# Sources for Lusitanian shipbuilding

RICHARD BARKER

## Introduction

*"...Still there is more. In the ancient archives of the kingdom, at whose head I found myself, there exists a most ancient manuscript that is a contract between the king D. Afonso III and the Master of the Knights of Santiago, Paio Peres. In that document it is determined that the tribute of mermaids and other animals fished on the beaches of the same Order ought to be paid not to the Master but to the Kings. From which it is easy to collect that mermaids were frequent in our waters, seeing that a law had been promulgated about them. Enough: it is not worth continuing to speak of tritons, sea-nymphs and mermaids, and we renew the thread of the discourse".*

Damião de Gois, *Lisboa de Quinhentos*, 1554 (Gois, 1554-1937, p. 30)[1], offers this sad tale of over-fishing in the third quarter of the thirteenth century. The same might have been said of the wrecks of Portuguese ships, whose absence had been the source of some woe to scholars such as João da Gama Pimentel Barata and Octávio Lixa Filgueiras. After all, it was Portuguese ships that really opened up the world in the fifteenth century, and even much of the so-called Spanish Armada had actually been seized from the Portuguese arsenals. Happily, the sirens have finally led our Portuguese colleagues to the true fishing grounds. Perhaps the mermaids will follow.

Portugal has a maritime history out of all proportion to its size, but after a brief survey, towards the overall theme of the conference, this paper will concentrate on three aspects of nautical archaeology that have been illuminated by the contents of Portuguese libraries. The implications go far beyond the interpretation of the present Portuguese wrecks, of roughly the fifteenth to seventeenth centuries. The three inter-linked strands are:

- The practical shipbuilding processes of hull form and frame moulding.
- The timbers that were used in shipbuilding, and particularly the issue of cork-oak, which is so prominent in the Portuguese writings of our period, and even leads to a review of the management of all oak forests in areas supplying shipbuilders.
- The different midship frame shapes that we have in the archives for European ships, and how and why they changed.

The writer's enquiries started in this last area thirty years ago. Consideration of the Portuguese case and evidence has brought them almost full circle: who would have thought that forest oak trees were systematically pruned?

However, the archaeology remains crucial to all these.

## Brief historical survey

In antiquity, Lusitania shared the Celtic heritage of the west of Europe: rafts and primitive types have been recorded (Filgueiras, 1980); skin boats are referred to (and even reconstructed)[2], dugouts too (Alves, 1988)[3]. We then have notice of Phoenician influence. Not only was the coast part of an ancient sea route from the Mediterranean to, for example, Cornish tin (Bowen, 1972, p. 56-60)[4], but the Tejo was a recognised harbour, under the Roman name Olisipo(nis), when the present Baixa was still a marshy inlet (Fonseca, 1990). The shoreline seen today has indeed been steadily reclaimed, with the sixteenth century waterfront, the old Ribeira das Naus and the eighteenth century dry-dock (Reis, 1988) all buried, but the major extensions were made in the early twentieth century. Indications of this process exist in both the half-buried state of the Chafariz del Rey[5], and in the succession of ship-timbers found in the recent works for the Metro extensions, in the general area of the old Ribeira.

The traces of some of this history can be seen in Portugal's inshore fishing craft, some of which are considered to be of Sumerian or Phoenician origin, iconographically, and from the known trade routes (Barata, 1973, 1989c)[6].

The earliest texts we have for shipbuilding are from 1115, in fragmentary accounts of how Genoese experts in galley warfare were invited by Bishop Gelmirez to construct galleys to clear the coast of pirates, Normans and Muslims alike (Filgueiras, 1991). In 1317 Manuel Pessanha took up the post of Admiral after a similar invitation from D. Diniz. It is sometimes suggested that the latter group were the first navigators in Portugal, but the probability is that they were military commanders who brought specialist shipbuilders with them, and who had no need of navigation: galleys were essentially limited to coasting voyages, both for reasons of sea-keeping capability and autonomy of operation. The planting of the forest of Leiria, explicitly pines for shipbuilding timber, is said to date from this period.

It would be wrong to suppose that there were no significant ships in Portuguese hands before the arrival of the Genoese in 1317: Afonso III for example had a fleet of *navios grossos* at the siege of Faro in 1270, and used these and galleys to harry the African Moors in the third quarter of the thirteenth century (Pina, 1907, p. 48, 53). (Lisbon had been recaptured with the aid of crusaders en route to the Mediterranean in 1147).

As for the form of shipbuilding, we may note that the earliest Italian manuscripts, of roughly this period, clearly use terms that show that elaborate geometrical hull moulding techniques were already in place (Chiggiato, 1987)[7]. It is a reasonable hypothesis that the recorded units of shipbuilding measurement in Portugal – the *palmo* and *goa* (256 and 768 mm) – derive from the early Genoese connection; just as Portuguese methods appear to have remained differentiated from the recorded methods of Venice. At the same time, there are other units of less certain origin, and many terms are of Arabic origin, probably related to the fishing vessels of the Muslim period. The *caravela* was a fishing vessel in Portuguese records from the thirteenth century, though in the form *qãrib* the term at least may be traced to older Mediterranean trades that are recorded as far as Spain by Goitein, from the Cairo Genizah material (Goitein, 1967, vol. 1, p. 305-306)[8].

Before that, lasting northern influence had reached the Douro in the fifth century: Filgueiras has demonstrated that the boats and ploughs alike of the Douro region match those of the Suevi, from the southern Baltic area (Filgueiras, 1979, 1963, p. 44; Beaudouin, 1965)[9]. The traditional local boats of the Douro and north of this line are still clinker, and to the south they are carvel (though we may note a strange outcrop on the statue of Pombal at the Rotunda in Lisbon). Clench-built vessels continued to be used for shipping at least to the end of the fifteenth century. Three ships were even purchased from Holland for the India voyage in 1506 (Brown, ed., 1864, I, p. 311, N.º 863)[10], whose construction was presumably shell-built, if not clinker. Thereafter a polemic arose as to the merits of different ship types, timbers and hull fastenings suitable for Portuguese voyages.

Thus Portugal was a meeting point for many traditions, and a springboard for greater things.

## Early records

Even though extant written records commence from the twelfth century, they are sparse (and often ambiguous) until the second half of the sixteenth century. The fifteenth century records are of three basic kinds for our purposes. The chronicles speak mostly of people and events, and maritime information is mostly incidental and imprecise. However, we know that until about 1436 Portuguese voyages utilised only *barcas* and *barineis*, both square-sailed, the latter clinker built. It may be noted, then, that the open-ocean islands of Madeira and the Azores were (re-)discovered and settled with such vessels. The *caravela* only appears as more than a fishing boat from the 1430's (Barata, 1987, 1989c; Filgueiras, 1969; Elbl, 1994; Filgueiras and Barroca, 1970). That is, it came into use as the *volta*, the wide oceanic sweep of the return journey, eventually via the Azores, necessitated by prevailing winds and currents, became progressively longer as the exploration of the African coast advanced. The critical factors were probably speed, and the ability to make some headway against headwinds if the prevailing winds failed, and thus to get back before water ran out. The *caravela* was otherwise far from an ideal choice. Its large lateen sail needed a large crew, and even then was dangerous; and the hull was too slight to carry stores and water for long periods. Dias, the first to pass the Cape, in 1487, called for different ships for the open Atlantic: he wanted higher sides, specifically; and was himself lost in the voyage of 1502. Indeed from about that time, *caravelas* often went out to India under square rig, just as they did to the West Indies. Columbus' opinion expressed in 1503 makes their limitations even under lateen rig perfectly plain[11]. Columbus was not one of the *caravelas*' most skilful proponents: his trail of abandoned ships has been a mainstay of recent archaeological searches.

