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The Potential Performance of Ancient Mediterranean Sailing Rigs

Julian Whitewright

Centre for Maritime Archaeology, Department of Archaeology, University of Southampton, Highfield, Southampton. SO17 1BJ, UK

A common statement in the academic literature relating to the ancient Mediterranean is that the lateen/settee rig superseded the Mediterranean square-sail because it provided superior upwind performance, greater manoeuvrability and higher overall speed. This statement has been repeated so often that it is now commonly accepted. Research by the author sets out to develop an insight into the relative performance of both types of rig, based on historical sources, ethnographic records and the performance of representative, full-size sailing vessels. This allows a reassessment to be made of the underlying reasons behind the adoption of the lateen/settee rig in the Mediterranean.

Key words: sailing performance, square-sail, lateen, settee, Mediterranean.

The invention and adoption of the lateen/settee rig in the Mediterranean is usually considered, either consciously or unconsciously, by scholars in terms of a 'need-driven' technological change. In this case, the 'need' driving the change is the logical desire among ancient mariners to improve the performance of their sailing vessels. In particular, scholars focus on the benefits to upwind performance which the lateen/settee rig allows. A recent statement on the subject can be considered representative of many other generalised thoughts, namely that:

> Lateen-rigged ships were probably faster, and achieved better sailing angles to the wind [than square-rigged ships]. Could speed and manoeuvrability be two of the main reasons that made lateen sails apparently so popular in the early-medieval Mediterranean? (Castro *et al*., 2008: 348).

This viewpoint is firmly lodged in the recent academic literature as the principal reason behind the invention of the lateen/settee rig. The paper referred to above is simply repeating an accepted 'standard view' expressed by many others (for example LeBaron-Bowen, 1949: 95; Hourani, 1951: 101; Lopez, 1959: 71; Kreutz, 1976: 81–2; White, 1984: 143–4; Pryor, 1994: 67–8; Campbell, 1995: 2; Casson, 1995: 243; Basch, 2001: 72; McCormick, 2001: 458; Makris, 2002: 96; Kingsley, 2004: 78; Polzer, 2008: 242; Castro *et al*., 2008: 347–8, 351).

Two main objections can be made to this 'standard view'. Firstly, that little, if any, evidence, whether from practical experience or from published sources, accompanies such statements. Secondly, the underlying theoretical assumption is one of technological determinism. The explanation of sailing-rig development within the fields of maritime archaeology and history has been based on the notion that observable change must have occurred for an explicable, logical reason; generally the 'need' for better windward performance. Within this schema, the development of the lateen sail, and its performance superiority over the square-sail, has allowed the establishment of a unilinear progression of sailing-rig technology, from the 'ancient' square-sail to the 'modern' bermudan rig (Fig. 1). Each step in the process allows a further leap forward in windward performance to be made.

The logical, predictable nature of progression, rendered in technologically deterministic terms, dictates that 'older, simpler' technologies must become redundant once 'newer, better' ones are developed. Such concepts have been the subject of strong criticism within the fields of archaeology and anthropology (for example Leeuw and Torrence, 1989: 1–2; Pfaffenberger, 1992; Loney, 2000: 647). As maritime archaeology continues to mature as a subject, its theoretical standpoint should broadly follow that of the wider discipline, unless, of course, the archaeological evidence is directly to the contrary. Recent work within maritime contexts illustrates that maritime archaeology and mainstream archaeological theory are mutually compatible (for example Gould, 2001; Adams, 2003; Schiffer, 2005). However, as this paper sets out to demonstrate, in the example of technological change

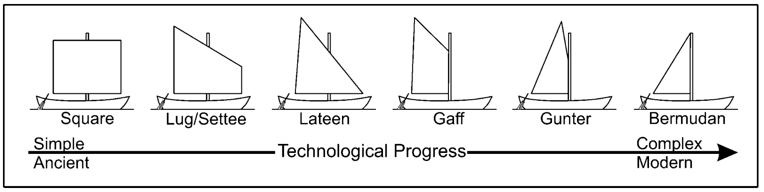

Figure 1. A generic example of the unilinear progression of sail development, viewed through sail-plan, as usually seen by maritime archaeologists and historians. It should be noted that the lug/settee rigs are usually grouped together on the basis of geometric sail-shape. If sail-handling/technical practice is used to characterise a sailing rig, then the lug and settee are easily differentiated. (J. Whitewright)

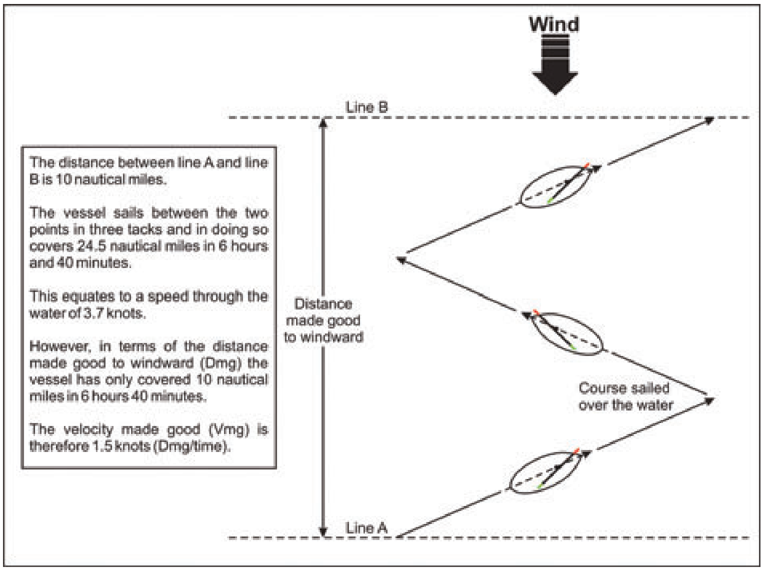

Figure 2. Simple diagrammatic explanation of 'Velocity made good' (Vmg). (J. Whitewright)

relating to the lateen/settee rig, the available evidence indicates that the currently-accepted theory is wide of the mark.

Approaches and methodology

The modern, global yachting industry has accrued a large body of knowledge relating to the bermudan rig currently favoured by most classes of yacht involved in organised racing (Marchaj, 1996: 152). There is now a growing body of literature and test-results relating to the performance of other, more traditional, sailing-rigs and reconstructed historical vessels (for example Crumlin-Pedersen and Vinner, 1986; Brandt and Hochkirch, 1995; Nomoto *et al.*, 2003; Englert, 2006; Bennett, 2009; Palmer, 2009a; Palmer, 2009b). However, there remains no direct comparison of the square-sail and lateen/settee rig. The accurate measurement of sailing-performance is fraught with problems, perhaps more so when trying to measure traditional craft which do not generally have complex instrumentation installed. A good account of these problems, and some of the methods that can be used to overcome them, is given by Palmer (2009c).

The lack of data relevant to the specific nature of the problem necessitates the use of a different approach to assess the relative potential performance of the antique Mediterranean square-sail and the lateen/settee rig. The author has approached the problem by drawing on the wide range of evidence relating to the performance of reconstructed historical ships, in conjunction with references to voyages in historical and ethnographic sources. In each case the evidence is derived from the performance of vessels operating in real conditions, carrying sailing-rigs broadly comparable to those seen in antiquity.

