aegean prior to this time (LH III C)[46], or, there must be earlier evidence for loose-footed rigs[47].In fact, it is possible that both the single and double yard rigs were used in the Aegean prior to the end of the Late Bronze Age[48].

Improvements on the single yard rig probably led to its eventual predominance. A single yard is described in the Odyssey[49] and continues to be preferred thereafter. I suspect that the double yard became technologically obsolete and was replaced by the efficient system depending exclusively on brails for adjusting the shape of the sail. There are many advantages in making the running rigging lighter and more easily maneuverable.

3.Conclusions

New finds may yet provide us with new information about rigging. At present, the hull and rigging designs do indeed suggest that a reach was the preferred angle to the wind and not a downwind run. This conclusion has important implications for the way in which ships traveled and for the routes they followed.

The visual sources underline the different ways in which designs evolved in neighboring and communicating cultural areas. Although the Egyptians traveled in the Mediterranean, their ships were not among the most seaworthy. For the most part, they were large and heavy merchantmen, not swift warships. It is the pirates, the raiders and the traders, namely the island and coastal populations, in particular, the inhabitants of the Aegean who were surely the most innovative and experimental boat designers. Their position demanded this.

The rigging system of the sailing ships in the Thera painting demonstrates Bronze Age experimentation with sail shape in order to achieve a closer angle to the wind. Greater flexibility was possible than previously thought. This is borne out by the material evidence for trade and contacts in the LBA in the eastern Mediterranean. Trade to and from islands involves ships. We should not underestimate the ships or the naval sophistication of those who built and used them. Even the earliest seafarers must have had some general concept of desired landfall. Thus, they could not have been entirely at the mercy of the winds, changing destinations as they went along. It was necessary to design ships that would allow for maximum flexibility and swift maneuvers.

Although these developments may have taken several generations to evolve, they were surely intentional technological changes brought about by skilled craftsmen and sailors who relied on experience and knowledge of the seas. It is clear that they created ships to fit the environment in which they ventured every day and in all seasons for subsistence and profit.

Submitted by H.S. Georgiou
University of California Irvine
September 1990

NOTES

1 Thanks are due Miriam Caskey and Christos Doumas for their interest and Michael Wedde and Lionel Casson for comments and productive criticism.
2 Georgiou1983: 75-78,88; Warren 1984; Georgiou 1986: 38, 52-53. Smith 1987; Hirschfeld 1990; Niemeier 1986.
3 Georgiou 1990 a, 1990 b.
4 Ibid. Typical are Barber's comments, 1987: 17-18,"ancient navigation seems to have been a seasonal affair"..."it is necessary always to keep in sight of land and suitable shelter."For similar opinions see also J. Davis 1979 and Schofield 1982. See White l984: 143-145 ff. on sailing to windward with square sails.
5 Morgan 1988: 121-142 passim; Georgiou1990 a and b; Bass 1967, 1989.
6 Georgiou 1990 b..
7 Morgan 1988: 121, fn. 2. Broodbank 1989: 319-337 passim.
8 White 1984: 141.
9 Continuity can be seen in the elongated shape shared by the EC shipsand the Thera ships. McGeehan Liritzis 1988. For iconography and earlier bibliography see Broodbank 1989: 327-329.
10 It is presumed that BA boats did not have permanent running rigging. Yet this may not be an important factor in the seaworthiness of the ships. Unsupported masts set in tabernacles are still common today, the catboat rig is an example. But the mast must be solid and relatively short in addition to being supported by vertical extension to the keel.The issue of stays,especially shrouds which can be rigged before setting sail, needs to be reconsidered and the iconographic evidence on this point reviewed. Although in Homer there is no mention of side stays, Minoan glyptic may provide other clues. When three stays are depicted on either side of the mast one pair may represent shrouds. Examples include CMS VII,no.104= Morgan 1988:Fig.80, MM IIa; Kenna 1960,94, no.49,50,pl.3, and Marinatos 1933 pl. 15,32 =Morgan 1988, Fig. 87, MM I-II.
11 Faulkner 1940 3-9; Landstrom 1970; Casson 1964:16. Wachsman 1989.
12 Casson 1964:16; In addition to sail power, Hatschepsut's boats are equipped with 15 rowing stations on each side.
13 Mediterranean Pilot Vol.V 8-23.
14 Mediterranean Pilot Vol. IV: 5-19.
15 Bass 1989: Fig. 2. Bass 1990 believes this may be a royal shipment of cargo dating to the second half of the 14th C or the very early l3th C.
16 Bass,personal communication.
17 Morgan 1988: 121-142. The ethnic origin of these ships is not an issue here.
18 Morgan 1988:Fig. 70; Fig. 1 in this text.
19 Morgan 1988: Fig. 71 and Fig. 2 in this text. Compare Fig. 3 in this text.
20 E.Davis1983: 3-14 addresses the specific character of the narration. Morgan 1988:124 assumes that the representation is to be taken to the letter because the patrons and the artist are asumed to be familiar with ships and their use. See Wachsman 1981:198 for related problems in Egyptian iconography.
21 Broodbank 1989: 327-329 includes earlier bibliography; McGeehan Liritzis 1988: 251,255.
22 See note 9 supra.
23 I see no indication of it in the original fragments.
24 Morgan 1988: footnote 105 and p. 135-137 concludes that it is a boarding plank. See this discussion for bibliography.
25 Morgan 1988:137.
26 Bass, personal communication.
27 Morgan 1988:124 suggests that the yards may consist of two poles each.