We should not forget that the *caravela* was a warship for most of our period. In 1501 there were 35 of them assigned to a pan-European fleet (Subrahmanyam, 1997, p. 186), in addition to large numbers on the India traffic. The chronicle of João II suggests that serious naval ordnance developments began in *caravelas* (Resende, 1622, chap. CLXXX)[12]. Not only were *caravelas* carrying very heavy guns on 2-wheeled carriages, firing forward or to the side[13], in the manner described by Cleves for about 1500, and incidentally as found on the half deck of the *Mary Rose*, but they had perfected the practices of ricochet firing, and stand-off artillery fire from line-ahead by 1501 at latest (Resende, 1622; Barker, 1996, 1998a).

As an aside, by the seventeenth century the situation had changed. Large numbers of *caravelas* continued to be built by merchants for the Brasil trade, and were lost also in large numbers to the Dutch with their cargoes, largely of sugar. It is an interesting question as to what became of the hulls: few resisted or are otherwise recorded as sunk. Neither hull form nor rig were suitable for Dutch use.

Gois records a standing fleet of two hundred vessels in 1554, equipped from what must indeed have been one of the greatest arsenals of naval ordnance and stores. There are records of astonishing ships in the Portuguese service throughout our period. While the vast *Madre de Deus* is well known[14], and visually at least the *Santa Catarina de Monte Sinai*, 800 tons, built in Cochin in 1512, and armed to the teeth for a voyage in 1516[15], some are less well known. The *1,000-ton nau* of about 1490 for example, guardship of the Tejo, though it also went to the Mediterranean (Resende, 1622, chap. CLXXX). Or the *São João* (popularly the *"Botafogo": Spitfire*) of 1533/4, one and a half times the length of the largest India ships, with an exaggerated but clearly exceptional armament[16]. Or in the 17th century the largest ship in the world, the *Padre Eterno*, built in Brasil, but whose remains are now rotting quietly somewhere off Montijo in the Tejo — a virtual site in the database. She carried home cargoes of 2,000 tons of sugar alone (Barker, 1998c, notes 25, 26).

Another area of interest is tonnage measurement, for fiscal and construction purposes. There are records from around 1500 that describe a fully developed administrative and technical procedure for gauging a ship, using the regulated hoops of standardised barrels, to determine actual capacity in tuns and fractions of tuns at stations along the hull, defined by the length of the tun. While the accounts beg a few questions about the use of the largest barrels as the basic measure, and how they were nested, the standard unit of keel length, the *rumo*, is related to the Lisbon tun of that period. Tonnage, as capacity in tuns, was clearly a reasonably precise measure long before the simplified (but probably less accurate) procedures of tonnage formulae emerged during the sixteenth century. Relating the cargo-space dimensions of archaeological finds to barrel sizes is clearly a pre-requisite[17].

We can also find inventories of the barrels carried in specific ships from this period, notably the first two voyages of Vasco da Gama in 1497 and 1502; by no means all were iron-bound, and this history has also to be unravelled.

A further aspect of the textual sources concerns timber for shipbuilding. One particular point is incidental to the development of Madeira: an infinite source of high quality timber from about 1420, excluding oaks, and pines (planted only from 1515). Dias Leite (publishing in 1589) speaks of the introduction of water-powered sawmills producing plank for the mainland, but also some more exotic species for furniture, and possibly ship-timbers. The issues are ambiguous in almost all the texts, and Dias Leite himself has a curious passage:

"…. There was such quantity of such beautiful and hard wood that they carried supplies of planks, beams, and masts to many parts, which was all sawn with water mills… And at this time, because of the great quantity of timber that they carried from here to the Kingdom, they began to make with it ships with top[-mast]s and fore castle, because before they did not have them in the Kingdom, nor anywhere to sail to, nor did they have more ships than *caravelas* of the Algarve, and *barineis* in Lisbon and in Porto" (Leite, 1989, p. 28-29).

This has been interpreted literally as meaning that previously the Portuguese *could* not build larger ships - defined as having topmasts, which is after all only 50 tons. However, authors of his own period claim that Portuguese shipbuilding was founded on cork oak and *pinhos bravo* and *manso*, all ideal for their ships (up to more than 1,000 tons). None of these timbers were available from Madeira. The interpretation is simply incompatible with the specialised shipbuilding texts of Oliveira and Lavanha. We could also note that the previously inadequate shipping had in fact reached Madeira; and that sawmills are of limited use for ship-timber.

An alternative interpretation might be that the larger ships were soon built precisely to *transport* the quantity of great timbers of Madeira.

We may insert at this point the interpretation of Pimentel Barata (Barata, 1981; a corrected version appears in Barata, 1989b) that the Portuguese used cork oak, exclusively (excepting only Indian and Brasilian timbers), for ship-timber. This is apparently an act of faith based on the preferences of Oliveira and Lavanha, though it is impossible to wholly reconcile these quasi-classical commentaries with the facts of economic history. The reality is that ships were built with what was available, and European oak was imported into Lisbon in the sixteenth century (Costa, 1997, p. 311-312, 321). Some of this was planking: more vulnerable to shipworm than frame timbers (though Lavanha speaks of teredo following the grain of treenails into framing). We need some archaeology.

Iconography is sparse too. There are occasional views of the Ribeira, and about 1535 the spectacular panorama of Lisbon, now in Leiden. However, many views of Lisbon showing shipbuilding are Dutch prints with the features of Lisbon, copied from one original or another, but clearly illustrating Dutch shipbuilding methods. Just such a one adorns the Academia de Marinha. Most of the iconography of the period of the discoveries was actually made in the second half of the sixteenth century, notably the *Memórias das Armadas* and *Livro de Lisuarte de Abreu*.

There are interesting questions arising from the launching of ships in Portugal (Barker, 1998c). A group of large vessels seen ashore in the Ribeira about 1520 in a Book of Hours[18] are variously bow, stern and broadside to the water. Fernandes alone of the technical sources provides even sketchy details, a cradle and groundways for a large *nau*, apparently bow-launched. An engraving of 1707 shows a ship under construction in just such a way[19]. It is a problem exemplified by the statement of Saverien, 1758: "the Portuguese... consider it better that the vessel enter the water by the stern than by the bow. They no doubt have their reasons, but it is not easy to discover them" (Saverien, 1758, art. *lancer*). An archaic sledge-cradle based on keel and bilgeways can be seen on Madeira: all these topics will hopefully be the subject of archaeology one day, both as infrastructure and for the permanent results that cradles and other aspects of launching and careening will leave in ships.

## Books and quasi-technical manuscripts

The first published work is Oliveira's *Arte da Guerra do Mar* (a single copy extant from 1555) (Oliveira, 1983), but as regards the ships themselves this is a poor source, compared with Oliveira's later works, from 1570 or so. The *Ars Nautica* contains the first drawing approximating to the later body plan, a hundred years before its time; but awaits full publication.