This study uses the concept of 'velocity made good' (Vmg) as central to the comparative assessment of appropriate sailing vessels, reconstruction or otherwise. Put simply, Vmg is the absolute speed of a vessel over a direct course between two points (Fig. 2). Analysis of Vmg allows the absolute performance of two vessels to be compared, independent of factors which are often the source of subjective observation, such as leeway or crew efficiency. It is of particular value when attempting to measure the effective speed of a vessel to windward (Englert, 2006: 39; *cf*. Vinner, 1986: 221), an area of particular importance in the

Table 1. *Summary of square-sail voyages (nos 1–20) and lateen/settee voyages (21–40) used during research*

No.	Route	Reference	Date
	Square-sail voyages		
1	Lilybaeum to Anquillaria	Caesar, *Civil Wars,* 2.23	mid-1st c. BC
2	Myos Hormos to Leuke Kome	Casson, 1989, *Periplus Maris Erythraei,* 19	1st c. AD
3	Puteoli to Ostia	Philostratus, *Life of Apollonius,* 7.16	early-3rd c. AD
4	Alexandria to Marseilles	Sulpicius Severus, *Dial*. 1.1.3	late-4th c. AD
5	Gaza to Byzantium	Mark the Deacon, *Life of Porphyry,* 26	AD 398
6	Caesarea to Rhodes	Mark the Deacon, *Life of Porphyry,* 34	AD 401
7	Rhodes to Byzantium	Mark the Deacon, *Life of Porphyry,* 37	AD 401
8	Sea of Azov to Rhodes	Diodorus Siculus, 3.34.5–35	mid-1st c. BC
9	Rhodes to Alexandria	Diodorus Siculus, 3.34.5–35	mid-1st c. BC
10	Utica to Caralis	Caesar, *African War,* 98	mid-1st c. BC
11	Rhegium to Puteoli	*Acts* 28.13	mid-1st c. AD
12	Ganges to Sri Lanka	Pliny, *Natural History,* 6.82 (1942)	mid-1st c. AD
13	Messina to Alexandria	Pliny, *Natural History,* 19.1 (1950)	mid-1st c. AD
14	Puteoli to Alexandria	Pliny, *Natural History,* 19.1 (1950)	mid-1st c. AD
15	Gades to Ostia	Pliny, *Natural History,* 19.1	mid-1st c. AD
16	Corinth to Puteoli	Philostratus, *Life of Appolonius,* 7.10	early-3rd c. AD
17	Puteoli to Tauromenium	Philostratus, *Life of Appolonius,* 8.15	early-3rd c. AD
18	Alexandria to Ephesus	Achilles Tatius, 5.15–17	late-3rd c. AD
19	Byzantium to Gaza	Mark the Deacon, *Life of Porphyry,* 27	AD 398
20	Byzantium to Rhodes	Mark the Deacon, *Life of Porphyry,* 54–55	AD 401
	Lateen/settee voyages		
21	Acre to Tinnis	Goitein, 1967: 316–17	AD 1073
22	Alexandria to Tripoli (Lebanon)	Goitein, 1967: 321	11th c. AD
23	Alexandria to Constantinople	Goitein, 1967: 326	11th c. AD
24	Tinnis to Ascalon	Goitein, 1967: 326	11th c. AD
25	Bahr al Zihār to Sha'b Sulaim	Ibn Mājid (Tibbets, 1971: 256)	15th c. AD
26	Khor Nawarat to The Brothers	Monfried, 1935: 116	1916
27	Aden to Mukalla	Villiers, 1940: 26–51	1938
28	Northern Red Sea	*Nakhooda* Said, pers. comm.	2003
29	Palermo to Alexandria	Goitein, 1967: 324, 326	11th c. AD
30	Tripoli (Libya) to Seville	Goitein, 1967: 318	AD 1140
31	Sardinia to Sicily	Ibn Jubayr (Broadhurst, 1952: 27–8)	AD 1183
32	Crete to Alexandria	Ibn Jubayr (Broadhurst, 1952: 29)	AD 1183
33	Bahr al Zihār to Sha'b Sulaim	Ibn Mājid (Tibbets, 1971: 256)	15th c. AD
34	Jeddah to Saibān	Ibn Mājid (Tibbets, 1971: 244)	15th c. AD
35	Saibān to Muqaidih	Ibn Mājid (Tibbets, 1971: 249)	15th c. AD
36	Ras Madraka to Ras Sauqira	Ibn Mājid (Tibbets, 1971: 152)	15th c. AD
37	Suez to Dahlak	Monfried, 1935: 270	1916
38	Bahrein (Manama) to Kuwait City	Villiers, 1940: 333–43	1939
39	Lamu to Mombasa	Prins, 1965: 250	mid-20th c. AD
40	Northern Red Sea	*Nakhooda* Said, pers. comm.	2003

context of the present study because of the traditional explanation for the adoption of the lateen/settee sail.

Recently, the application of Vmg derived from historical sources has allowed a reassessment of the capability of Roman sailing vessels in the northern Red Sea (Whitewright, 2007a). A comparable, although more general, study has also been carried out into north European medieval voyaging on the basis of the historical resource in conjunction with the performance of reconstructed historical vessels (see Englert, 2007). This type of approach is expanded in this study. The data derived for square-sail and lateen/settee-rigged vessels is detailed in a series of 40 historical voyages (Table 1). Analysis based on these voyages is presented below. The principal aim has been to try to establish the relative performance of the two rigs, not to establish a detailed set of performance characteristics. As will be seen, the available evidence is simply not detailed enough for such a study to be achievable. However, it does allow a start to be made in assessing the performance of ancient Mediterranean sailing vessels.

Considerations

One of the advantages of using Vmg to compare the performance of different sailing vessels is that only a relatively small amount of information is required. It is worth taking the time briefly to consider the following factors: the rig-plan of the vessel (square-sail or lateen/settee); the hull-form of ancient vessels; the start and finish point of the voyage; whether or not the voyage was non-stop; the time taken to complete the voyage; and the over-riding weather conditions.

Rig-plan

It is obviously important to establish the type of sailing-rig used by a vessel on a given voyage. With modern voyages this is usually simple due to the survival of photographs, log-books or other detailed contemporary records. Historical voyages present more of a problem because they were usually only recorded in general terms, by people who had no reason to record details such as the nature of the sailing-rig. In these cases it is necessary to assume that a vessel was rigged in a generic way for a particular period. For example, a ship of the early Roman Imperial period would most probably have been rigged with a Mediterranean square-sail rig. From the late-12th/early-13th century AD the northern European cog, with a single-masted, square-sail rig began to be built and used in the Mediterranean (Adams, 2003: 64; Pryor, 1994: 78). Before this, Mediterranean vessels would probably have been rigged with a lateen/settee sail (*cf.* Whitewright, 2009). It is usually impossible to know whether a vessel had two or more masts, so Vmg can only be calculated for an overall rig-type; either square-sail or lateen/settee, rather than for variants within these general types.

Within the context of the present study, it is of interest to note that the use of the sprit-sail is attested in Mediterranean iconography from the 2nd century BC onwards (see Casson, 1960; Casson, 1995: xxvi and fig. 176). An extended period of use for this rig can be postulated from its presence in the archaeological record in the 10th/11th century AD (for example Yenikapi 6, see Kocabaş and Kocabaş, 2008: 103–12). The significance of this lies in modern test results. In wind-tunnel tests the sprit-sail outperformed the three forms of lateen rig that were also tested (Palmer, 1990: 85–6; Marchaj, 1996: 161, figs 144–5). Controlled on-water comparative tests confirmed these results and indicated that the sprit-sail was more efficient on windward and reaching courses than the lateen rig (Palmer 1984: 1390; 1986: 188–93; 1990: 82–3). This suggests that, if windward performance alone was the driving force behind sailing-rig development, the sprit-sail, not the lateen, would have become widespread in the ancient Mediterranean from the 2nd century BC onwards.