28 See n. 10 supra.
29 Morgan 1988:126.
30 Il. Il.135.
31 The rigging of this ship has been reconstructed by Morgan 1988: Fig.71, reproduced in Fig. 2 here.
32 Morgan concurs, 1988:125.
33 Georgiou 1990 b.
34 Morgan 1988: Fig. 71. The reconstructed rigging diagram is difficult to interpret, possibly due to the size of the printed figure.
35 Morgan 1988: 125.
36 The terms stays, braces, and sheets are synonyms.
37 I agree with Morgan 1988: 124, fn.19, that convention requires the sail to be depicted parallel to the gunwale. My concern is not with the angle at which this sail is depicted but with the the angle that it can potentially achieve.
38 Casson alludes to this in 1971: 277,Fig.188, regarding a ship with a single yard.
39 See Christensen and Morrison 1976 passim for experiments with square sails.
40 Casson 1964:16; 1971: 274.
41 Comments of Antonis Basiliadis, skipper of the Kyrenia. My experience with flat cut spinnakers designed to sail as close as 15 degrees to the wind suggests the same.
42 Wachsman 1981; Raban 1989.
43 Linder 1973: 319-322; Raban 1989:168.
44 Casson 1971:37 supports neither an Egyptian nor Aegean origin while Raban 1989: 167 suggests that it is a composite type of rig combining Cretan and Canaanite modifications. Wachsman 1981:214 believes the source to have been Syria.
45 Raban 1989: 170-171.
46 Wachsman 1981: 201-202for LH III C Skyros ship with loose-footed sail.
47 CMS VII,no.254
48 Single yard: HM sealing no.146 from Knossos in PM II:244, Fig.141b and 140=PM IV,827,Fig. 806= Marinatos 1933,78,no.54,pl. XVI (MM or LM III A ?); CMS VII:254a ; Marinatos 1933: Pl. XIII,#16 (LH III). Double yard: PM I:254, Fig.190c (LM?); Kenna #107; PM II:243, Fig.139 (LM I);CMS VII,#104 (LM II); Marinatos 1933: Pl. XVI, #52 (LM); CMS II.1, : 287 (MM I-II); PM IV: 828, Fig. 807 (LM I); CMS VIII,106 (LM Ib); Morgan 1988: Fig. 80; Betts 1971: Fig.9 (LMI?).
49 Od.V.254.

BIBLIOGRAPHY

Admiralty Hydrographic Department. Great Britain. (1937.Third Ed. Supplement no.8,1949). *Mediterranean Pilot V.* Comprising the Coasts of Libya,Egypt,Palestine and Syria; the Southern Coast of Turkey,and the Island of Cyprus. London: Taylor, Garnett, Evans & Co.

Admiralty Hydrographic Department. Great Britain. (1941. Seventh Ed. Supplement no.5, 1950). *The Mediterranean Pilot Vol. IV.* Comprising the Islands of the Grecian Archipelago,with the adjacent Coasts of Greece and Turkey from Cape Tainaron on the West to Kara Burun on the East; Including also the Island of Kriti.

Barber, R. L. N. (1987). *The Cyclades in the bronze Age.* London.

Bass, G. F. (1967). Cape Gelidonya: a Bronze Age Shipwreck. *Transactions of the American Philosophical Society,* vol 57, part 8 .Philadelphia.

Bass, G. F. (1990). Nautical Archaeology and Biblical Archaeology. *Biblical Archaeologist,* 53(1.An Underwater View of the Ancient World), 4-10.