Between 1570 and 1625 we have a number of major manuscript sources, first studied at an acceptable level by Pimentel Barata, though several were known or had been published from the late nineteenth century. Oliveira's *Livro da Fábrica das Naus*, Lavanha's *Livro Primeiro da Architectura Naval*, and Fernandes' *Livro de Traças de Carpintaria* have all been published, from the period (1580-1640) when Portugal was ruled by Spain, and in the early part of which Portuguese shipbuilding was highly developed. Lavanha for example held senior positions in the Spanish administration.

There is a mass of little-used archive material for the later part of our period — *Livro Náutico*, Palha MSS, and collections in the major archives, all slowly emerging.

## Components of the manuscripts — timber and structural features

The major texts of Oliveira and Lavanha commence with classical introductions, establishing the credentials of the writers, and little more. There are long sections on timber for shipbuilding, which also rely heavily on classical authors, then only relatively recently recovered and published. These tend to suffer from being out of context for the Iberian scene and also following the errors of the originals. Oliveira discovered that he had been misled by grammarians between writing *Arte da Guerra da Mar* and *Livro da Fábrica das Naus*. The most conspicuous problem is with the mysterious *lerez*, presented as a Portuguese shipbuilding timber, while translated as larch in modern material, and confused by Oliveira and Lavanha with that Alpine timber, used in Italy and Germany. It may have been a black pine; but the first timber found that is not an oak, or *pinhos bravo* or *manso*, must be a candidate.

Oak is a favourite topic. The wonders of cork oak (*Q. suber*) for a ship's skeleton (but not planking) are clearly already part of the mythology of Portuguese shipbuilding. The reality may be rather different. Conspicuously, frame timbers greater than one *palmo* square (256 mm) are not mentioned in the Portuguese texts. Whether this reflects a continuing Mediterranean construction style, or simply the lack of larger ship-timber is not known, but it is a topic that needs to be pursued. Oddly, European oak is cited as used in masts, though Freire Costa qualifies this as for the *madres*, the cores of made-masts, as drawn by Fernandes.

One point to emphasise is that no current image of cork oak trees (any more than of European oak) is a safe basis for consideration of the form of cork oaks available in the Ribatejo four or five hundred years ago, managed in different ways. Photographs of massive, ancient cork oaks exist, but reveal no more ship-timber than in the Major Oak of Sherwood Forest: and were probably as hollow and rotten. The modern Alentejo cork oaks, managed for cork production, are no better guides. The curious point is that it is only damaged trees that produce significant compass timber naturally, from loss of the leading shoot, for example. We will return to this.

There is much in Oliveira, Lavanha (and at a practical level, Fernandes) on the geometry involved in shipbuilding, both of the overall skeleton and midship frames, and of the *graminhos*, the full scale measures for the progressive adjustment of frames at numerous key points - rising and narrowing, overlap of floors and futtocks, etc.

There is a mismatch in frame terminology between Portuguese and English traditions, reflecting the different frame shapes seen in the late sixteenth century. Tumblehome occurs, but is generally less pronounced than in an English ship of the same tonnage. Pimentel Barata traces several variants of the midship frame's geometric construction from the manuscripts, notably in *Traçado das Naus e Galeões*....(Barata, 1989a), but the core design appears to be a flat floor, and a single circular arc for the side, from an apparent hard chine. Several observations can be made here.

It is not known how this worked in practice, whether it was ever planked as such, or always rounded out locally, as suggested by several pencil modifications and ambiguities (Fernandes, 1616, facsimile 1989). The unique body plan of Oliveira's *Ars Nautica*, of around 1570, shows several frames amidships with this feature, but hardly resolves the issue. Lavanha draws one form of the section with a chine, fixes the *côvado* or junction of the floor and *braço* at one *palmo* above the base, and the chine rounded out with an arbitrary arc between these points (Lavanha, c. 1610, 1965; facsimile 1996)[20]. The location of the *côvado* itself distinguishes the method from the English methods. It seems likely that a short reconciling arc applied by eye may be the direct result of the *espalhamento* method, with frame rotation about the *côvado*, which inevitably introduces a discontinuity in the surface.

This sharp transition is however remarkably reminiscent of the sort of timbers that would be available from cork oak trees as drawn by Vieira Natividade for twentieth century stock - grown for cork not timber, but with the same basic genetic coding for branch formation. That is, the trees ideally spread at the top of a short trunk, into 2 to 4 branches, all lying at about 45 degrees to the horizontal (Natividade, 1990; Instituto Florestal, 1995). These might well form half-floors and the turn of the bilge as drawn by Lavanha, for example; and also for the *couce*.

The details of frame shape, framing and planking in this area will be one of the key features to be reported in excavations of Portuguese wrecks.

The sections published for the *Santo António de Tanna* (Piercy, 1977, 1978), built in India, show two different shapes, neither of which appear compatible with the archives.

The *couce*, the knee joining the sternpost to the keel, has been found in the present excavations, to match Lavanha, and Fernandes in principle. It is of course also a feature of Basque construction, where it was one of several surprises in the Red Bay wreck. It has not been found in any other tradition.

One conspicuous feature of Lavanha and Fernandes (but not in the more theoretical — and we might note, earlier — work of Oliveira) is the *dente* (lit.: tooth), the integral corbel moulded on the inside of the frames, for which there is no adequate rationale stated, and which appears to be unique to Portuguese methods. This writer's view is that it was moulded with the frame patterns to ensure a fair curve for the sheer of the decks, differing from the rising. Lavanha sketches straight (and very slender, unpropped) beams bearing directly on them, but that leaves the location of any beam shelf a mystery. At the time of writing, there is no physical evidence for such beam-teeth reported.

Neither is there yet any physical evidence for the second level of surmarks and mortices between the first and second *braços*, as drawn by Lavanha in his five-part pre-erected frames.

A feature found in Fernandes, but also in Baker's *Fragments of Ancient English Shipwrightry*, is a projection to the surround of the hawsehole, like a cedilla, though conspicuously it faces aft, away from the normal drag of the anchor cable. It would be interesting to discover both how superficial this reinforcing (?) piece was; and also how widespread it might have been in practice.

A final point to mention is the *esporão*, a debatable item that might be a spur or vestigial ram, well above the waterline, or a rigging feature (Pimentel Barata considered it erroneous for Portuguese ships). Something of the kind occurs in English drawings, and also in the Spanish ships in Wieringen's great painting of the Spanish-Dutch action off Gibraltar in 1607, in the Nederland's Scheepvaart Museum, Amsterdam.

Wieringen is of course the best evidence for outboard loading of ordnance in battle, though not for how common it may have been (this writer's view being that a more general arrangement was lashing to the side for firing, and hauling in for loading; in combination with a high proportion of breech-loaders prior to developed truck carriages) (Barker, 1992c), there are many things to be learned about ordnance at sea. An English drawing of around 1567 shows side-hinged gun-ports (Evans, 1948)[21] — so does Marcos de Aguilar. There is said to be an early Portuguese drawing of truck carriages (Guilmartin, 1994, p. 146, note 25).