Hull-form

The hull-form of a vessel has a large influence on its performance, particularly on upwind courses. Put simply, the deeper in the water and more developed the keel of a vessel, the better its performance will be to windward (Palmer, 2009b: 316–18). The projection of the keel helps to resist the lateral forces imposed on the vessel during sailing. The visible consequence of such forces is usually termed leeway and is most easily visualised in the sideways drift experienced by a vessel while sailing forwards. This has the greatest effect when sailing close-hauled. Flat-bottomed vessels will generally experience more leeway, and a corresponding reduction in performance, than vessels with substantially-projecting keels. Evidence of the effect of increasing the depth of keel comes from the sailing-trials of half-scale reconstructions of the Sutton Hoo and Graveney boats (Gifford and Gifford, 1996; *cf.* Palmer, 2009b: 316–18). Although half-scale, the performance of these vessels can still be considered in this study, as vessels rigged with square-sails, rather than representing the real performance of either the Sutton Hoo or Graveney vessels. The addition of a false keel to the Graveney boat reduced the observed leeway by half to *c.*10° (Gifford and Gifford, 1996: 139) Similarly on the reconstruction of the Sutton Hoo ship, the increase of the keel projection from 20 to 40 mm reduced the observed leeway from *c.*20° to 12° (Gifford and Gifford, 1996: 150). These results need to be treated with some caution due to the methods used to measure performance, but they do indicate the general principle.

It is practically impossible to determine the underwater hull-shape of a vessel referred to in a literary source. However, shipwreck remains from the Mediterranean indicate that a wide variety of hull-forms existed (Fig. 3), including flat-bottomed vessels, such as Cavalière (Charlin *et al.*, 1978: fig. 34) or Laurons 2 (Gassend *et al.*, 1984: fig. 17c) and those with significant underwater profiles, such as Kyrenia (Steffy, 1985: ill. 6), Madrague de Giens (Rival, 1991: fig. 62) or the 4th century AD Yassi Ada vessel (Bass and van Doorninck, 1971: fig 5). The assumption must therefore be that historically-recorded voyages represent a cross-section of this shipping because of the impossibility of distinguishing between hull-form on the basis of a literary reference.

The visible variation in hull-form within a corpus of ancient ship-types gives some indication as to the importance of vessel specialisation for various environmental, economic or social reasons. Hulls more suitable for windward sailing than their contemporaries were constructed regularly during antiquity (for example Kyrenia, Madrague de Giens or 4th-century Yassi Ada). The failure of such hull-forms to become ubiquitous gives an indication of the relative

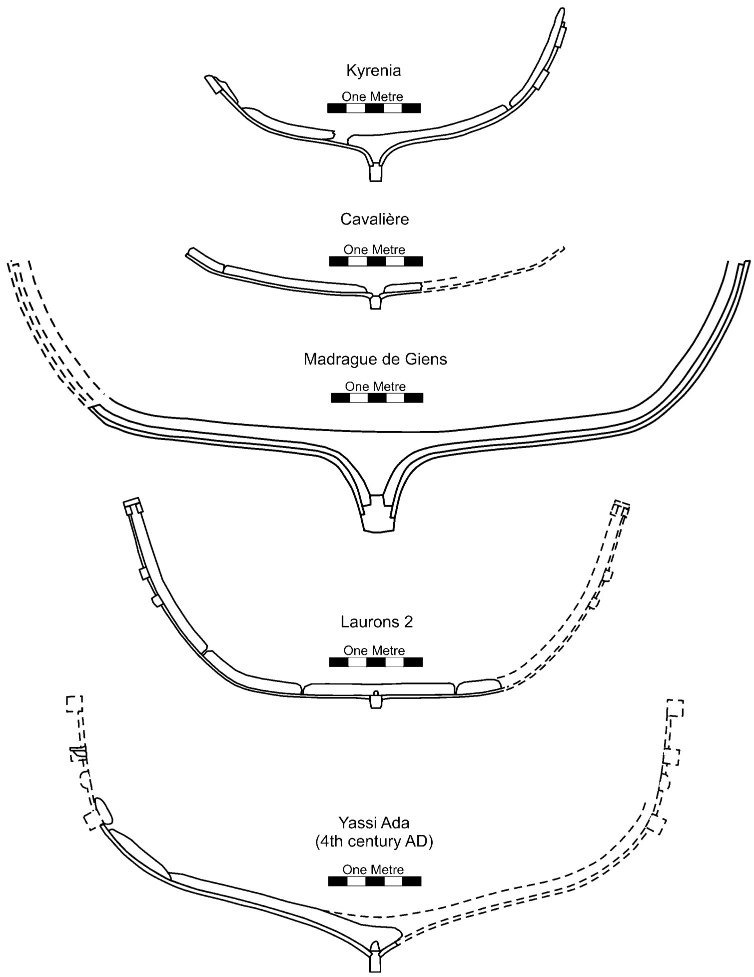

Figure 3. Different hull-forms, Mediterranean Classical, Roman and late-antique contexts. The cross-sectional forms constructed by ancient shipwrights range from flat-bottomed to relatively deep-keeled. (redrawn by author from: Kyrenia (Steffy, 1985: ill. 6); Cavaliére (Charlin *et al.*, 1978: fig. 34); Madrague de Giens (Rival, 1991: fig. 62); Laurons 2 (Gassend *et al.*, 1984: fig. 17c); 4th century Yassi Ada (Bass and van Doorninck, 1971: fig 5)

importance of the 'need' for windward performance when set against other social, economic or environmental factors. Quite simply, windward performance was not as important as other factors. If it had been, then a higher percentage of ancient shipwrecks would exhibit a hull-shape similar to these three vessels. In many cases flat-bottomed vessels were being constructed at much later dates than deeper-keeled vessels. The flat-bottomed Laurons 2 ship was constructed *c.*500 years after the deep-keeled Kyrenia ship. This further emphasises the lack of a predictable linear narrative to the development of maritime technology in the ancient Mediterranean.

Voyage details and weather conditions

The details of the voyages analysed are obviously of great importance in establishing a comparable Vmg figure. The start and finish points must both be known in order to calculate the distance made good at the end of the voyage. It is also important to establish that the voyage did not include any stops en route, as these might greatly increase the time taken to complete the voyage, without adding to the distance travelled. The duration of voyages is rarely measured with accuracy greater than half a day. When a voyage was recorded as taking '2–3 days', a compromise figure of $2^1/_2$ days may be used. Finally, the type of weather encountered during the voyage must also be considered. Ancient sources, while not always specific about weather conditions, do provide some significant information. If the wind-direction is such that a vessel can sail on a reach or a run to its destination the wind may be referred to as 'favourable'. In contrast, wind from an unfavourable direction is usually described as 'foul' which, in the context of ancient sailing, may be taken to mean coming from the direction of the destination, or that the voyage has to be made in generally upwind conditions. Where details of winds are not given it is sometimes possible to reconstruct the most likely wind to have been encountered in specific areas where the wind is very predictable, such as the northern Red Sea.