Bass, G. F. (1987). Oldest Known Shipwreck Reveals Splendors of the Bronze Age. *National Geographic,* 172(6), 693-733.

Bass, G. F. ,. (1989). The Bronze Age Shipwreck at Ulu Burun: 1986 Campaign. *AJA,* 93, 1-29.

Betts, J. H. (1973). Ships on Minoan Seals. in D.J. Blackman (ed.), *Marine Archaeology.* Proceedings of the 23rd Symposium of the Colston Research Society held in the University of Bristol, 4-8 April 1971. (pp. 325-328). Lon

Broodbank, C. (1989). The Longboat and Society in the Cyclades in the Keros-Syros Culture. *AJA,* 93, 319-337.

Casson, L. (1959). *The Ancient Mariners.*: Minerva Press.

Casson, L. (1971). *Ships and Seamanship in the Ancient World.* N.Y.: Doubleday.

Christensen, & Morrison. (1976). *IJNA,*

Davis, E. (1983). *The Iconography of the Ships Fresco from Thera. In Ancient Greek Art and Iconography.* (pp. 3-14). Madison, Wisconsin: The University of Wisconsin Press.

Evans, A. J. (1921,1928,1930,1935). *The Palace of Minos at Knossos,*I-IV. [Index by J. & A. Evans,1936]. London.

Faulkner, R. O. (1940). Egyptian Seagoing Ships. *JEA,* 26, 3-9.

Georgiou, H. S. (1986). Ayia Irini: Specialized Domestic and Industrial Pottery. *Keos,* vol. VI. Mainz: Von Zabern.

Georgiou, H. S. (1990 in the press). *Bronze Age Sailing and Homeric Evidence.* Archaeology and Heinrich Schliemann: A Century After His Death. International Congress, Athens 1990.,

Georgiou, H. S. (1983). Minoan coarse wares and Minoan Technology. In O.

Krzyszkowska, & L. Nixon (editors.), *Minoan Society.* (pp. 75-92). Bristol: Bristol Classical Pres

Georgiou, H. S. (1990 in the press). *A Sea Approach to Trade in the Aegean Bronze Age.* in C. Zerner (ed.), Wace and Blegen. *Pottery as Evidence for Trade in the Aegean Bronze Age: 1939-1989* [A Conference sponsored by the American School of Classical Studies and the British School of Archaeology at Athens. December 2-3, 1989].

Hirschfeld, N. (1990). Fine Tuning: An Analysis of Bronze Age Potmarks as Clues to Maritime Trade. *INA* Newsletter, 17(1), 18-21.

Kenna, V. E. G. (1960). Cretan Seals, with *a Catalogue of the Minoan Gems in the Ashmolean Museum.* Oxford.

Landstrom, B. (1970). *Ships of the Pharaohs.* London.

Linder, E. (1973). Naval Warfare in the El-Amarna age. in D.J. Blackman (Ed.), *Marine Archaeology.* (pp. 317-322).

Marinatos, S. (1974). *Excavations at* Thera VI. Athens.

Marinatos, S. (1933). La marine créto-mycénienne. *BCH*, 57, 170 -235.

Matz, F., Biesantz, H., & Pini, I. (eds.). (1964-). *Corpus der minoischen und mykenischen Siegel.* Berlin.

McGeehan Liritzis, V. (1988). Seafaring craft and cultural contact in the Aegean during the 3rd millenium BC. *IJNA*, 17(3), 237-256.

Newberry, P. E. (1894). El Bersheh I: *The Tomb of Tehuti-hetep.* London.Niemeier, W. D. (1886). Creta,Egeo e mediterraneo agli inizi del bronzo tardo. *in Traffici Micenei nel mediterraneo. Problemi storici e documentazione archeologica. Atti del convegno di Palermo* (11-12 maggio e 3-6 dicembre 1984). (pp. 245-270). Taranto.

Raban, A. (1989). The Medinet Habu Ships: Another Intepretation. *IJNA*, 18(2), 163-171.

Schofield, E. (1982). Plus and Minus Thera: Trade in the Western Aegean in Late Cycladic I-II. *TUAS*, 7, 9-14.

Morgan, L. (1988). *The miniature wall paintings of Thera: a study in Aegean culture and iconography.* Cambridge Classical Studies: Cambridge

University Press.

Smith, T. R. (1987). Mycenaean trade and interaction in the west central mediterranean 1600-1000 B.C. Oxford: *British Archaeological Reports*. International Series, v.371.