## Frame design – features and possibilities

We have touched on structural features in the frames illustrated in the manuscript sources. There is another aspect of frame design that will also offer diagnostic information about a wreck, once we have cracked the code. The three traditions for which we have significant bodies of early manuscript sources — Italian, English and Portuguese — are all radically different in their approaches to the geometric construction of the basic midship frame shape. Ostensibly, the English evidence offers a reasonable process of evolution through the sixteenth century, developed from what might be termed the Old Method (after Fournier, who records it enigmatically in 1643), based primarily on the manuscript *Fragments of Ancient English Shipwrightry* (Barker, 1998a, 1998b). Unfortunately there are three recognised problems with this assessment. The first two are old: the English whole-moulding that appears in records only from the eighteenth century is rather different (and this writer's current view is that it is a decayed relic of the full system, used in small boats); and an English record of the Venetian system around 1550 describes something rather different from what the Venetian records themselves describe for the same period. This may be due to differences between Venetian masters, perhaps inside and outside the Arsenal: we do not know, but it places a doubt in the sequence of developments. The third is new, and arises from the Red Bay work, where the frame geometry is apparently a remarkably good match for English methods of the succeeding decades[22]; though it does now appear that the *Mary Rose* used a similar system in 1509, varying only in the actual proportions. That immediately poses a question as to the sequence of development. Was the English case as independent as supposed? Where did the Basque method come from? Who copied from whom, and when? We simply do not know, and are dependent on a few more fortuitous wrecks to provide some definitive answers.

As far as the units of measurement can tell us, there may be a common strand from Genoa and Provence to Portugal, in the palm of about 256 mm. While Catalan warships of an early period have been studied, notably by Foerster and Mott, little seems to have emerged as to hull shape and moulding and construction from any of these intermediate areas.

It is worth noting a couple of other factors though. Brad Loewen highlighted one recently, from the accounts for the great ship built for King Henry V in Bayonne in 1419 (Loewen, 1997). This record not only touches on apparent frame moulding controls in clinker construction – near heretical, but also emphasises the probability that Basque shipbuilders (supposing for this purpose that Bayonne was the same as Basque) used clinker methods in the fifteenth century, just like most of their northern neighbours. We have to define their process of conversion to carvel, too.

The second is that there is a record from Caesar, and some archaeology, to demonstrate that 2000 years ago the North had its own heavy construction processes that were not clinker; and in the case of the Guernsey Gallo-Roman wreck apparently skeleton built in the lower hull area (though the report is terrified of referring to moulding) (Rule and Monaghan, 1993). The text describes two stages of fashioning the floor timbers, rough hewn, *without* a variable pattern, but then placed in their *planned* positions on the keel, to *establish the lines*, *without battens*; and then fine-dressing; but the recorded section immediately illustrates a third, to form the lands of the planking — not a convincing account. What happened to these processes? It is not beyond the bounds of possibility that they preserved classical methods transmitted by the trade routes themselves, but which were lost with the bulk trades during the Dark Ages.

As to the actual geometry, we can say that the Old Method was close to two quadrants separated by a flat floor. It appears that the Portuguese tended to use something closer to single arcs on the apparent hard chine, perhaps becoming more complex in larger ships; and that after 1550 English methods moved towards three more differentiated arcs, already present in principle in the *Mary Rose*, though the result was not far from a quadrant. All these relate to the hull up to its broadest part, at midships. The logic of the construction of the centres for the arcs all varied correspondingly. The methods recorded in Venice do not apparently use arcs at all, but offsets. It is worth noting that the mid-sixteenth century transitional methods recorded by Baker include traces of offsets at key points between the arcs (though the Venetian methods contain far too many for these all to be records of tangent touches, except in the smaller vessels where only the *trepie* and *seipie* are used in the lower hull, and could conceivably record tangent points).

The most obvious feature of ship design in our period is the use of pure arcs of circles in basic features — stems, counters, and above all in frames; and also in superficial features such as the curvature of wales, and in narrowing and rising lines. They even occur in Viking ships — the archetypal "built-by-eye" ships. All these can be recovered from reasonably intact structures or clean timbers, to some degree. The units of measurement of the radii, the patterns of the centres, and proportions, will all be highly informative in time[23].

The lesser marks, more a craft device for implementation of a design, will also be of interest, where they survive cutting and dubbing — centrelines, surmarks, bevels, etc. An interesting distinction may arise between circular arcs, swept with a cord or trammel (perhaps thence via a wooden pattern) and graminhos. The latter are far more likely on long radii — curvature of beams and masts typically, but also the risings and narrowings in the central body of the ship. The abscissae markings may well survive on the moulded face of a beam, for example, whereas we might expect all frames to be composed of moulded arcs, with single surmarks at overlaps, at least in the pre-moulded parts.

Frame timbers made to standard circular arcs have to be adjusted along the length of the hull, and yet produce a fair hull form. The graduation of the overlap or rotation required controls: *graminhos* or other form of full size drawing. Equally, since the actual timber needed to be overlapped in some way, either with the previous timber in a frame, or some control such as ribband, it ought to be possible to work backwards from a wreck, and deduce what form of graduation was in use. The latter is not in general likely to produce very precise measurements, and much of the evidence may get cut away in forming the timbers, or in subsequent dubbing; but the process has yielded results at Red Bay.

These *graminhos* will not just occur in the Iberian tradition: neither are they something new. They occur in Greek temples too, for which we have physical proof in the construction drawings still scribed in an unfinished temple, for the taper of successive stones in its columns (Haselburger, 1985); and probably much earlier. The common strand is an essentially practical matter — how to efficiently build something so large, so that it all fits and creates the desired result.

In principle, the same may be true of bevelling, which over the pre-moulded sections could be cut prior to assembly — and that occurs in English texts of the early seventeenth century as well as Portuguese; different methods to the same end, but all based on geometry. Unfortunately, the bevelling marks may be more likely to be cut away in the process of working the timber, as they serve no continuing function, unlike the surmarks, which record the intended alignments with adjoining pieces.

We might then expect a record of the moulding processes in "carpenter's" marks, as suggested in 1988 (Barker, 1991), in addition to the frame mortices that were just beginning to be found in archaeology, and had been first published from the manuscripts in 1965, by Pimentel Barata.

It is unclear how frame mortices were marked; and they appear to have been relatively loosely controlled as to orientation at the surmarks of the floor and futtock. There is a curious lack of symmetry in the dovetails on the moulded faces in the Red Bay ship, for example. That is odd. Whatever the function — strength or alignment — they had to fit well, or they were counter-productive. We might suppose that the two halves of the joint were marked from the same mould, and at the same time — so why are they different? A profusion of marks on the moulds, for shape, *graminhos* and surmarks, for mortices and tenons could lead to confusion. Does it reflect different workmen on the different stages — moulding and jointing? Was it deliberate, to make the timbers unique, and highlight any incorrect assembly, even of numbered pieces?

How were they marked on the timbers, if not from a pattern, and thence symmetrically? Cut by eye on first timber moulded, and the mating timber marked from that? Which first — mortice or tenon? Something else we can say: that it illustrates an abiding truth of wooden shipbuilding: timber scantlings had less to do with the strength of the timber, and far more to do with the joints, and fastenings. If the timber stock was of relatively small scantling, the issue of large treenails versus smaller iron fastenings to transmit the same load is doubly significant. Cost and corrosion and rot may be less important.