Weather conditions are obviously of prime importance in determining the speed of a sailing vessel. A vessel travelling a relatively short distance may experience ideal conditions and record a record run. On other occasions the captain and crew may be unlucky and have to sail a long voyage in adverse conditions, leading to an exceptionally long journey-time. The weather encountered on a voyage is not always recorded. However, if the start point and destination are known, then the most likely weather conditions which may have been encountered may be estimated by comparison with regional and seasonal wind-patterns. Similarly, data derived from ethnographic observation or from the trials of reconstructed vessels with comparable rigs may give an indication of the likely performance in certain weather conditions, or when the wind was from a certain relative direction.

Sea-state

One of the major determinants of the extent to which a vessel rigged with any type of sail-plan makes positive ground to windward is the state of the sea (Monfried, 1935; Gillmer, 1979: 179; Heikell, 1989: 23; Smitt, 1986: 172; Vinner, 1986: 222; Palmer, 2009b: 329). Generally speaking, the calmer the water the better the vessel will perform in a windward direction. This is because waves stop the progress of the vessel through the water and increase its leeway. In certain conditions even modern vessels with a hull and rig specifically designed for windward performance struggle to make ground because of the influence of wave-action (for example Heikell, 1989: 23). It may be the case in some of the voyages noted in Table 1 that although a vessel encountered wind from an unfavourable direction that wind remained light enough to enable the vessel to make progress to windward in calm seas. It must also have been part of the skill of navigation in the ancient world to select courses which led to sailing in sheltered waters, unaffected by significant wave-action and where speed could be maximised. Island-groups and archipelagos have been cited as slowing down passage-time (Casson, 1995: 288; McGrail, 1998: 264), but they may actually have allowed vessels to speed up by providing calm waters in which to sail to windward. This approach was used by Monfried (1935) in 1916 in his passage up the entire length of the Red Sea into the prevailing wind at an unfavourable time of year. His vessel carried a lateen/settee rig and he made constant use of every island-group or reef-system available and constantly commented on his preference for sheltered water in which to sail, for example; 'on the starboard tack I ventured in among the reefs of the inner sea which stretches to the north-west. There I could work profitably to windward in these waters which are always calm, despite the strong breeze blowing' (Monfried, 1935: 135).

Table 2. *Heading-angle, relative to wind-direction, of reconstruction vessels rigged with square-sails. In the cases of* Sea Stallion, Bialy Kon, Roar Ege, Hanse Cog *and* Oselven *data was measured using GPS or other accurate instruments. In the remaining examples heading-angle and leeway were estimated*

Vessel	Angle	Reference
Sea Stallion (Skuldelev 2)	60°	Søren Nielsen, pers. comm.
Bialy Kon (Slavonic)	68°	Englert *et al*., 1998: 24
Bialy Kon and *Dziki Kon* (Slavonic)	60–65°	Gülland, 2003: 361
Kyrenia II (Kyrenia)	*c*.61°	Cariolou, 1997: 92
Imme Skinfaxe (Skuldelev 3)	63–68°	Vadstrup, 1986: 91
Roar Ege (Skuldelev 3)	63–79°	Palmer, 2009b: 325, fig. 23
Roar Ege (Skuldelev 3)	65–72°	Vinner, 1986: 224
Olympias (Trireme)	65–72°	Morrison *et al*., 2000: 262
Hanse Cog (Bremen)	67–75°	Brandt and Hochkirch, 1995: 7–8
Oselven (Faroese traditional)	68–77°	Palmer, 2009b: 325, fig. 22
Imme Aros (Ellingå)	70°	Vadstrup, 1986: 87
Ottor (Graveney, half-scale)	70°	Gifford and Gifford, 1996: 139

A further example of the impact of sea-state comes in the performance of one of the Hanse Cog reconstructions (Brandt and Hochkirch, 1995; *cf.* Hoffmann and Hoffmann, 2009: 287–93). Sailing-trials, measured with a GPS, produced two contrasting results. With light winds and calm seas, the Hanse Cog reconstruction was able to make 0.63 knots Vmg to windward. In much stronger winds and associated rougher seas, the vessel actually lost ground and made –0.1 knots Vmg (Brandt and Hochkirch, 1995: 7; Palmer, 2009b: fig. 18).

Mediterranean square-sail performance

The potential performance of the single square-sail rig of the ancient Mediterranean (and similar rigs in north-west Europe) has long been the source of speculation amongst scholars, who have largely focused on the ability of vessels to sail to windward (for example Holmes, 1909; Gillmer, 1979; Rougé, 1981: 22; Tilley, 1994; Casson, 1995: 273–4; Roberts, 1995). All have concluded that the single-masted square-rigged vessel, such as those of the Roman period, had some ability to sail above 90° to the wind, the consensus being that vessels were able to steer a course 65–80° off the wind. This correlates with the range of close-hauled heading-angles reported from the sailing-trials of reconstructed historic square-sail vessels (Table 2). It should be noted that these figures almost certainly represent the 'best' results produced by a particular vessel during trials.

Literary references to close-hauled sailing

In addition to the information provided by the trial voyages of reconstructed vessels, there are numerous passages from ancient sources which describe the practice of sailing against a contrary wind. These leave little doubt that sailing close-hauled was practised in antiquity. The most notable of these is probably the passage from Aristotle, dating to the 4th century BC:

> Why is it that, when the wind is unfavourable and they wish to run before it, they reef the sail in the direction of the helmsman, and slacken the part of the sheet towards the bows? Is it because the rudder cannot act against the wind when it is stormy, but can when the wind is slight and so they shorten sail? In this way the wind carries the ship forward, but the rudder turns it into the wind, acting against the sea as a lever. At the same time the sailors fight against the wind; for they lean over in the opposite direction (Aristotle, 1955, 851b.7).

This passage represents a concerted effort by the ancient mariner to balance the rig of his vessel, using the characteristic brails of the Mediterranean square-sail, while sailing on a close-hauled course. The need to balance the Centre of Effort (CE) and Centre of Lateral Resistance (CLR) of the vessel becomes critical on such courses (although it is still important on other courses) (*cf.* Palmer, 2009a). The inference therefore is that such an action would be less remarkable if the vessel was only sailing on downwind courses.

In the same vein, the following passage from Pliny will be familiar to anyone who has ever helmed a boat upwind in a confined waterway: 'Vessels by means of slacking the sheets can sail in contrary direction with the same winds, so that collisions occur, usually at night, between ships on opposite tacks' (Pliny, 1938, 2.48). Pliny's observation that the sheets are slackened may suggest that the ships are sailing downwind. However, it should be remembered that in order to sail close-hauled with a square-sail rig one of the sheets must be slackened off enough for the tack of the sail to be secured in the bow of the vessel, while the other sheet remains led aft.

Finally, Achilles Tatius dramatically describes a ship encountering a wind-shift which causes headwinds and, as a result, an extended period of tacking into the wind. It is of interest that the practice of shortening half the sail-area is also mentioned:

> On the third day of our voyage, the perfect calm we had hitherto experienced was suddenly overcast by dark clouds and the daylight disappeared, a wind blew upwards from the sea full in the ship's face, and the helmsman bade the sailyard be slewed round. The sailors hastened to effect this, bunching up half the sail upon the yard by main force, for the increasing violence of the gusts obstructed their efforts; for the rest, they kept enough of the full spread [of the sail] to make the wind help them to tack. As a result of this the ship lay on her side, one bulwark raised upward into the air and the deck a steep slope, so that most of us thought that she must heel over when the next gale struck us. We transferred ourselves therefore to that part of the boat which was highest out of the water … the wind suddenly shifted to the other side so that the ship was almost sent under water, and instantly that part of the boat which had been down in the waves was now violently thrown up … all changed their station, running, with shouts and cries, to the position in which they had been before they moved; and the same thing happened a third and a fourth, nay, many times, we thus imitated the motion of the ship (Achilles Tatius, 1917, III.1–2).