Vinson, S. (1990). Ships in the Ancient Mediterranean. *Biblical Archaeologist*, 53(1), 13-18.

Wachsman, S. (1989). Sea Going Ships and Seamanship in the Late Bronze Age Levant. Jerusalem: The Hebrew University. Unpublished Ph.D. Dissertation.

Wachsman, S. (1981). The Ships of the Sea Peoples. *IJNA*, 10, 187-220.

ILLUSTRATIONS

1. Extant fragments of Thera sailing ship- after Morgan l988 Fig.70.
2. The rigging of the sailing ship- after Morgan 1988 Fig. 71.
3. New rigging diagram
4. Rigging diagram showing triangulated sail.

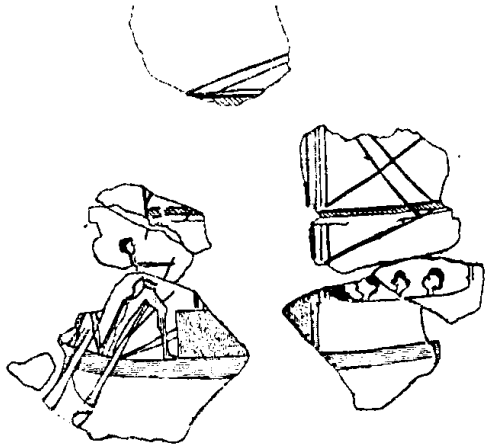

FIG. 1

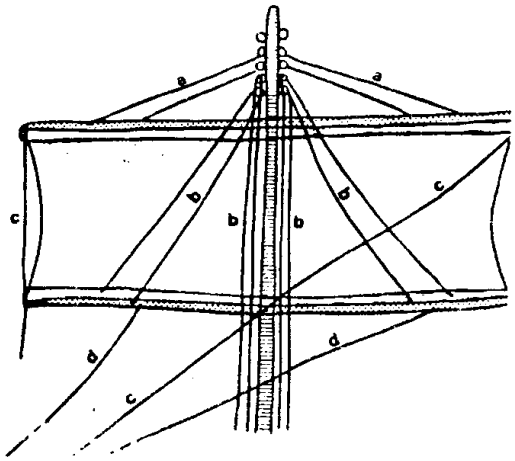

FIG. 2

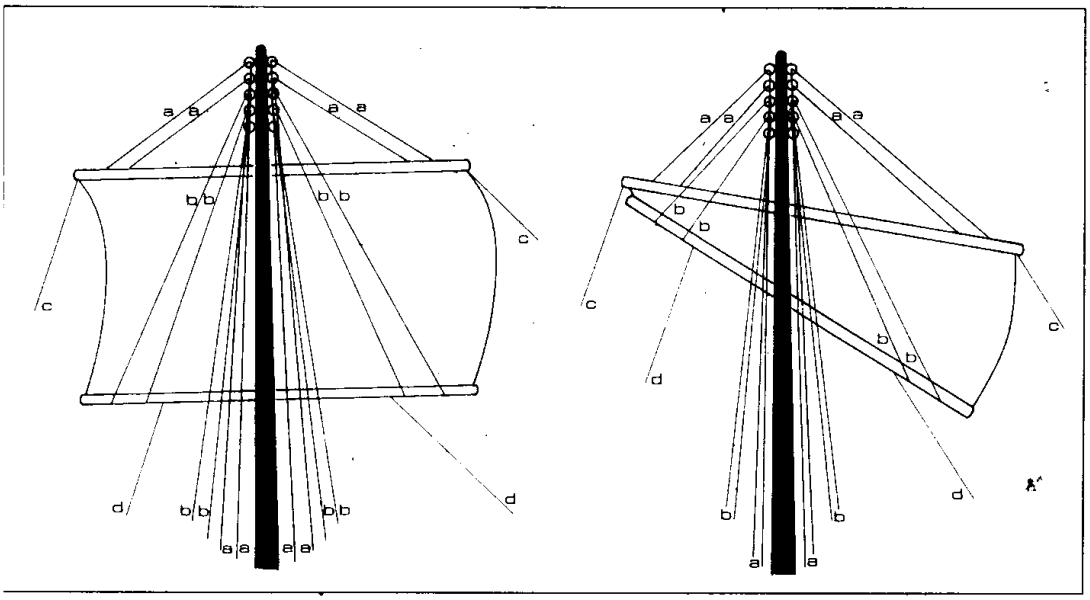

FIG. 3

FIG. 4