## Reconstruction of a ship's lines

Producing the lines in any modern sense serves no purpose other than pictorial, and to allow quasi-quantitative estimates of hydrodynamic characteristics, using modern design packages (Wilson, 1994)[24]: the original ships required no drawings as we know them. However, to retain any semblance of credibility, those lines have to be generated from proportions and geometry, just as the original ships were, in this context. This is actually virtually impossible with our present knowledge in any tradition, but there are peculiar difficulties with the Portuguese sources: there is too much critical, practical information missing from the extant texts. This would be true even if we could generalise about overall proportions. Barkham has attempted to establish standard proportions for Basque ships, but if we compare the extant English texts with the official records of the actual leading dimensions of Royal ships, there is negligible match. Broad trends may appear as identified by Glasgow (1964), but to suppose that we understand all the factors and can predict proportions in any region from hindsight is an illusion (Barker, 1994). It will of course require very large numbers of substantially intact wrecks to alter that situation[25].

We may note the paper by Pimentel Barata given at Greenwich in 1979 (Barata, 1981; a corrected version appears in Barata, 1989b), which attempts to produce rules for Portuguese proportions spanning 75 years for *naus* and *galeões*. These are ostensibly based on the *Livro de Traças de Carpintaria* primarily, but the process is not declared anywhere. It has frankly to be said that the production by Greenwich was unsympathetic, and Pimentel Barata's case is simply not made — the version published in *Estudos de Arqueologia Naval* at least has the typographic errors corrected. The paper is nonetheless the best summary guide available to likely dimensions in the period 1550-1625, based on decades of work. There remains an unpublished manuscript for a book, which may or may not be a synthesis.

It is Pimentel Barata's attempts to link esoteric geometry, presented in various places but scarcely published, that requires caution, and is subject to the problems of all attempts to impose harmonic geometry retrospectively. As this writer has commented previously (Barker, 1992b), such things are inextricably mixed up with the indispensable practical geometry of all construction. Neither is there the slightest doubt of the significance of proportion in all construction prior to the advent of plans as we know them. However, even a masonry structure cannot be measured after the event with any expectation of reproducing the design dimensions precisely.

However, readers should not scoff, and may not be aware that harmonic design is alive and well. The new Vasco da Gama Bridge over the Tejo was designed (allegedly aesthetically, be it understood) using the Golden Proportion (Yee and Stanley, 1997)[26]. One does not have to look very closely at the published outline sketches to see that such systems rapidly depart from any intellectual rigour, but they exert a powerful attraction, and in our period were models for the whole universe, to be emulated.

## Timber supply

The single circular arc of the Portuguese designs poses problems akin to Fournier's Old Method, or the *Mary Rose* as found: what was the source of such timber, in large quantities, and to a specific size and radius, over considerable lengths? Generally speaking, oak trees do not produce great lengths of truly compass timber in one plane. Even if they do in silhouette, there may be strong bends in more than one plane, or side branches with large knots or bad grain just where bending strength was required. Size is also an issue: 256 mm squared, free of sapwood, requires a cork oak limb probably in excess of 450 mm in diameter, allowing for its generally thicker cork bark, and even if its actual curvature exactly matches the arc required. It is no wonder that Lavanha speaks of the tool necessary to mould over a wany edge, the *chinco*.

Beyond maturity at around 150 years any oak tree may well be rotten in its heartwood. Evelyn writing in 1664 expressed this as: "a timber-tree is a Merchant Adventurer, you shall never know what he is worth, till he be dead"(Evelyn, 1664, facsimile 1972, p. 15). Monceau adduces evidence for the same phenomenon: large ships simply were not lasting as long as those made from smaller timber, attributed to the same cause (Duhamel du Monceau, 1764, vol. I, p. 648ff.). There is thus an additional benefit if trees of the right form can be found, rather than cutting to waste from larger, older timber.

Cork oak trees today are heavily and systematically pruned to improve the cork produced — so are holm oaks, more especially in Spain, supposedly to improve the acorn yield. It is not impossible that such practices are older than we know — though on the face of it cork was a serious economic crop only from around 1800, for bottle stoppers (Parsons, 1962). That however ignores the fact that Dom João II made the export of cork a Royal monopoly in the late fifteenth century, to finance his imports of copper for his new naval ordnance, but this may have been only the cork taken from trees felled for other purposes, for floats and shoes, where greater thickness than the modern economic norm may have been beneficial anyway.

At the same time there are indications that pruning of oaks for another crop, firewood, may have been prevalent. There was a prohibition on cutting cork oaks in the Ribatejo in 1546, so as to conserve them for shipbuilding, but it is not to cutting timber, but to felling the whole tree at the root, "*corte pelo pé*" (Costa, 1997, p. 316). It echoes a phrase of D. Dinis from 1310, cited by Vieira Natividade: "so that the cork oaks may not be harmed". A parallel text in England from 1616 cites objections to leaving standing timber in accordance with the Statutes, on the grounds that the crowns would shade out the valuable underwood "if those trees be suffered to grow full of boughs*; but being used as before,* they will no whit hinder the growing of the underwood" (Standish, 1616, f. 17). Both these may be taken as evidence that oak trees intended for timber were commonly lopped and pruned, probably primarily to provide fuel. There are many other factors at work. How deliberately the pruning was also directed to forming improved constructional timber (and within economic reach of shipyards, ship-timber) is a moot point, but there is a vast literature to suggest that it is an old idea. Indeed, one translator of Theophrastus' *Enquiry into Plants* suggests a corruption where the text has a term bentwood for ships (Theophrastus: V.vii.3, ed. 1916 by Hort, p. 457, note 5). Perhaps not. Surprisingly, there was an English occupation of "forest pruner", one would have supposed a job for life; but it also occurs as *podadeiro* and *elagageur*. As one forester put it: "If well directed, pruning is one of the most useful, and if ill directed, it is one of the most mischievous, operations that can take place in forests" (Michie, 1888, p. 210).

There is one final curiosity that must be resolved within an acceptable history of the use of cork oak in shipbuilding. Contemporary and later writers all praise the great hardness and density of the timber, which improved resistance to rot and worm. Data presented in the past cited air-dried sample densities even greater than water (Natividade, 1990, p. 319)[27], and consistent with the mythology. However, modern data reports the average density of air-dried material, grown in *sobreirais*, closest to natural conditions, as only 0,75, while samples produced by the most intensive pruning and cork-stripping in *montadas* reaches 0,82 in the heartwood (Carvalho, 1997; and personal communication 1998). Even allowing for variations in soil and climate, and position in the tree, this variation is extraordinary, and bespeaks some savage treatment of cork oaks within reach of large populations in the past, for fuel presumably. These densities are evidence that there is something about the history of cork oaks, probably of all oaks, that we do not yet understand.