All these passages, in different ways, recount the experience and practice of sailing a Mediterranean square-sail vessel on a close-hauled course.

The **artemon** *and mizzen sail*

The appearance of the *artemon* and mizzen sails as part of the ancient sailing rig is also instructive about the types of courses being sailed. These sails add relatively little to speed on downwind courses, but both can play a crucial role when attempting to balance and steer a vessel on close-hauled courses. The *artemon* is crucial for the balance of vessels rigged with the mainmast amidships (*cf.* Palmer, 2009a: fig. 10). A mizzen sail provides an invaluable aid to steering, particularly when forcing a vessel through the wind during a tack and for keeping the bow of the vessel 'on the wind'. This observation does not require any further analysis, its truth is confirmed by every traditional boat afloat that carries a mizzen sail. The development and incorporation of *artemon* and mizzen sails into the rigs of the ancient Mediterranean may have reduced the emphasis on using brails as a way of fine-tuning a vessel's balance.

The mizzen and *artemon* sails in iconographic and literary sources can explicitly be associated with the practice of sailing on courses above 90° to the wind. Their appearance in the sources, therefore, can probably indicate periods when such sailing became increasingly common practice. A similar point can be made for the use of bowlines on Mediterranean ships in the Roman period (for iconographic examples see Basch, 1989: figs 3–4). This rigging component has no function other than to maintain tension on the luff of the sail when sailing close-hauled, and is another indicator that such courses were sailed in antiquity.

The Vmg of square-sail vessels

Before analysing a series of voyages by square-sail vessels it is useful to be able to establish some parameters within which results might be expected to fit, particularly when it is not known whether a voyage was made with 'fair' or 'foul' winds (offwind or upwind respectively). The performance of reconstruction square-sail vessels (Table 3), in known conditions, can give an indication of the possible conditions experienced by ancient vessels where the actual conditions are not mentioned by the author. The voyage in question can then be categorised accordingly. Trials of reconstructed historical vessels are often carried out in good conditions and by a crew who are actively trying

Table 3. *The Vmg to windward of reconstructed vessels rigged with single square-sails*

Vessel	Vmg	Reference
Roar Ege (Skuldelev 3)	1.5–2 knots	Vinner, 1986: 224
Imme Skinfaxe (Skuldelev 3)	1.5–2 knots	Vadstrup, 1986: 91
Saga Sigla (Skuldelev 1)	1.3 knots	Johansen, 2009: 68
Ottor (Graveney)	1 knot	Gifford and Gifford, 1996: 140–41
Sæ Wyfling (Sutton Hoo)	1 knot	Gifford and Gifford, 1996: 149–50
Ottar (Skuldelev 1)	1 knot	Englert, pers. comm.
Hanse Cog (Bremen)	0.63 knots	Brandt and Hochkirch, 1995: 7
Hanse Cog (Bremen)	–0.1 knots	Brandt and Hochkirch, 1995: 7

Table 4. *Summary of ancient square-sail voyages made in unfavourable conditions*

No.	Route	Distance (nautical miles)	Time (days)	Vmg (knots)
1	Lilybaeum to Anquillaria	90	$2^1/_2$	1.5
2	Myos Hormos to Leuke Kome	125	$2^1/_2$	2
3	Puteoli to Ostia	120	$2^1/_2$	2
4	Alexandria to Marseilles	1500	30	2.1
5	Gaza to Byzantium	855	20	1.8
6	Caesarea to Rhodes	400	10	1.7
7	Rhodes to Byzantium	445	10	1.8
		1.8		average 1.8

to achieve the best performance available, upwind or downwind. As such they provide an 'optimal yardstick' by which the data from historical voyages can be measured. It should be noted that vessels with a hull-form pre-disposed to lower speeds (those with a lower length:beam ratio) are likely to produce inferior results when directly compared to longer, faster vessels.

Analysis of these results indicates that vessels rigged with single square-sails can be expected to achieve a maximum of 2 knots Vmg when sailing close-hauled (*cf*. Crumlin-Pedersen, 1984: 32–3; Johansen, 2009: 65). Such figures are only likely to be achieved by a vessel with a relatively-efficient hull-shape (such as Skuldelev 3) and in optimal conditions of moderate winds and calm seas (*cf*. Palmer, 2009b: 329). Beamier vessels (such as Skuldelev 1) may produce lower results, while vessels lacking a substantial keel, such as the Graveney, Sutton Hoo and Hanse Cog replicas, may not even achieve 1 knot Vmg. In non-optimal conditions (strong wind and rough sea) significant ground may be lost to windward while sailing close-hauled. When considering the performance of Mediterranean cargo ships, it is notable that Skuldelev 1 (a relatively-beamy vessel designed specifically for carrying cargo) has produced good results over many years of testing two separate reconstructions.

Potential square-sail performance

Literary sources provide commentary on the time taken to sail a number of different routes on vessels rigged with the Mediterranean square-sail. The majority of these voyages occurred in the Mediterranean, but some in the Indian Ocean and Red Sea. Archaeological evidence attests to the use of the Mediterranean square-sail in these waters during antiquity (Whitewright, 2007b). A summary of these voyages can be found in Tables 4 and 5. Analysis of these voyages can give a reasonable indication of the Vmg of vessels rigged with the Mediterranean square-sail on unfavourable (upwind) or favourable (downwind) courses, and suggests that such vessels could attain a maximum of 2 knots Vmg in suitable conditions on close-hauled courses. This tallies closely with the probable performance suggested by trials of reconstructed vessels.

As well as providing as indication of the potential speed of sailing ships when attempting to sail to windward, literary sources can also supply information on their speed on other courses (cross-wind or downwind). Marchaj (1996: 147, 149, figs 127, 131) has demonstrated that, all other things being equal, the square-sail is amongst the best performer on such courses. On running courses with the wind coming over the vessel's quarter a low aspect-ratio (AR) sail represents the optimum sail-plan, while on broad reaches a sail plan with an AR of *c*.1 is the best. The fastest average speed recorded in ancient sources is 6.2 knots on a voyage from Corinth to Puteoli (Table 5, no. 16). The combined information indicates that with wind from a favourable direction, average speeds of 4–6 knots could be achieved on reaching and running courses. Such speeds tally with the observations of reconstructed square-sail merchant vessels

Table 5. *Summary of ancient square-sail voyages made in favourable conditions*

No.	Route	Distance (nautical miles)	Time (days)	Vmg (knots)
8	Sea of Azov to Rhodes	880	10	3.7
9	Rhodes to Alexandria	325	4	3.4
10	Utica to Caralis	140	2	3
11	Rhegium to Puteoli	175	1½	5
12	Ganges to Sri Lanka	900	7	5.4
13	Straits of Messina to Alexandria	830	7	4.9
14	Puteoli to Alexandria	1000	9	4.6
15	Gades to Ostia	1030	7	6.1
16	Corinth to Puteoli	670	4½	6.2
17	Puteoli to Tauromenium	205	2½	3.4
18	Alexandria to Ephesus	472	6	3.2
19	Byzantium to Gaza	855	10	3.6
20	Byzantium to Rhodes	445	5	3.7
				average 4.4

Table 6. *Summary of potential ancient Mediterranean square-sail performance in optimum conditions*

Potential square-sail performance	
Possible maximum heading-angle (close-hauled)	60–65°
Maximum Vmg to windward	2 knots
Likely average speed range on reaching and running courses	4–6 knots
Maximum speed on reaching and running courses	+12 knots

(such as Skuldelev 1 or Kyrenia) on similar courses (Katzev, 1990: 245–6, 248; Englert, 2006: 41). Maximum speeds can also be indicated by data from replica voyages, which suggest speeds in excess of 10 knots (for example Katzev, 1990: 252; Johansen, 2009: 62). In some cases a record exists of the outbound voyage made with the prevailing wind and the homeward voyage made against it, or *vice versa*. In each case the speed (and journey time) against the prevailing wind is double the figure for the reverse voyage. This correlates broadly with the overall difference between the Vmg of voyages made into the wind and with the wind.