But the practice of pruning and training forest trees is not unknown elsewhere. It clearly occurred in Italy from the sixteenth century at latest. There are manuscripts showing severe pruning to favour the production of knees and other ship-timber; and Lane had clearly seen manuscripts describing other processes in the regions supplying Venice (Lane, 1934, p. 224-225), though he did not pursue the matter. Albion gives a drawing for "binding and pinning young oaks to produce compass timber", but ignores the subject beyond that (Albion, 1926, p. 7-8, fig. 9). There is evidence from the Basque area that bending young trees to form a standardised crop of compass timber was a well-defined procedure in shipbuilding areas (Loewen, 1998, in press), but that it perhaps died out the seventeenth century. In Britain, there are numerous texts from about 1600 onwards, up to as late as the 1830's that describe the practice, and the benefits of training oak trees for ship-timbers — even in northern Scotland (indeed one gentleman was trying to grow cork oaks in the north of Scotland, though not, it has to be said, for ship timber). Duhamel du Monceau has much to say on these topics, and also on the importance of tree roots for ship-timber — knees especially (Duhamel du Monceau, 1764, vol. I, p. 419 ff., 1760, p. 359). Some texts may be copying without real experience, and the problem is that no cases can clearly be cited as proving widespread early, or ingrained local practice. The weight of evidence however is that such things did occur — both pruning and training. If pruning still exists as an economic activity in oaks in Iberia, and the whole of Western Europe has had similar forest laws and management since feudal times, all based on oak forests, there are good grounds for investigating the matter in the prime evidence: the frames of wrecks. Are there extensive areas of framing with identical curvature, and made from trees ideally suited to that pattern, and without large knots? Are there knees that are actually root timber? There was a process described to convert the sapwood roots of European oak to mature timber in the years before felling, by progressive exposure to the air.

It is noteworthy that pruning appears as a feature of many texts on forestry, albeit the circumstances where it is now economically viable are limited — though it has been commended recently even for straight oak timber in the USA. That makes it even more curious that general texts on woodland and forest history completely ignore it, even when they cite for other purposes the very source texts that describe it at length as highly desirable for ship-timber. It is as though not only has the practice been lost in European oak, but that there is a tendency to suppress its past existence as fanciful. The original trees themselves of course have either been felled, or have simply sprouted so many uncontrolled branches that they are no longer recognisable as pruned trees. A particular case arises in the work of Rackham, who actually recognises the existence of saw-pruned branches, cleanly grown over, within mediaeval structural timbers in one study (Rackham, 1980, p. 157-159, fig. 10.13.) but denies that there was ever a shortage of timber for shipbuilding in England. While his general thesis may stand, it is unsafe for ship-timber as such, based as it is on eighteenth century shipbuilding using double frames, iron-fastened, and while it includes a statement such as: "The Navy preferred to scrounge timber from the wood-pasture of the Royal Forests, and when forced to buy *expected to get the large sizes and special shapes* of timber for building warships at no more than the average price for ordinary oak. HMS *Victory*, built 1759-1765 is *ingeniously put together from great numbers of the smallest*, and therefore, cheapest, practicable oaks" (Rackham, 1995, p. 91). This is clearly open to an interpretation of a real shortage of ship-timber; and reflects the problems experienced by Portuguese shipbuilders when they built ever-larger vessels in the sixteenth century. A preliminary examination of the actual critical frame timbers (first futtocks and floor riders) in the *Mary Rose* (which we may suppose to be hardly removed from the form of a large mediaeval ship), of an eighteenth century 74-gun ship, and the *Victory*, shows that they are virtually identical in form — length and curvature — despite the different size, shape and dates of the ships, and many changes in construction style. Those changes span the change from inserted frames in clinker hulls, to carvel construction with single frames, from quadrant sections to differentiated arcs, and finally to arcs further separated by straight segments, and double frames through-fastened. Yet the largest oak timbers, were evidently similar in all these cases, and not so freely available as to be used throughout the frames. Du Monceau has much to say on the problem, including the English case. While there is a vast literature on the subject of pruning of forest trees, it cannot be presented here. The proof for shipbuilding must in any event come from the archaeology of ship-timber; but as one seventeenth century writer on pruning forest trees, including oaks, put it:

"Reader if thy faith hold out, read on;
But if you find you can't believe, be gone".

This broad theme will be explored further in a paper for International Reunion for Nautical Science and Hydrography, 1998, entitled *what Fernando Oliveira did not say about cork oaks*.

## Conclusion

One conclusion that this writer has reached time and again over the last 15 years is that Portugal holds many keys to the development of the oceanic ship. This is true whether one considers the collection of manuscript sources for shipbuilding, for barrel technology, tonnage measurement, or other aspects such as naval artillery; even the importance of river navigations, for timber transport, for example. It is indeed fortunate that we have finally some Portuguese wrecks to study.

### NOTES

1 English translation by this writer.
2 For neighbouring Galicia see Alonso Romero, 1991.
3 There is a suggestion that they may have been made in Madeira too - Leite, 1989, p. 25.
4 Bowen suggests both that the Veneti controlled the routes, and that Mediterranean vessels transhipped in NW Spain. There is little doubt that other migrants passed along these routes, however.
5 The drinking fountains of Lisbon and a more general history of water supply for shipping are discussed in Barker, 1992a.
6 The migration is also traced in several works by O. L. Filgueiras cited here, especially Filgueiras, 1988.
7 Terms suggestive of the technique are extant from no later than 1275, and a fuller text from Genoa survives from 1333.
8 Arabic or Hebrew *qārib* or Greek *karabo* is a sea-going tender or smaller ship in the eleventh-thirteenth century records presented. *Karib* still occurs in modern Arabic in the Red Sea with the meaning of small shore boat: Moore, 1920, p. 76.
9 François Beaudouin, 1965, who would add the spritsail.
10 A letter from Vincenzo Quirini to Venice, from Middelburgh, 4 January 1506. Three ships for the King of Portugal of 1,000, 700 and 300 butts, to go to Calicut.
11 The limitations of even *caravelas* in windward sailing are given in a letter of 1503, cited in Mariaga, 1949, p. 377.
12 Written in 1533. Various sources suggest that the purchase of copper in Flanders for the ordnance was financed from the cork export monopoly from about 1484-1498.
13 Original drawing in Leiden University Library, ref J29-15-7831-110/30; published in Barata, 1987; Filgueiras, 1969.
14 Reckoned at 1,600 tons when captured in 1592, 165 feet from beakhead to stern, 46'10" beam, with four complete decks and three in each castle, 100 feet keel, 121 feet mainmast of 11 feet circumference, 106 feet mainyard, carrying 32 bronze guns and 6-700 passengers.
15 A. Anthoniszoon, painting now known as "Portuguese carracks off a rocky coast, 1521", in the National Maritime Museum, Greenwich. There is a remarkable description by Garcia de Resende - Ida da Iffante Dona Breatiz pera Saboya. In Verdelho, 1994, p. 491-506.
16 Coelho, Jorge (1734) - Memoria do celebrado galeam São João...., Lisbon. (Text kindly provided by José Virgílio Pissarra, in an unpublished paper O galeão São João: dados para uma monografia, Universidade de Lisboa, 1997).
17 Brad Loewen has done work on the barrels of the Red Bay wreck, and their stowage, in press. Howard, 1996, presents illustrations of later stowage patterns. The Douro boats also use a standard *rumo* as a basic measure of frame spacing in Filgueiras, 1961. It is not however clear that the northern tun was always equal to the Lisbon standard of the sixteenth century, with a length of six palmos de goa, 1,536 m. Curiously the nineteenth century port wine export pipe was a completely different, longer shape. See also note 5.
18 Livro de Horas de D. Manuel, Museu Nacional de Arte Antiga. In Oceanos, 26, Lisbon, 1996, p. 45; also published INCM Lisbon (not seen).
19 Palácio dos Cortes-Reais, in Castelo-Branco, 1990.
20 See Fig. 2 of the facsimile section, and English text p. 150-151.
21 Marcos de Aguilar - Advertências de Navegantes (unpublished MS ca 1640 referred to for other purposes by J. da Gama Pimentel Barata), kindly provided by José Virgílio Pissarra.
22 Personal communication, Brad Loewen, on draft reports.
23 It seems fitting to note another pioneer at this point, whose work is largely unsung: William Salisbury, who contributed many significant texts and ideas before illness overtook him. A telling little note in Salisbury, 1965, p. 98, refers to the importance of being able to determine rapidly and confidently the provenance of any wreck discovered in construction works, especially from a partial sight of the bottom, which at that time was near impossible.
24 Reveals such a rigmarole of uncalibrated procedural fudges between a yacht package and heavy square-rigged hulls as simply to illustrate that that process is untenable. Simple hydrostatic analysis of a fragmentary wooden hull is quite sufficiently imprecise.
25 We are very, very far from a situation where Lavanha's idealisation will bear fruit: "...when from some shipwreck only one entire part is found, from that it is possible to know its size and to make another ship wholly similar...". Lavanha, 1996, Chap 4, p. 139. A recent paper attempting to derive hull dimensions from an incomplete rudder was wildly optimistic.
26 However fine the towers, the abrupt transition to the side-span columns is a disaster in this writer's view, and would have benefitted from the use of a *graminho*.
27 He cites four sources from 1877-1920, ranging from 0.803 to 1.056 air-dried density. Copies of the originals have not been seen.