Accurately quantifying the speed at which ancient shipping could travel under sail is difficult. In many cases the data is simply not detailed enough. However the combination of archaeological, experimental, literary and iconographic evidence can give a broad indication of the potential optimum performance of Mediterranean square-sail vessels (summarised in Table 6). The rigging and technical practice used would have allowed windward sailing in light-to-moderate winds and relatively calm seas. The available evidence indicates that on close-hauled courses in such ideal conditions a vessel could possibly have achieved a heading of 60–65° with a potential maximum Vmg of up to 2 knots (*cf.* Crumlin-Pedersen, 1984: 32–3; Johansen, 2009 for Viking-age square-sail performance). On reaching and running courses average speeds of 4–6 knots might be attained with maximum speeds (over short distances) in excess of 10 knots. It should be reiterated here that these are the 'best' figures that might have been achieved. In the majority of cases it is unlikely that such performance would have encouraged ancient mariners to set out on a voyage against the wind. The practice of waiting for a suitable wind-direction must have been the norm. These figures simply illustrate that the ancient Mediterranean square-sail was not as one-directional (downwind) as is often thought. Ground could be made to windward if the conditions were right and circumstance required it.

The lateen/settee sail

Assessing the potential performance of ancient Mediterranean vessels with a lateen/settee sail-plan presents a similar set of problems, and can be approached in the same way. The relative lack of reconstruction lateen/settee-rigged vessels (and corresponding lack of data) is largely compensated for by the data available from ethnographic observations of commercial lateen/settee-rigged sailing vessels in the Red Sea and Indian Ocean in the last century (for example Monfried, 1935; Villiers, 1940; Prins, 1965). Additionally, in 2003 the author was able to interview fisherman at the Egyptian Red Sea port of Marsa Alam regarding the use and performance of their lateen/settee-rigged sailing vessels.

As well as providing data relating to the lateen/settee rig, these sources also recount personal observations about the advantages, limitations and general use of this rig. These recent voyages, along with medieval

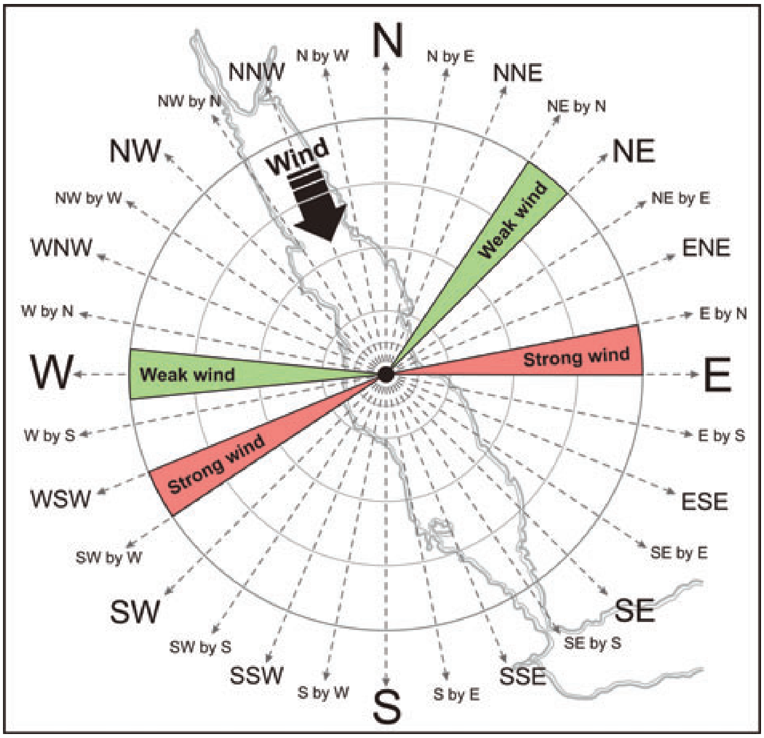

Figure 4. Illustration of the *takkiya* headings given by Sulaimān al-Mahrī. These give a good indication of the effect of different wind-strengths on close-hauled heading-angles of medieval lateen/settee-rigged ships in the Red Sea. Some inaccuracy is inevitable because of the need to take an average wind-direction of NNW. The variance in real wind-direction is reflected in the fact that a range of courses is given by Sulaimān al-Mahrī for each circumstance. (J. Whitewright)

voyages described in literary sources, provide further, historically-contextualised evidence for rig performance. A dataset is therefore available which is comparable to the one used for the analysis of the Mediterranean square-sail. The presence of a body of ethnographically-derived data may be seen as particularly valuable, as these voyages represent 'real-life' situations, where the primary motive was not to produce data for a scientific test, but simply to carry on their everyday business. The results will therefore represent normality.

Medieval literary sources

Valuable information about the use and, by inference, performance of lateen/settee-rigged vessels can be derived from the writings of the Arab navigators of the late-medieval period. With regard to the Red Sea, Tibbets (1961) singles out two navigators as giving the most valuable information about windward sailing; Ibn Mājid and Sulaimān al-Mahrī. Of particular interest is the practice of *takkiya* which was used when vessels sailing northwards up the Red Sea encountered the prevailing northerly winds above the 18th parallel (Tibbets 1961: 326). *Takkiya* entailed turning from a northerly course in the centre of the Red Sea to sailing towards either the Arabian or African coast—a manoeuvre consistent with having to alter course on meeting the prevailing northerly wind. Tables of *takkiya* described which islands or coastal landmarks would be sighted first if a vessel steered for the coast from a known position (observed via star altitude) in the centre of the sea. Additionally, Sulaimān al-Mahrī also gives the sailing courses for two sets of conditions, a strong and a weak northerly wind. These accounts allow conclusions to be drawn regarding the heading-angles which could be achieved in different conditions by medieval Arab lateen/settee-rigged merchant ships.

The northerly winds in the Red Sea generally blow from between north and north-west (Davies and Morgan, 1995: 29) so it seems reasonable to take north-north-west as a compromise direction. Sulaimān al-Mahrī recounts that in a strong wind a vessel steers east by north or due east for the Arabian coast and west-south-west or south-west by west for the African coast. In a weak wind the courses are north-east or north-east by north and due west respectively (Tibbets, 1961: 327). These different courses are shown diagrammatically in Fig. 4. The close-hauled heading in strong winds equates to *c*. 90–100° (*c*.8–10 points), improving to *c*.56–73° (*c*.5–6$^1/_2$ points) in lighter winds.