ALBION, R. G. (1926) - *Forests and sea power. The timber problem of the Royal Navy, 1652-1862.* Cambridge Mass (Harvard Economic Studies; XXIX)

ALONSO ROMERO, F., (1991) - Traditional clinker and carvel techniques in the Northwest of Spain. In REINDERS, R.; PAUL, K., eds. - *Carvel Construction Technique.* Oxford, p. 103-111.

ALVES, F. J. S. (1988) - The dugout of Geraz do Lima. In FILGUEIRAS, O. L. , ed. - *Local Boats.* Part II. Oxford, p. 287-292.

BAKER, M. (c. 1580) - *Fragments of Ancient English Shipwrightry.* Cambridge: Magdelene College, Pepsyian Library, Ms 2820.

BARATA, J. da G. P. (1973) - *Introdução à arqueologia naval: A crítica da documentação plástica.* Lisbon: Centro de Estudos de Marinha.

BARATA, J. da G. P. (1981) - The Portuguese Galleon 1519-1625. In *Five Hundred Years of Nautical Science 1400-1900.* Greenwich: D. Howse, p. 181-191.

BARATA, J. da G. P. (1987) - A caravela, breve estudo geral. *Studia.* Vol. 46, p. 157-184.

BARATA, J. da G. P. (1989a) - O traçado das naus e galeões portuguesas de 1550-80 a 1640, in *Estudos de Arqueologia Naval.* Vol. I. Lisbon: INCM, 1989, p. 153-202.

BARATA, J. da G. P. (1989b) - The Portuguese Galleon 1519-1625. In *Estudos de Arqueologia Naval.* Vol. 1. Lisboa: INCM, p. 327-338.

BARATA, J. da G. P. (1989c) - *Estudos de Arqueologia Naval.* 2 Vols. Lisbon: INCM.

BARKER, R. A. (1988) - Many may peruse us: Ribbands, moulds and models in the dockyards. *Revista da Universidade de Coimbra.* Vol. XXXIV, p. 539-559.

BARKER, R. A. (1991) - Design in the Dockyards, about 1600. In REINDERS, R.; PAUL, K., eds. - *Carvel Construction Technique.* Oxford, p. 61-69.

BARKER, R. A. (1992a) - Barrels at Sea: water, stowage and guns on the Portuguese Ocean. In *As Navegações Portuguesas no Atlântico e o Descobrimento da América.* Lisbon: Academia de Marinha, p. 365-379.

BARKER, R. A. (1992b) - From Genoa to Goa, via geometry. In EARLE, T. F.; PARKINSON, S., eds. - *Studies in the Portuguese Discoveries*, I. Warminster, p. 53-69.

BARKER, R. A. (1992c) - Shipshape for Discoveries, and Return. *Mariner's Mirror.* 78, p. 433-447.

BARKER, R. A. (1994) - A manuscript on shipbuilding, circa 1600, copied by Newton. *Mariner's Mirror.* 80, p. 16-29.

BARKER, R. A. (1996) - A gun-list from Portuguese India, 1525. *Journal of the Ordnance Society.* 8, p. 52-71.

BARKER, R. A. (1998a) - A glance at ricochet. *Journal of the Ordnance Society.* 10, p. 1-16.

BARKER, R. A. (1998b) - English shipbuilding in the sixteenth century: evidence for the processes of conception and construction. In RIETH, E., ed. - *Concevoir et construire les navires.* Ramonville Saint-Agne, p. 109-126.

BARKER, R. A. (1998c) - Cradles of navigation. In *Limites do Mar e Terra, Actas da VIII Reunião Internacional de História da Náutica e da Hidrografia (Viana 1994).* Cascais: Patrimonia, p. 67-81.

BEAUDOUIN, F. (1965) - *Les Bateaux du Douro. Étude des origines. Actas do Congresso Internacional de Etnografia, Santo Tirso, 1963.* Vol. V. Lisbon: Junta de Investigacões do Ultramar.

BOWEN, E. G. (1972) - *Britain and the Western Seaways.* London.

BROWN, R., ed. (1864) - *Calendar of State Papers, Venetian.* I. London.

CARVALHO, A. de (1997) - *Madeiras Portuguesas.* Vol. II. Lisbon.

CARVALHO, A. de (1998) - *Personal communication.*

CASTELO-BRANCO, F. (1990) - *Lisboa Seiscentista.* 4.ª ed. Lisboa.

CHIGGIATO, A. (1987) - *Le Ragione Antique dell'Architettura Navale.* In DOSIO, G. B., ed. - *Ragione Antique spettanti all'arte del mare et fabriche de vasselli.* Venice, p. 57-83.

COELHO, J. (1734) - *Memoria do celebrado galeam São João chamado vulgarmente Bota-fogo.* Lisbon.

COSTA, L. F. (1997) - *Naus e galeões na Ribeira de Lisboa. A construção naval no século XVI para a Rota do Cabo.* Cascais.

DUHAMEL DU MONCEAU, H. L. (1760) - *Des semis, et plantations des arbres et de leur culture.* Paris.

DUHAMEL DU MONCEAU, H. L. (1764) - *L'exploitation des bois*. Paris.

ELBL, M. (1994) - The caravel. In GARDINER, R.; UNGER, R., eds. - *Cogs, caravels and galleons: the sailing ship 1000-1650*. London: Conway Maritime Press, p. 91-98.

EVANS, H. V. (1948) - Some sixteenth century ship-drawings by John Goghe. *Mariner's Mirror*. 34, p. 123-125.

EVELYN, J. (1664, facsímile 1972) - *Sylva*. London.

FERNANDES, M. (1616, facsímile 1989) - *Livro de Traças de Carpintaria*, MS 52 XIV 21. Lisbon: Ajuda Library, facsimile by Academia de Marinha.

FILGUEIRAS, O. L. (1961) - Rumo, palavre-chave da arte da construcão naval. *Revista de Guimarães*. Guimarães. 71:3-4, p. 3-15.