Ibn Mājid also gives bearings for *takkiya* from the island of Bahr al Zihār on the approaches to the harbour of al-Lith. When the wind is blowing weakly from the north-west the bearing is north by east or north-north-east, which equates to a heading angle of

5–6 points off the wind. When the wind is blowing hard then the ship must bear north-east or further east, giving a bearing of 8 points or more. Both these courses are consistent with those given by Sulaimān al-Mahrī. Taken together, the *takkiya* headings provide an indication of the windward performance of late-medieval lateen/settee rigged vessels in the Red Sea. This equates to a sustainable course of between 5 and $6^1/_2$ points (*c*.56–73°) off the wind in ideal conditions, diminishing to *c*.8–10 points (*c*.90–100°) off the wind in strong winds. The variance in the given course probably reflects variations in the encountered wind direction in conjunction with differences in vessel performance. Severin (1991: 238) notes that the settee-rigged sewn vessel *Sohar* could achieve 65–70° off the wind when close-hauled, including leeway. Although his method of measurement is not given and may therefore be inaccurate, it does offer broad confirmation of the figures derived from the textual sources.

As well as providing information on lateen/settee close-hauled headings, this re-emphasises the point made above that windward performance is adversely affected by sea-state. Strong winds result in rougher seas and decrease the ability of a vessel to hold a course to windward due to a subsequent increase in leeway. Elements of the rig are also adversely affected by stronger wind, seen in the stretching of sailcloth and rigging. Reducing sail as the wind increases will also reduce windward performance. In the case of late-medieval vessels in the Red Sea the difference is as much as 3 points (*c*.33°) in terms of the course sailed when compared to a vessel sailing in weaker winds (Fig. 4). Further evidence for such problems can be found in the writings of Ibn Mājid, who describes the effect of an increasing north wind on landfall when sailing toward the Arabian coast from the same point in the centre of the Red Sea (Tibbets, 1971: 253, 386). He describes the strength of the wind in four ways; 'weak', 'moderate', 'of medium size' and 'foul and blowing hard'. With each increase in wind-strength, landfall is made further to the south, reflecting the loss in performance associated with higher wind speeds.

Ibn Mājid also describes the sailing seasons around Socatra and notes that sailing from Fartak and Hairij (on the Yemen coast) to Socatra is difficult because one does so at that season with 'a wind of two sails' (Tibbets, 1971: 229); the journey is contrary to the wind and is not attempted unless the wind is light. The term 'wind of two sails' is used to describe travelling to a destination to windward. The vessel in question sails two tacks to complete the trip, one with the sail(s) on one side of the vessel and one with them on the other, hence the 'two sails'. The term was recently still in use in East Africa and was noted in the same context by Prins (1965: 252) in his ethnography of Lamu. The same technique is used by fishermen in the northern Red Sea when sailing to windward (personal observation).

Villiers also notes the effect which sea-state might have on a vessel's performance, in terms of both the ground made to windward and in dictating which course was sailed. Returning home from the annual voyage to East Africa, the Kuwaiti boom he sailed on met persistent strong headwinds at the entrance to the Persian Gulf and was able to make little ground to windward (Villiers, 1940: 313, 317–8). In his earlier voyage in a Red Sea *zaruq*, Villiers noted that a pair of *sambuk*s, in order to beat to windward, had sailed 'the inside passage' between the coast and the offshore reefs in order to take advantage of the flat water there (Villiers, 1961: 251). Such an approach was also adopted by Monfried (1935) in his voyage up the Red Sea from Djibouti to Suez (above).

Finally, Ibn Jubayr describes in some detail the voyages which he undertook. The ships on which he travelled generally attempted to sail in favourable conditions with the wind from astern or abeam, even if this meant waiting in port for several days (for example Broadhurst, 1952: 326, 361–2). Such an approach has strong echoes of earlier practices on Mediterranean square-sail vessels. Once at sea, in some instances when encountering headwinds, Ibn Jubayr's vessel was able to continue on its course (for example Broadhurst, 1952: 327, 364), suggesting relatively calm conditions. At other times the wind was too strong for the ship to make headway and the vessel was forced downwind (Broadhurst, 1952: 331–2, 362).

These sources offer a variety of information, some of it carefully recorded by master navigators, some simply the observations of seasoned travellers. It can, however, be interpreted to develop a picture of lateen/settee-rigged vessels from a range of contexts which can sail upwind at *c*.56–73° in favourable conditions, but which cannot hold their position as the wind increases and the sea-state deteriorates.

The Vmg of lateen/settee rigged vessels

Medieval and modern sources provide a range of data that can give an impression of the Vmg achieved by lateen/settee rigged vessels in a variety of conditions and contexts (Tables 7 and 8), and overall performance (Table 9). This evidence suggests that the best Vmg on upwind courses could have reached nearly 2 knots. In stronger winds, with an associated increase in wave-action, modern observations and historical sources both indicate that lateen/settee-rigged vessels would experience difficulty in making meaningful ground to windward. On courses with a more favourable wind (running and reaching courses), it would seem that lateen/settee-rigged ships were capable of achieving a Vmg of 4–6 knots. The maximum speed which lateen/settee rigged vessels could attain remains open to speculation. Villiers (1940: 336) records the Kuwaiti boom *Bayen* reaching speeds of 10 knots. Similarly, Severin (1991: 238) records *Sohar* achieving speeds of 8–9 knots. Of further interest is the fact that the speeds and sailing practices given in the medieval period tally

Table 7. *Summary of lateen/settee voyages made in unfavourable conditions. The average Vmg is undoubtedly skewed downwards by the slow times of voyages 24 and 27. If these are discounted, then the average rises to 1.64 knots. If only the medieval voyages 21–23 are counted then Vmg rises further to 1.82 knots*

No.	Route	Distance (nautical miles)	Time (days)	Vmg (knots)
21	Acre to Tinnis	180	4 days	1.85
22	Alexandria to Tripoli (Lebanon)	360	8 days	1.9
23	Alexandria to Constantinople	730	18 days	1.7
24	Tinnis to Ascalon	127	7 days	0.7
25	Bahr al Zihār to Sha'b Sulaim	12	7.5 hours	1.6
26	Khor Nawarat to The Brothers	520	14 days	1.54
27	Aden to Mukalla	266	12 days	0.92
28	Northern Red Sea	15	12 hours	1.25
				average 1.4

Table 8. *Summary of latee/settee voyages made in favourable conditions*

No.	Route	Distance (nautical miles)	Time (days)	Vmg (knots)
29	Palermo to Alexandria	1000	13	3.2
30	Tripoli (Libya) to Seville	1200	8	6.2
31	Sardinia to Sicily	190	2	4
32	Crete to Alexandria	400	4	4.2
33	Bahr al Zihār to Sha'b Sulaim	12	3 hours	4
34	Jeddah to Saibān	400	105 hours	3.8
35	Saibān to Muqaidih	55	12 hours	4.6
36	Ras Madraka to Ras Sauqira	107	1	4.5
37	Suez to Dahlak	940	9	4.3
38	Bahrein (Manama) to Kuwait City	240	2	5
39	Lamu to Mombasa	145	1	6
40	Northern Red Sea	50	12 hours	4.2
				average 4.5

Table 9. *Summary of the potential performance of late-antique Mediterranean lateen/settee rigged ships in optimum conditions*

Potential lateen/settee sailing rig performance	
Possible maximum heading-angle (close-hauled)	56–67°
Maximum Vmg to windward	1.9 knots
Possible average speed-range on reaching and running courses	4–6 knots
Maximum speed on reaching and running courses	+10 knots

closely with those recorded during the 20th century, suggesting little change in overall performance during the intervening period.

Conclusion

The research contained in this paper does not attempt to provide a definitive answer to the subject of ancient/medieval sail performance. Neither does it set out to define sail performance in the exacting, accurate terms required by modern naval architects or yachtsmen. The nature of the range of evidence used dictates that the results will always be approximate or generalised. This is unavoidable, but it does serve to set a starting point for future, wider-ranging research, or even direct, comparative modern testing. Despite these caveats, it is possible to begin to paint a broad picture of the possible relative performance of the Mediterranean square-sail and lateen/settee sail.

The Mediterranean square-sail rig and the lateen/settee rig which replaced it during the late-antique period share certain performance characteristics. Using the data derived from voyages of full-sized vessels, in conjunction with historical sources, a series of conclusions can be reached which outline the performance of either rig. These are summarised in Table 10 and visualised in Fig. 5. Allowing for the approximate nature of the results, the windward heading-angles achieved by vessels rigged with square-sails or lateen/settee sails is very similar. The results of analysis of the Vmg achieved by such vessels is also broadly similar, both on windward and off-wind courses. It seems that differences in performance are far more likely to have occurred as a result of differences in hull-form, rather than in sailing rig.

The evidence currently available would therefore seem to indicate that there is very little difference in the overall performance of a sailing vessel with a Mediterranean square-sail rig when compared with a similar vessel with a lateen/settee rig from the late-antique, medieval or modern era. Figure 6 highlights this, illustrating the Vmg of all the voyages studied, in favourable or unfavourable conditions, from antiquity to the present day, *regardless of the rig of the vessel*. Square-sail rigged vessels from antiquity are plotted along the same curve as medieval lateen/settee-rigged vessels. It is notable that there is no improvement in the Vmg on unfavourable courses over this period. Likewise, the Vmg in favourable conditions remains confined within a reasonably limited range.

The development and adoption of the lateen/settee rig, at the expense of the established square-sail, did not therefore lead to a subsequent increase in the windward performance or overall speed of sailing vessels in the Mediterranean. Equally, it seems counter-intuitive that abandoning the *artemon* and mizzen sail led to an improvement in manoeuvrability. The apparent ongoing quest for windward performance, so often given as the reason for the invention and adoption of the lateen/settee rig, does not in fact provide the rationale for this technological change.

Table 10. *Comparative potential performance summary of ancient Mediterranean square-sail and lateen/settee rigs*

Potential sailing rig performance	Square-sail	Lateen/settee
Possible maximum heading-angle (close-hauled)	*c*.60–65°	*c*.56–67°
Maximum Vmg to windward	2 knots	1.9 knots
Possible average speed-range, reaching and running courses	4–6 knots	4–6 knots
Maximum speed on reaching and running courses	+12 knots	+10 knots

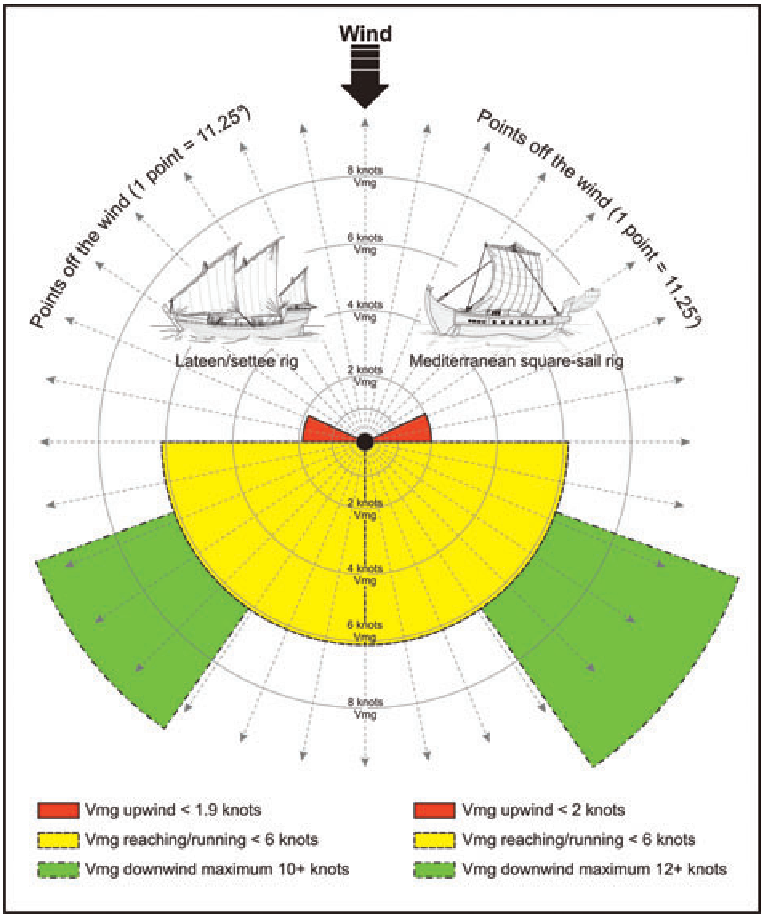

Figure 5. Comparative visualisation of the potential performance of Mediterranean square-sail and lateen/settee-rigged ships on upwind and downwind courses. Relative speeds are expressed in terms of Vmg; the fastest maximum speed is assumed to occur on a broad reach. (J. Whitewright)

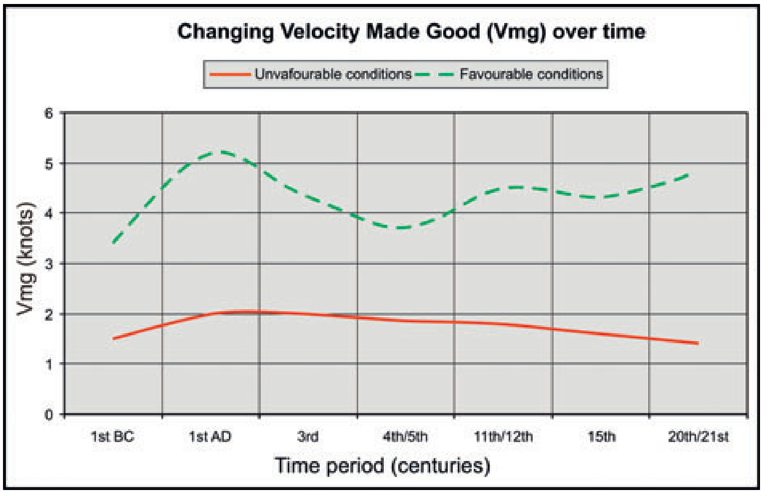

Figure 6. Chart plotting changing Vmg over time, as documented in the recorded voyages studied during the author's research (Whitewright, 2008). Data is derived from averaging all the analysed voyages undertaken in both square-sail and lateen/settee-rigged vessels. (J. Whitewright)

The technologically-determinist standpoint that has underpinned investigation into this area of maritime archaeology can therefore be seen to be fundamentally flawed.

In general terms, it is necessary that maritime archaeologists reassess their emphasis on the importance of windward performance as a factor influencing the evolution of ship-design. In the context of the ancient Mediterranean, an efficient hull-form was in use by the 3rd century BC, and the sprit-sail, more-efficient than either the square-sail or lateen/settee sail, was used from the 2nd century BC onwards. That such technological developments, individually or in combination, did not become ubiquitous across the Mediterranean is significant. It indicates that windward performance was simply not as important a contributory factor as the current academic literature suggests. A range of other factors was exerting a greater influence on the design of sailing vessels than the 'need' to sail to windward.

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