FILGUEIRAS, O. L. (1963) - Entre Normandos e Árabes nas margens do Douro. In *Studium Generale*. Vol X. Porto, p. 5-49.

FILGUEIRAS, O. L. (1969) – Da caravela portuguesa. *Anais do Clube Militar Naval*. Lisboa. Vol. XCIX, p. 3-42.

FILGUEIRAS, O. L.; BARROCA, A. (1970) - *O caíque do Algarve e a caravela Portuguesa*. Coimbra: Junta de Investigações do Ultramar.

FILGUEIRAS, O. L. (1979) - A presumptive Germanic heritage for a Portuguese boat-building tradition. In MCGRAIL, S., ed. - *Medieval ships and harbours in Northern Europe*. Oxford, p. 45-75.

FILGUEIRAS, O. L.; MCKEE, E., trad. (1980) - *The decline of Portuguese regional boats*. Greenwich (Maritime Monograph; 47).

FILGUEIRAS, O. L. (1988) - The traditional Portuguese boats in the context of the settlement process: a general survey. In FILGUEIRAS, O. L. , ed. - *Local Boats*. Part II. Oxford, p. 375-413.

FILGUEIRAS, O. L. (1991) - Gelmirez and the reconversion of the W. Peninsular shipbuilding tradition (XI-XIIth centuries). In RENDERS, R.; PAUL, K., eds. - *Carvel Construction Technique*. Oxford, p. 32-41.

FONSECA, H. A. da (1990) - *Os Estaleiros da Ribeira das Naus*. Lisbon: Academia de Marinha.

GLASGOW, T. (1964) - The shape of the ships that defeated the Spanish Armada. *Mariner's Mirror*. 50, p. 177-187.

GOITEIN, S. D. (1967) - *A Mediterranean Society*. Vol. I. London.

GOIS, D. (1554-1937) - *Lisboa de Quinhentos*. Translation of Latin text by Raúl Machado, Lisbon 1937.

GUILMARTIN, J. R. (1994) - Guns and Gunnery. In GARDINER, R.; UNGER, R., eds. - *Cogs, caravels and galleons: the sailing ship 1000-1650*. London: Conway Maritime Press, p. 139-150.

HASELBURGER, L. (1985) - The construction plans for the Temple of Apollo at Didyma. *Scientific American*. Dec., p. 114-122.

HOWARD, M. (1996) - Coopers and casks in the whaling trade, 1800-1850. *Mariner's Mirror*. 82, p. 436-450.

INSTITUTO FLORESTAL (1995) - *ABC de podador de sobreiros e do tirador de cortiça*. 6th ed. Lisbon.

LAVANHA, J. B. (c. 1610, published 1965) - O Livro Primeiro da Architectura Naval. *Ethnos*. Vol. IV, p. 221-298.

LAVANHA, J. B. (c. 1610, 1996) - *O Livro Primeiro da Architectura Naval*. Facsimile, new transcription, and translation. Lisbon: Academia de Marinha.

LANE, F. C. (1934) - *Venetian ships and shipbuilders*. Baltimore.

LEITE, J. D. (1989) - *Descobrimento da ilha de Madeira*, Lisbon 1589. Lisbon: Ed. Luís de Albuquerque.

LIVRO DE HORAS DE D. MANUEL (1996) - *Oceanos*. Lisbon. 26, p. 45.

LOEWEN, B. (1997) - Bayonne 1419. Lapstraking and moulded frames in the same hull ?. *Mariner's Mirror*. 83, p. 328-331.

LOEWEN, B. (in press 1998) - Recent advances in ship history and archaeology, 1450-1650.... *Northern Mariner*.

MARIAGA, S. de (1949) - *Christopher Columbus*. London, p. 377.

MICHIE, C. Y. (1888) - *The practice of forestry*. London.

MOORE, A. (1920) - Craft of the Red Sea and Gulf of Aden. *Mariner's Mirror*. 6, p. 76.

NATIVIDADE, J. V. (1990) - *Subericultura*. Lisbon.

OLIVEIRA, F. (1983) - *A Arte da Guerra do Mar*. Lisbon: Edições Culturais da Marinha.

PARSONS, J. J. (1962) - The cork oak forests and the evolution of the cork industry in southern Spain and Portugal. *Economic geography*. Worcester MA. 38, p. 195-214.

PIERCY, R. C. M. (1977) - Mombasa wreck excavation, preliminary report 1977. *International Journal for Nautical Archaeology and Underwater Exploration*. 6, p. 331-347.

PIERCY, R. C. M. (1978) - Mombasa wreck excavation, second preliminary report, 1978. *International Journal for Nautical Archaeology and Underwater Exploration*. 7, p. 301-320.

PINA, R. de (1907) - *Coronica do muito alto e esclarecido Principe D. Affonso III quinto Rei de Portugal*. Lisbon.

PISSARRA, J. V. (2000) - O galeão S. João (c. 1530-1551). Dados para uma monografia. In *Fernando Oliveira e o seu tempo. Actas da IX Reunião Internacional de História da Náutica e da Hidrografia (Aveiro 1998)*. Cascais: Patrimonia. p. 185-224.

RACKHAM, O. (1980) - *Ancient woodland, its history, vegetation and uses in England*. London.

RACKHAM, O. (1995) - *The history of the countryside*. London.

REIS, A. E. dos (1988) - *O Dique da Ribeira das Naus*. Lisbon: Academia de Marinha.

RESENDE, G. DE (1622) - *Chronica dos valerosos e insigne feitos del Rey Dom João II*, chapter CLXXX (in this edition). Lisbon.

RULE, M.; MONAGHAN, J. (1993) - *A Gallo-Roman trading vessel from Guernsey*. Guernsey (Museum Monograph; 5).

SALISBURY, W. (1965) - Marine and naval archaeology. *Mariner's Mirror*. 51, p. 98.

SAVERIEN (1758) - *Dictionnaire historique, théorique et pratique de marine*. Paris: art: lancer.

STANDISH, A. (1616) - *New directions...for the increasing of timber and fire-wood...* London.

SUBRAHMANYAM, S. (1997) - *The career and legend of Vasco da Gama*. London.

THEOPHRASTUS (1916) - *Enquiry into Plants*. HORT, A., ed. London.

VERDELHO, E. (1994) - *Livro das obras de Garcia de Resende*. Lisbon.

WILSON, G. (1994) - Computer documentation and analysis of historic ship design. In WESTERDAHL, C., ed. - *Crossroads in ancient shipbuilding*. Oxford, p. 265-269.

YEE, R.; STANLEY, R. P. (1997) - The golden proportion and its use in the aesthetic design of bridges. Proceedings of the Institution of Civil Engineers. *Civil Engineering*. 120, p. 154-164.

RMS Lusitania was a British ocean liner that a German submarine sank in World War I, causing a major diplomatic uproar. The ship was a holder of the Blue Riband, and briefly the world's largest passenger ship until the completion of her sister ship Mauretania. The Cunard Line launched Lusitania in 1906, at a time of fierce competition for the North Atlantic trade. She made a total of 202 trans-Atlantic crossings.[3].Â  First class cabins ranged from one shared room through various ensuite arrangements in a choice of decorative styles culminating in the two regal suites which each had two bedrooms, dining room, parlour and bathroom. The port suite decoration was modelled on the Petit Trianon.[23].